Conception des Systèmes d'Information : une approche centrée sur les Patrons de Gestion de la Qualité

Kashif Mehmood

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A Quality Pattern Based Approach for the Analysis and Design of Information Systems

By

Kashif MEHMOOD

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Defended on 03rd September 2010 in front of the following jury:

Geert Poels	Professor	Ghent University	Reviewer
Oscar Pastor	Professor	Universidad Politécnica de Valencia	Reviewer
Jacky Akoka	Professor	CEDRIC-CNAM	Examiner
Mokrane Bouzeghoub	Professor	PRiSM	Examiner
Camille Rosenthal-Sabroux	Professor	Université Paris-Dauphine	Examiner
Nicolas Prat	Associate Professor	ESSEC Business School	Examiner
Isabelle Comyn-Wattiau	Professor	CNAM & ESSEC Business School	Supervisor
Samira Si-Said Cherfi	Maître de Conférences	CEDRIC-CNAM	Supervisor

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To my parents,

To my wife Sameet.

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Abstract

Conceptual models (CM) serve as the blueprints of information systems and their quality plays decisive role in the success of the end system. It has been witnessed that majority of the IS change-requests result due to deficient functionalities in the information systems. Therefore, a good analysis and design method should ensure that CM are correct and complete, as they are the communicating mediator between the users and the development team. Our approach targets the problems related to conceptual modeling quality by proposing a comprehensive solution. We designed multiple artifacts for different aspects of CM quality. These artifacts include the following:

i. Formulation of comprehensive quality criteria (quality attributes, metrics, etc.) by federating the existing quality frameworks and identifying the quality criteria for gray areas. Most of the existing literature on CM quality evaluation represents disparate and autonomous quality frameworks proposing non-converging solutions. Thus, we synthesized (existing concepts proposed by researchers) and added the new concepts to formulate a comprehensive quality approach for conceptual models that also resulted in federating the existing quality frameworks.

ii. Formulation of quality patterns to encapsulate past-experiences and good practices as the selection of relevant quality criteria (including quality attributes and metrics) with respect to a particular requirement (or goal) remains trickier for a non-expert user. These quality patterns encapsulate valuable knowledge in the form of established and better solutions to resolve quality problems in CM.

iii. Designing of the guided quality driven process encompassing methods and techniques to evaluate and improve the conceptual models with respect to a specific user requirement or goal. Our process guides the user in formulating the desired quality goal, helps him/her in identifying the relevant quality patterns or quality attributes with respect to the quality goal and finally the process helps in evaluating the quality of the model and propose relevant recommendations for improvement.

iv. Development of a software prototype "CM-Quality". Our prototype implements all the above mentioned artifacts and proposes a workflow enabling its users to evaluate and improve CMs efficiently and effectively.

We conducted a survey to validate the selection of the quality attributes through the above mentioned federating activity and also conducted three step detailed experiment to evaluate the efficacy and efficiency of our overall approach and proposed artifacts.

Keywords: Conceptual Model Quality, Quality Evaluation, Quality Assessment, Quality Improvement, Quality Criteria, Quality Framework, Quality Patterns, Quality Attributes, Metrics.

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List of Abbreviations and Terminologies

A list of commonly used abbreviations and the different terminologies that frequently are used throughout the thesis:

CM: Conceptual Model

ER: Entity-Relationship

ERP: Enterprise Resource Planning

GQM: Goal-Question-Metric

HR: Human Resource

IS: Information System

ISO: International Organization for Standardization

Model: Conceptual Model

UML: Unified Modeling Language

XML: Extensible Markup Language

XMI: XML Metadata Interchange

Chapter 1
Introduction

1.1 Domain of the thesis

Information systems (IS) create, process, store, and generate information to help individuals make meaningful decisions [Gupta 01]. These systems can be at personal, workgroup and enterprise levels depending upon their usage and implementation. For example, enterprise wide systems support the entire organization by providing them with comprehensive and processed information for taking decision at the enterprise level. However, IS are useful only if they bring the required information and functionalities they are conceived for. If IS are not able to furnish the information required by different stakeholders then their strategic position in the decision making process will be questionable and users might not utilize it.

Incorporation of missing/new requirements or functionalities to the information systems comes under its evolution or maintenance. Such change requests (both for missing and new requirements/functionalities) can be minimized or avoided by careful analysis and design activities during the system development lifecycle. The major problem with maintenance and evolution activities is their high costs depending on the lifecycle stage at which these missing requirements were identified or new requirements were generated. These high maintenance/evolution costs can play a decisive role in deciding the fate of future information systems. Information systems projects failure is a common story. Most of these failures were resulted due to increase cost induced by rapidly changing requirements. Even if the information system was successfully developed and deployed, its maintenance cost can darken its future. [Erlikh 00] reported that the relative cost for maintaining IS and managing its evolution represents more than 90% of the total cost.

It is due to the above mentioned reasons that software quality is considered as an important issue in research laboratories and in IS firms. Quality problems can inflate system development cost and consume scarce resources in addition to increase error detection and correction costs [Thiagarajan et al., 1994]. Moreover, [Ackoff 67] found that the existence of defects or

deficiencies can hamper IS quality and put its adoption at stake as IS adoption is linked to IS quality, satisfaction and usage as reported by [Nelson et al., 2005].

Information systems evaluation has always been a hot issue. Many efforts are devoted towards the research and development of methods to improve the software quality. Different researchers have proposed different perspectives and methods to evaluate IS. Similarly, IS industry has appreciated the benefits of employing software quality assurance (SQA) activities to improve the software quality and reduce the modification cost. However, the major problem with the existing SQA or software evaluation activities is that it is performed at the last stage of development i.e. usually SQA activities are placed as the last stage of software development lifecycle. The famous alpha testing is done once the software is fully developed and just prior to its deployment. It's too late to identify the defects and deficiencies if the software is already developed, as the maintenance cost of these defects could be enormous and might require major design or architectural modifications. It is witnessed that most of the missing requirements are identified during the beta testing by the clients (testing done at the client site before IS acceptance) or post deployment after the acceptance. It has been noticed that majority of the IS change-requests results from deficient functionalities in the information systems such as the lack of desired functionalities within a system, etc. However, as mentioned above, these change order requests will be expensive to fix as the system is already developed. In the early stages of development, it is emphasized that the resulting system should work (in terms of execution) whereas once the systems works, it is deemed that it should work correctly. But now it is too late to hope for a correctly working system, if correctness has not been taken care of in all the steps of the development lifecycle process. Studies show that defect detection in the early stages of the application development can be thirty three times more cost effective than testing done at the end of development [Walrad et al., 1993]. More precisely, the earlier we can measure the quality of future software, the more we can improve it by being able to correct errors at the specifications level and the less will be the cost of these corrections, thus improving software quality.

Therefore, it is imperative to emphasize the need of introducing quality mechanisms at the earlier stages of development such as during analysis and design. It has now been widely agreed that the quality of the end-system depends on the quality of the design deliverables such as conceptual models (CM). CMs serve as the blueprints of information systems and their quality plays a decisive role in the success of the end-system. CMs are designed as part of the analysis phase and are the basis for further design and implementation. As CM precede the other development activities, therefore it will be more effective to catch requirements defects as soon as they occur [Moody et al., 2003].

As mentioned above, majority of the IS change-requests results due to deficient functionalities in the IS. Therefore, a good analysis and design method should ensure that CMs must adhere to some quality criteria, as they are the communicating mediator between the users and the development team. Hence if the conceptual models are scanned for defects and the defects be corrected then it is likely to reduce the number of change requests for the end system. Moreover, these errors and deficiencies in the CMs will not be propagated along the development process. Improvements in the quality of the conceptual models lead towards the improvements in the overall quality of the delivered systems [Moody 05]. Thus a higher quality CM will yield a higher quality IS and will affect the efficiency (time, cost, effort) and effectiveness (quality of results) of IS development and maintenance.

For these reasons, different methodologies propose different methods and guidelines to ensure a certain degree of quality to the produced deliverables. However there exist numerous difficulties and problems in evaluating the quality of conceptual models. They are discussed in the next section.

In order to illustrate the importance of implementing quality at the conceptual models, let us consider an example in a totally different industry and domain. Architectural diagrams such as floor plans can be regarded as CMs of the construction industry. If these architectural diagrams contain errors that are diagnosed once the building is already constructed then the cost of rectifying these errors will be enormous. For example, if the client wants a parking in the underground area and showrooms on the ground floor whereas the architectural diagrams models parking on the ground floor and showrooms on the first floor. If the building is constructed based on the architectural models, then adding an underground parking over the constructed building will be almost impossible. Even if it's possible then the cost will be enormous or perhaps its incorporation poses severe threats to the already constructed building. However, if this design flaw was found before the construction then the cost of incorporating these modifications would be marginal. The same situation holds for CM in IS. Sometimes basic changes in IS require major architectural and design modifications or can pose threats to the overall system. Analogously the cost of incorporating post development modifications is higher than the cost of redeveloping the entire system from scratch.

The problems addressed during this thesis are discussed in the next section.

1.2 Problem statement

The domain of software quality evaluation is more than three decades old and is well matured. This can be witnessed by the fact that multiple quality standards have been proposed by different autonomous bodies for information systems such as ISO/IEC-9126 for software product quality, ISO/IEC-14598 for software product evaluation, ISO/IEC 15504 for software process assessment, etc. ISO/IEC-9126 (2001) has widely been employed for evaluating information systems. This standard defines a set of six characteristics (functionality, reliability, usability, efficiency, maintainability and portability) to evaluate software quality. The biggest shortfall with these evaluation methods is that they are applied on the already developed software. All the characteristics described in ISO/IEC-9126 (2001) make sense if the software is already developed. Once the software is developed, we can employ these evaluation methods or standards to identify the errors or shortcoming and may be to classify the errors but the rectification of these errors is expensive and difficult [Boehm 84].

In response to the above issue, ensuring the quality at the elicitation, analysis and design levels becomes essential. Within the context of this thesis we are concerned with the quality of conceptual models that are designed during the design phase to model the end-system based on the requirements gathered during the requirements elicitation phase. The quality of conceptual models can play a decisive role in the success of the end system.

The problem in evaluating conceptual models is due to the fact that they are an abstraction of the future solution and not the solution itself. Indeed, in order to test information systems, we can execute the program and run test cases on it to obtain the system's response. Whereas in order to evaluate the model, we have to execute the test cases manually to check if the model remains valid. Moreover, there is a population who considers conceptual modeling as a time wasting activity. Thus demonstrating the importance of implementing quality approach for CM to this population is out of question. Even for populations who regard conceptual modeling as an important design activity, it gets difficult to demonstrate the importance of incorporating a quality mechanism on CM as it is difficult to visualize the problem and solution since CM are not physical.

Another class of problems is related to the fact that researchers treat conceptual models as objects and thus try to measure them by defining different metrics whereas conceptual models are imperfect, incomplete and abstract representations of the future system. Thus they are difficult to predict and calculate. Even if we measure the quality of these CMs, then how will we define "quality" so that different measures can be compared with each other? For example, different

researchers have evaluated the models based on their complexities then how can we compare their results? How can we predict that the value assessed by one researcher is comparable to the value computed by another researcher? Or which measure is better since literature lacks such classifications?

The domain of CM quality evaluation is rather young and thus unlike the software engineering discipline where there is a proliferation of the methods and metrics for evaluating the quality of the product, there is significantly little literature devoted towards the quality of the conceptual models [Cherfi et al., 2002b]. This literature includes several quality frameworks for evaluating the quality of the conceptual models. However, there are no generally accepted guidelines for evaluating the quality of the conceptual models and little agreement exists among the experts as to what makes a "good" conceptual model. Moreover, despite the wide agreement among the research community and industry leaders, to date there is neither a standard nor an agreed framework for managing quality of the conceptual models.

[Moody 05] reviewed existing work on conceptual modeling quality and found lack of generalizability among the frameworks and lack of collaboration between researchers and practitioners. He identified that only a handful of quality frameworks have been empirically validated.

The main problems targeted within the context of this thesis are listed in the following.

- **Disparity among existing autonomous quality frameworks**

One of the major reasons behind lack of adopting quality framework(s) for CM in practice is due to the fact that existing frameworks on CM quality are independent of other and don't draw conclusions from other works. Most of the existing quality frameworks propose their vision of CM quality and emphasize on their identified characteristics as relevant to quality. This leads to the existence of disparate and autonomous quality frameworks proposing non-converging solutions. Thus a designer is left with a perplexed vision of problems related to CM quality and existing solutions to cater them.

Moreover, there doesn't exist any approach (or an ontology) that can help in the identification of these existing evaluation criteria or quality frameworks. Thus it is left to analysts/designers to identify and use the relevant criteria individually. The absence of consolidated and agreed quality criteria for CM has de-motivated the acceptance and adoption of evaluation based strategies for CM.

The presence of these autonomous and independent quality frameworks has resulted in the existence of multiple definitions for the same concept and different names for semantically same concepts. For example [Nelson et al., 2005] have identified nine different definitions for quality attribute "completeness". Such issues have also restricted the adoption of the existing quality frameworks in practice [Moody 05].

Another related problem is associated to the classification of the identified quality concepts. All existing criteria proposed by researchers have been classified by themselves into their self identified dimensions, attributes, characteristics, properties, etc. that are not even at the same level of abstraction as their other counterparts. Thus same criteria have been placed by different researchers at different levels of abstraction. For example, completeness for some researchers is a quality attribute whereas for others it is a dimension or even a metric. Moreover, the reader gets confused by the existence of different classification vocabularies such as dimensions, characteristics, properties, attributes, concepts, etc. and what differentiates each one of them.

- **Lack of validation**

Most of the existing work on CM quality can be categorized into two types:

i. Frameworks having theoretical basis but no practical validation and viability and

ii. Frameworks having practical validation and viability but no theoretical basis.

Both types are not good for wide acceptability as usually the practically viable frameworks lack substance and thus don't cover difficult areas whereas theoretical frameworks are difficult to understand and implement. [Moody 05] have reported that most of the existing quality frameworks in CM quality have never been validated. He found that approximately 18% of the total quality frameworks have been validated.

Absence of practical validation questioned the applicability and feasibility of the quality frameworks. Usually if validation or experimental results are demonstrated along with the frameworks then they are considered as practically viable and readers can analyze the results to be sure of their benefits.

- **Absence of capitalization of experiences**

With the existence of multiple quality criteria, the process for selecting the relevant quality criteria (including quality attributes) with respect to a particular requirement remains trickier for a non-expert analyst/designer as it requires in-depth knowledge about each of these attributes and what they propose. We found that there is a lack of methodologies putting together the evaluation

of CMs through a guidance process. Often the readers are left with a proposed set of evaluation criteria that can be used for evaluation. And since these evaluation criteria are independent of other proposed criteria thus the reader can only think of employing the proposed set of criteria in hand. Moreover, in the domain of CM quality there doesn't exist any approach that capitalizes existing knowledge and past experiences so that it can utilized by analyst/designer to identify the best set of evaluation criteria for the problem in hand and a set of recommendations for its improvement. Thus if someone is interested in evaluating the CMs then he/she must have in depth knowledge about each and every available quality criterion so that the best set of evaluation criteria can be selected for the problem.

- **Lack of guided process**

Quality evaluation is only a step to improve the conceptual models but most of the quality frameworks focus exclusively on defect detection (quality evaluation) and ignore the defect correction (quality improvement) aspects. Thus they may help in identifying the problem but the analysts must rely on themselves for the solution [Moody 05]. Similarly, the domain of CM quality lacks a guided process helping analysts/designers to identify the relevant quality criteria with respect to their needs and also help them in improving their models.

- **Lack of automation in quality evaluation**

One of the major hurdles in evaluating the quality of conceptual models is the lack of tools automating the evaluation process. Most of the existing modeling software tools such as Rational Rose, Objecteering, etc. don't provide a comprehensive evaluation mechanism. Following are some of the problems related to the absence of automation tool:

i. Rational Rose, Objecteering, etc. incorporate some basic metrics for evaluation that can neither be added nor edited.

ii. Since they evaluate the models based on metrics thus their interpretation is difficult for a non-expert analyst/designer due to lack of abstraction as metrics results are difficult to interpret and require in-depth knowledge about metrics.

iii. None of the existing utility supports goal-based quality evaluations or customizable evaluation processes.

iv. None of the softwares provide post evaluation recommendations for improvements with an exception to UMLQuality (evaluation software) that proposes limited recommendations in an add-on.

1.3 Objective of the Thesis

The primary objective of a conceptual model is to provide the developer with a semi-formal vision of user requirements. However, there are various ways to model the universe of discourse. Although these various formulations can be correct, they might not necessarily be equal in terms of their usage. The core objective of this thesis is to develop a comprehensive quality approach for conceptual models. But this objective can be divided into the following goals.

- **Federate the existing work**

One of the major problems in the domain of CM quality is linked with the existence of independent and autonomous quality frameworks not drawing conclusions from other works. This has resulted in a non-optimal and non-converging solution. Most of the existing work is concentrated on complexity and maintainability of conceptual models thus creating gray areas.

At this stage, it becomes essential to perform a thorough literature review to federate the existing works so that a comprehensive quality framework can be formulated and gray areas can be identified. This will help us in targeting the gray areas so that a more crisp and clear picture of CM quality can be obtained.

- **Structure quality knowledge**

One of the problems with the existing quality frameworks is that they are generally only applicable to a particular CM type such as class diagrams, ER diagrams, etc. If we classify the existing literature then we will find that most of the literature on quality evaluation is valid only on class diagrams, ER diagrams or Use-cases as these frameworks were formulated with respect to these specific model types. [Moody 05] reported that only 5% of the existing quality frameworks are generalizable (that is they can be applied on multiple types of conceptual models) whereas the remaining 95% are valid for a certain model type only.

In view of the above, it becomes imperative that the formulated/proposed quality approach should encompass evaluation criteria that should be generic and remains valid for different types of conceptual models. Moreover, this formulated quality approach should be easy to use so that more and more designers use it while evaluating their models.

Similarly, in order to measure the formulated quality criteria, relevant and effective metrics should be proposed or devised so that the impact can be quantified.

- **Propose a guided process for quality evaluation and improvement**

Another problem with existing quality approaches is that they don't propose a guided process. They merely identify and propose evaluation criteria and leave the analyst/designer on his/her own for evaluation. Similarly, majority of the quality frameworks fails to provide post-evaluation recommendations for improvement. Thus once the analyst/designer is done with evaluation, he/she is left without any guidelines for improvement.

It is therefore required that the proposed quality approach should encompass a complete guidance process helping analysts/designers in selecting the relevant quality criteria with respect to their goals, evaluate the model and guide them in improving the quality of their CM based on the evaluation results and quality goals.

- **Develop a software utility to automate the evaluation and improvement process**

Quality evaluation in CM doesn't attract many users as it is difficult to evaluate the model manually. People find it difficult to calculate the metrics by hand. This situation gets worse if the metrics or model is complex. Similarly, identifying the relevant quality criteria with respect to a quality goal is a time consuming activity.

CM quality evaluation can become much easier and efficient if the proposed quality approach is supported by a software tool able to perform the following:

i. Implement a guidance system
ii. Manage a hierarchy of quality criteria such as attributes, metrics, etc.
iii. Maintain a knowledgebase of evaluation criteria
iv. Define new quality criteria
v. Calculate metrics automatically on the model
vi. Provide post-evaluation recommendations for improvement
vii. Implements a mechanism for capitalizing knowledge or past experience so that it can be reused in future to guide non-expert analysts/designers in evaluating and improving their models.

1.4 Overview of the Solution

Conceptual modeling is still considered as an art which is poorly supported by methods and tools. The subject of CM quality evaluation has occupied a substantial part of the effort devoted towards conceptual modeling. The impact of CM quality is of central concern to computer scientists, as well as to end-users, and more generally to those who seek to evaluate software

quality. The literature provides lists of desirable properties of CM. The formalization of these properties is not yet sufficiently well understood and there is no general agreement on the list of desired properties and on the way they could be measured.

The domain of CM quality is rather young and is fighting with the problems mentioned in Section-1.2. During this thesis we tried to address these problems in the following way.

- **Formulation of comprehensive quality criteria by federating existing quality frameworks**

In order to reply to the problems mentioned in Section-1.2 and to provide a common yet comprehensive basis for quality evaluation, we have relied on the proposition by [Moody 05] and considered synthesizing existing concepts proposed by researchers and adding new concepts to formulate a comprehensive quality approach for conceptual models.

In order to formulate a consolidated set of criteria for CM quality evaluation, different quality criteria from the previously existing quality frameworks or literature were extracted and filtered. This aggregation activity used the philosophy behind conceptual modeling and quality as its basis and enriched the model by extracting different concepts from the previously existing literature. This activity involved the selection of numerous metrics and various attributes from the literature, selecting generic quality attributes (quality attributes that are generic to every conceptual model) and merging non-generic attributes into generic attributes that are closest with respect to semantics.

This consolidation activity resulted in the selection/identification of a set of quality attributes that were generic and represent different aspects of the conceptual models such as complexity, maintainability, etc. Moreover, the advantage of this process was the elimination of redundant concepts in addition to unification of different frameworks and identification of grey areas. This can be regarded as an important step in our approach. This enrichment activity contributed in the literature by providing a more comprehensive and flexible set of quality criteria for conceptual models. We identified a set of quality attributes that incorporates a wide range of quality criteria already existing in the literature. Moreover, this comprehensive view helped in the identification of uncovered/gray areas of conceptual modeling quality. For example, we identified that only a handful of researchers have addressed the notion of social quality in models. Social quality is linked with the stakeholders agreement about the model (Social quality is discussed in Section-2.5.2.5)

In order to cater the issues related to the existence of multiple definitions for the same concept and different names for semantically same concepts, our solution incorporates these concepts as attributes and their different definitions as metrics. For example, as per our approach completeness is equivalent to a quality attribute and thus we combined all the definitions of completeness within a single quality attribute named as "completeness" and formulated different metrics to cater the dissimilar requirements of the existing nine definitions. Thus, completeness will have different meaning in different contexts with respect to different metrics.

The existing work on CM quality has classified its evaluation criteria into dimensions, characteristics, properties, attributes, metrics, etc. There is a clear distinction between metrics and other classification categories due to the widely accepted format of metrics. However, there exists a huge confusion among the definitions of attributes, dimensions, properties, etc. In order to address this issue, we merged all the attributes, dimensions, properties, etc. into either attributes or metrics. A quality attribute in our approach aggregates all the dimensions, attributes, characteristics/sub-characteristics, criteria, properties, etc. Whereas if an existing concept is a measurement criterion or a formula then it is classified as a metric. This simple distinction among different concepts helped us in facilitating the comparison between different concepts by reducing it at concepts on the same level.

- **Identification of quality patterns to encapsulate past-experiences and good practices**

Design patterns can be regarded as a good example for storing past experiences as they encapsulate valuable knowledge in the form of established and better solution to resolve design problems. However, design patterns were not meant to explicitly target the quality.

We adapted the idea behind design patterns to propose a set of quality patterns targeting quality problems in conceptual models. We identified the recurring problems in CM and proposed the best set of quality criteria for their evaluation and improvement and encapsulated this information in the form of quality patterns. Thus whenever someone has the same type of problem, he/she can easily employ our proposed quality pattern to evaluate and improve his/her models.

- **Propose a guided evaluation and improvement process**

We proposed a quality driven process encompassing methods and techniques to evaluate and improve the conceptual models with respect to a specific analyst/designer requirement or goal. Our approach guides the analyst/designer during each step of the process. The analyst/designer starts by formulating the desired quality goal. Our approach helps the analyst/designer in

identifying the relevant quality patterns or quality attributes for CM evaluation. Once the relevant quality patterns or attributes are identified, the process evaluates the model and proposes recommendations, based on the evaluation results, to improve the model.

The strength of our guided process lies in the fact that every analyst/designer (including experienced and inexperienced) can employ our process to evaluate and improve the model without any prior knowledge about any evaluation criterion or quality framework. Our process employs a knowledgebase containing all the identified quality criteria including quality patterns, quality attributes, metrics, etc.

- **Software tool automating our proposed approach**

We implemented our proposed approach in a software prototype CM-Quality. CM-Quality incorporates a complete guidance process for evaluating and improving CMs. The following functionalities are proposed through CM-Quality:

i. It implements and stores a hierarchy of quality concepts including quality patterns, quality attributes, metrics, recommendations, etc. in a knowledgebase. All these quality concepts can be added/edited/deleted from the knowledgebase.

ii. It can be used to evaluate CM based on an analyst/designer specific quality goal.

iii. It helps the analyst/designer in identifying the relevant quality criteria with respect to their formulated quality goal.

iv. It can even evaluate dynamic models.

v. It proposes post-evaluation feedback in the form of recommendations for model improvement.

vi. It provides three different levels of abstractions i.e. quality goals, quality patterns and quality attributes. Therefore the understandability of evaluation results is fairly simpler.

vii. Multiple models can be evaluated or compared using CM-Quality.

viii. It can be used to evaluate models designed using any existing modeler such as Rational Rose, Objecteering, etc. as long as they are capable of exporting their models in XMI (XML Metadata Interchange) standard.

- **Validation of proposed quality approach**

Our approach involves practitioners' viewpoint as its practical foundation. The basic idea was twofold: one to study the evaluation strategy employed in practice and second to validate our approach. We involved experts both academics and practitioners using surveys, interviews, etc. For example, in order to be sure that the resultant set of quality attributes (identified from the literature or defined as new concepts) represents most of the important aspects (if not entirely) in the evaluation of CM, an interim validation exercise was planned and performed having professionals including practitioners as the respondents. This validation exercise tried to collect the responders' views on the holistic quality of the conceptual models in addition to their feedback over the identified/selected set of quality criteria. Their feedback was evaluated and modifications were made to selected set of evaluation criteria.

Similarly, we also tried to extract knowledge about the practices by asking them feedback questions such as to identify the quality aspects that are important to them in a conceptual model. Such questions enabled us to study their practices and also to find the quality criteria that had been used in practice but are unknown to theory. For example, a lot of our respondent listed the aspects related to practicability of the model to be relevant to quality. They consider that if models are not practicable due to implementation difficulties (such as unprocurable technology, scarce resources, etc.), design difficulties or time constraints then it is not good. Thus we selected practicability into our set of quality attributes. Practicability is different from the already existing implementability quality attribute as implementability is related only to the efforts needed for implementing a model meaning that model is feasible and implementable. Whereas practicability is related to the factors that signifies that the model is not feasible and implementable.

Such large scale experiment has never been performed with academics and practitioners as respondents. We have carefully selected the respondents for this validation experiment and the average modeling experience among our respondents turned out to be of four years. Whereas most of the previously reported experiments were conducted on students and thus lacked the experience.

Another validation exercise in this regard involved an experiment to assess the efficiency of employing our approach to improve the conceptual models. This experiment consisted of three steps in which respondents were required to do the following:

i. Improve the quality of a model using their existing knowledge or cognition. With this exercise, we tried to study the cognitive efforts put in by respondents and the criteria employed by them to evaluate and improve the CM using their existing knowledge.

Moreover, this step served as an interesting source of knowledge for identifying and enriching our proposed quality patterns.

ii. Improve the quality of a model using proposed quality pattern concept. This step helped in validating the quality patterns' understandability and ease of use.

iii. Evaluate the results of quality improvement obtained by applying quality patterns on the given CM. This step helped in validating the efficiency of using quality patterns.

1.5 Organization of the thesis

The thesis is organized in a sequential way starting with a thorough state of the art in chapter-2. Different existing evaluation methodologies and quality frameworks are categorized and discussed in detail to obtain an overall idea of current state of the target domain. We have also discussed the other aspects of information systems quality and data quality.

In *chapter-3*, we discuss our proposed solution in detail. It starts with the formulation of a multi-faceted quality approach for conceptual models where we outlined the theoretical, practical and epistemological foundations of our work. It is followed by the description about our quality model including the descriptions about each of its components such as goals (including details about formulating structured goals), questions and quality patterns. This complete data model is illustrated by a brief example. As our solution is based on quality pattern and it is one of our major contributions therefore we describe the concept of quality pattern in details along with all of its components such as quality attributes, metrics and recommendations. Lastly we include a complete quality pattern description along with all the relevant details as an example.

In *chapter-4*, we discuss the quality driven development process (Q2dP). This chapter is divided into two main parts. In the first part, we discuss the processes involved in the creation of the quality vision such as the identification of new quality patterns, quality attributes and metrics whereas in the second part, we describe the processes involved in applying our quality vision on the CMs. It includes the processes to formulate analyst/designer specific quality goals (in a structured way), mapping of these goals onto quality patterns, attributes and metrics for evaluation. In the last section of this chapter we discuss the evaluation and improvement process proposed by our approach.

In *chapter-5*, we applied our proposed solution and process on a case study to evaluate their efficacy. We took a real world class diagram of a Human Resource (HR) system for evaluation and improvement with respect to a quality goal. This class diagram is extracted from a model that was used to develop the HR module for a huge Enterprise Resource Planning (ERP) software. The

original model was approximately ten times bigger than the selected one and contains several organization specific concepts that were difficult to understand by normal readers. Therefore we selected only those classes and concepts, for our case-study model, that are common among different organizations and thus might be easier for readers to understand. Next we formulated a quality goal and identified the relevant quality patterns and attributes with respect to the formulated goal. All the metrics were calculated and recommendations were generated following the processes described in *chapter-4*. In the next step, we applied all the recommendations on the target class diagram and re-evaluated the transformed model to check if the proposed recommendations actually improved the model or not. Lastly, the initial results were compared with the post-implementation results and the findings were discussed.

In *chapter-6*, we presented our software prototype *"CM-Quality"* implementing our proposed solution and process. In the first part of the chapter we describe the application architecture at multiple levels of granularities whereas in the second part we presented different interfaces available in CM-Quality for quality definition and quality evaluation operations. We have taken small examples to demonstrate the flow of the application and also described the searching process for automatic detection of relevant quality patterns with respect to a formulated quality goal.

In *chapter-7*, we discuss the two validation experiments conducted for our approach. In the first section, we describe on first experiment and the results aiming at validating the selection of the quality attributes from a thorough literature review. In the second section, we discuss our second experiment that was conducted to validate the efficacy of our complete approach including quality patterns.

In *chapter-8* some perspectives of the work are discussed along with the conclusions of the thesis.

Six appendixes are given at the end. *Appendix-A* describes the twenty one quality attributes that were federated through the literature review. *Appendix-B* describes the different quality patterns. *Appendix-C* illustrates the human resource ontology used in chapter-5 to identify different clusters for improving model complexity. *Appendix-D* lists the excerpts from the user requirement document (for HR system, as mentioned above) that are used in Chapter 5 for evaluation. *Appendix-E* is the evaluation report generated by our prototype and *Appendix-F* is the summary of the thesis in French language.

Bibliography is given after the appendixes. A list of author's publications is provided in the last part of the thesis.

Chapter 2
State of the Art

Quality is defined differently by different researchers as quality is highly contextual and is dependent on multiple view points (consumer, producer, etc.). Quality is not an absolute measure but approximated on the factors considered important for an object (product, process, services, etc.) from a particular viewpoint. Thus, the notion of quality for an object from one viewpoint might not hold for another viewpoint. [Reeves et al. 1994] defined four views of quality:

i. Quality as an excellence i.e. quality accessed on some absolute standards.

ii. Quality as value i.e. assessment of standards of excellence with respect to the cost of achieving it.

iii. Quality as conformance with specifications i.e. consistent and quantifiable delivery of value in relation to specific design ideal.

iv. Quality as meeting expectations i.e. conformance with respect to customer expectations.

Quality is considered as an integral part of every object (product, process, services, etc.). Different methodologies or factors have been identified by different societies or bodies to ensure the quality of these objects within their domain. For example, International Organization for Standardization (ISO) has formulated more than 500 standards for ensuring standardized processes (production, distribution, etc.). These standards are widely adopted in every industry and bring prestige to its implementing organization. These standards incorporate the best practices and tend to propose the criteria to evaluate objects (product, process, services, etc.) with respect to best practices. Thus, conformance of a process or product with respect to the best practices in ISO standards is considered to be of good quality. Thus, inherent quality related to ISO standards implements the *"quality as an excellence"* as defined by [Reeves et al. 1994].

In the field of computer science, the notion of quality is defined and evaluated for the following objects (but not limited to):

i. Quality of Requirements Engineering (both process and product such as documents, etc.)

ii. Quality of Models (conceptual models such as class diagrams, entity-relationship diagrams, etc.)

iii. Quality of Computer Systems

iv. Quality of Data

v. Quality of services

As this thesis is concerned with the quality of models, therefore we will be discussing quality of computer systems and quality of data in this chapter in addition to quality of models. We chose to review literature on quality of computer systems as there is a group of researchers who consider that model quality is computer systems quality as models represents computer systems. Similarly, another group of researchers considers model quality as information quality and thus we chose to review literature on quality of data to identify if indeed model quality is information quality.

In the next section, we review existing literature on software quality.

2.1 Software Quality

Information Systems (IS) require high cost for their maintenance activities and therefore software quality is considered as an important issue in research laboratories and in IS firms. The relative cost for maintaining software and managing its evolution represents more than 90% of the total cost [Erlikh 00]. Quality problems inflate system development cost and consume scarce resources in addition to increase error detection and correction cost [Thiagarajanet al., 1994]. Similarly, successful adoption of an information system is linked to its quality, satisfaction and usage [Nelson et al., 2005].

Information systems evaluation has always been a hot issue. Many efforts are devoted towards the research and development of the methods to improve the software quality. Different researchers have proposed different perspectives and methods to evaluate IS. However, importantly the evaluation of IS must be based on the criteria acceptable to users. For example, if a user demands a graphical interface then he will not accept command line software (like UNIX, DOS). [Boehm 81] considers high user satisfaction levels, portability, maintainability, robustness and fitness of use to be the constituents of systems quality. Whereas, [Elion 93] argues that user satisfaction levels are inappropriate measures of quality as user satisfaction is subjective and varies from person to person and thus cannot yield stable results. Similarly, [Hamilton et al., 1981] also argued about the evaluation of IS based on the user satisfaction level. He highlighted the need to consider different viewpoints for evaluating an IS and thus regards the user satisfaction to be just one view point.

Literature on software evaluation can be divided into four broad streams:

i. General (abstract) evaluation approaches for information systems

ii. Defect detection and its rectification

iii. Identification of quality criteria (dimensions, attributes, metrics, etc.) for evaluation

iv. Evaluation of service quality

2.1.1 Evaluation Approaches for Information Systems

[Avison et al., 1993] identified that existing IS evaluation approaches can be classified into the following:

i. Cost substitution: Comparison between the procurement cost of old systems and new system.

ii. The value added approach: Effects of the systems on the organization's performance.

iii. Organizational evaluation: Impact on organization structure and user attitudes.

iv. Evaluation of the process by which systems are produced.

However, rapid development and changes in the IS industry have strongly affected the above mentioned approaches. For example, the procurement cost of IS is much less now as compared to previous times due to abundance of software development firms and outsourcing. [Avison et al., 1993] has proposed different approaches to evaluation. Such as:

i. Impact Analysis: IS impact on the operations and functions of the organization.

ii. Measures of effectiveness: Economic effectiveness (cost benefit analysis), satisfaction of system objectives, the extent of system use and the opinions of the systems and information users.

iii. Economic Approaches: Economic benefits attained by the organizations due to IS such as decrease in costs, etc.

iv. Objectives: Extent to which the system has satisfied its objectives.

v. User satisfaction: Individual users' opinions or satisfaction about the functionality of the IS.

vi. Usage: Effective systems are frequently used by users.

vii. Standards: Achievement of the satisfactory standards as opposed to the attainment of the objectives.

viii. Usability: Deficiencies of the system for example, if the latter lacks functionality then user opinion about the usefulness of the system might hurt.

2.1.2 Defect Detection and Rectification

[Ackoff 67] took a different direction and regarded existence of defects to hamper IS quality. He can be seen as a pioneer to identify the reasons behind deficiencies in information system rather than discussing deficiencies alone. He identified five assumptions, made by IS-Designers, which trigger deficiencies in IS. These assumptions are:

i. The critical deficiency under which most managers operate is the lack of relevant information (whereas current IS provide so much information that its management becomes a difficult task for managers and the latter are left with confused minds as to what should be appropriate for their requirements).

ii. The manager needs the information he wants (Thus implying that managers are aware of their needs whereas in reality managers have only a fraction of idea about their needs and thus new requirements emerge over the evolution of IS thus resulting the change order requests).

iii. If a manager has the information he needs his decision making will improve.

iv. Better communication between managers improves organizational performance.

v. A manager does not have to understand how his/her information system works, only how to use it. Whereas, an IS must never be installed unless the managers, for whom it is intended, are trained to evaluate and hence control it rather than be controlled by it.

Thus, as per [Ackoff 67] if IS designers get over these assumptions, they are likely to design information systems that have limited deficient functionalities and thus reducing the maintenance cost and improving the quality of the information system. Carnegie Mellon report [Florac 92] contrasts the above findings and classified the software defects to be either of the following type:

i. Requirements Defect: Errors made in the definition or specification of the customer's requirements. This includes defects found in functional specifications such as interface, design, and test requirements; and specified standards.

ii. Design Defect: It includes all the defects made in the design of a software product such as defects found in functional descriptions (interfaces, control logic, data structures, error checking etc)

iii. Code defect: A mistake made in the implementation or coding of a program. It includes all the defects found in program logic, interface handling, data definitions, computation, and coding standards.

iv. Document defect: These include defects made to software product publication but doesn't include mistakes made to requirements, design, or coding documents.

v. Test case defect: A mistake in the test case that causes the software product to give unexpected results.

vi. Other work product defect: These defects include the errors found in software artifacts that are used to support the development or maintenance activities of a software product such as defects in test tools, compilers, configuration libraries, computer-aided software engineering tools, etc.

[Lausen et al., 2001] chose a narrower definition and proposed that IS defects can be divided into either implementation defects or requirements defects. They have empirically shown the impact of these defects on the system development and have also identified some prevention techniques.

2.1.3 Identification of Quality Criteria (Dimensions, Attributes, Metrics, etc.) for Evaluation

Another stream of literature targets the identification of quality criteria to evaluate the quality of information systems. For example, [Stylianou et al., 2000] have identified six dimensions of information system quality:

i. Infrastructure Quality: The quality of the infrastructure both hardware and software (operating system and other utilities required by the built software).

ii. Software Quality: The quality of the developed/maintained/supported application or software by IS.

iii. Data Quality: The overall quality of the data entering to the information systems through all sources.

iv. Information Quality: The quality of the output or reports originating from the information systems.

v. Administrative Quality: The quality of the management of the IS functions such as budgeting, planning, and scheduling.

vi. Service Quality: The quality of the service component of the IS such as customer support processes, help desk, etc.

Whereas, [Thiagarajanet al., 1994] divides the system quality into two dimensions: product quality (system quality and information quality) and process quality (productivity and development cycle time). [Nelson et al., 2005] proposed and empirically validated five dimensions of systems quality: Accessibility i.e. the ease with which information can be accessed from the system, Reliability or uptime, response time, flexibility i.e. the degree to which a system can adapt to variety of user needs, and integration i.e. provision of information from different sources. Similarly, [Chang et al., 2000] has assessed the performance of an information system along three dimensions: System performance, information effectiveness and service performance and three perspectives: IS effectiveness/Success, IS function evaluation and IS service quality.

[Iivari et al., 1987] identified three constructs, informativeness, accessibility and adaptability to be the measure of systems quality. Informativeness can be measured by employing relevance, comprehensiveness, recentness, accuracy and credibility whereas accessibility can be measured by convenience, timeliness and interpretability.

[Florac 92] proposed a structure for deriving and describing measurable attributes for software problems and defects to quantify software quality. This report proposed a Problem Count Definition Checklist and numerous supporting forms to organize software problem and defect measurements. The report lists the following five activities that should be checked for possible defects to improve the quality: Product synthesis, Inspections, formal review, testing (Modules, Components, Products, Systems, User publications, and Installation procedures) and customer service. [Garcia et al. 2006] propose a software measurement ontology and provides a framework that integrates the modeling and measurement of software processes. They also propose a model driven software utility that can be used to evaluate different aspects of conceptual models.

[Stylianou et al., 2000] have identified multiple attributes to evaluate quality for two IS processes. Such as for System Development, he regards cost, time, bugs, ease of use, user satisfaction and ease of fixing problems to be related to quality. Similarly, for system maintenance he proposes problem resolution time, service quality, cycle time and responsiveness to changes. Likewise, [Hamilton et al., 1981] regards compliance to design, completeness of controls, data currency, response time, and turnaround time as the criteria important for the quality of a system. Whereas, [Thiagarajanet al., 1994] emphasizes the impact of reusability on the quality of systems as reusable components carry maturity and have been tested over the time.

There exist several articles discussing the use of different quantitative measures such as metrics to quantify the impact of quality attributes. Such as, [Purao et al., 2003] performed a thorough review about different types of metrics that can be used to evaluate object oriented systems. They presented a survey about existing metrics for object oriented systems. For example, they analyzed the metrics for the coverage of entities, attributes and development states (or stages). They classified these metrics in multiple ways such as each metric belongs to either direct metric type (i.e. metrics that are simple and doesn't require any interpretations such as number of classes) or indirect metric type (i.e. metrics requiring interpretations). Moreover, they also provided the evolution of different metrics over the time.

2.1.4 Evaluation of service quality

Another stream exists for evaluating the service quality of information systems. [Parasuraman et al., 1988] can be regarded as the most influential article for evaluating the service quality. They proposed a 22-item instrument (SERVQUAL) to access customer perception of service quality in service and retail organizations. However, SERVQUAL has received equal appreciation and adoption into the information system domain. Several researchers have used SERVQUAL to measure IS service quality such as [Jiang et al., 2002]. SERVQUAL classifies the 22-items instruments into five dimensions:

i. Tangible i.e. physical facilities, equipment and appearance of personnel
ii. Reliability i.e. the ability to perform promised service dependably and accurately
iii. Responsiveness i.e. willingness to help customers and provide prompt services
iv. Assurance i.e. knowledge and courtesy of employees and their ability to inspire trust and confidence
v. Empathy i.e. providing caring and individualized attention to customers

Different researchers have applied SERVQUAL model on the information systems domain. For example, [Jiang et al., 2002] has used SERVQUAL items to examine its validity in IS professional population. Their empirical results shows that SERVQUAL can be usefully applied on IS service evaluation systems. Contrary, several researchers have criticized the adoption of SERVQUAL model in information systems. [Van-Dyke et al., 1997] provides a review of different problems and issues regarding SERVQUAL that are highlighted by different IS researchers.

Similarly, a lot of research has been done in devising methods and approaches to evaluate the software quality automatically. For example, [Akoka et al., 1996] proposed an expert system for evaluating the information systems in a semi-automatic way. Their system combines qualitative and quantitative techniques to propose domain specific evaluation of information systems.

After going through the literature one can be ascertain about the abundance of different approaches to evaluate the information systems. However, it is evident that none approach will be sufficient to evaluate the system. Therefore, it will be important to formulate a comprehensive and multi-perspective evaluation approach for implementing the notion of quality on information systems. Here it will be important to re-emphasize the [Hamilton et al., 1981] argument about the importance of different viewpoints. That is if the system is evaluated only on one viewpoint then this clearly shows that all the other viewpoints are either neglected or are not being discovered.

2.1.5 Standards

Different standards have been proposed by different autonomous bodies for information systems such as ISO/IEC-9126 for software product quality, ISO/IEC-14598 for software product evaluation, ISO/IEC 15504 for software process assessment, etc. Similarly, standards such as ISO 9001 and ISO 9000-3 can be applied on software quality systems for certifying processes, products and services within a software development organization according to the ISO 9000 model [Wang 02]. However, ISO/IEC-9126 (2001) has widely been employed for evaluating information systems within the IS community.

2.1.5.1 ISO/IEC-9126

ISO/IEC-9126 is an international standard formulated by ISO for evaluating software product quality. Its first version was proposed in 1991 and defined software quality through six quality characteristics and proposed software product evaluation process model. Current version of ISO/IEC-9126(2001) is a revision of ISO/IEC 9126 (1991), and retains the same software quality characteristics. The major differences, as mentioned in [ISO9126, 2001], are:

i. The specification of a quality model;

ii. The introduction of quality in use;

iii. The Removal of evaluation process (which is now specified in the ISO/IEC 14598 standards);

iv. The Co-ordination of the content with ISO/IEC 14598-1.

ISO/IEC 9126: Software Engineering – Product Quality (Year 2001) has been divided into four parts:

i. Quality Model: This is the first, the most influential and widely renowned part of ISO 9126 standard. This document contains the set of characteristics and the relationships between them which provide the basis for specifying quality requirements and evaluating quality [ISO9126, 2001], [ISO25030, 2007].

ii. External Metrics: This document contains all the metrics that are used to measure attributes or characteristics of a software product. These metrics can only be applied on the executable software i.e. in later stages of development.

iii. Internal Metrics: This document contains all the metrics that are derived from the product itself. These metrics are applicable to non-executable software products i.e. during designing and coding [Zeiss et al., 2007].

iv. Quality in use Metrics: This document contains the metrics that can be employed only if the software product is used in real conditions.

[Suryn et al., 2003] summarized the ISO/IEC-9126 quality model with respect to product life cycle. Relationships among each of the four parts, mentioned above, can be understood easily from Figure - 1.

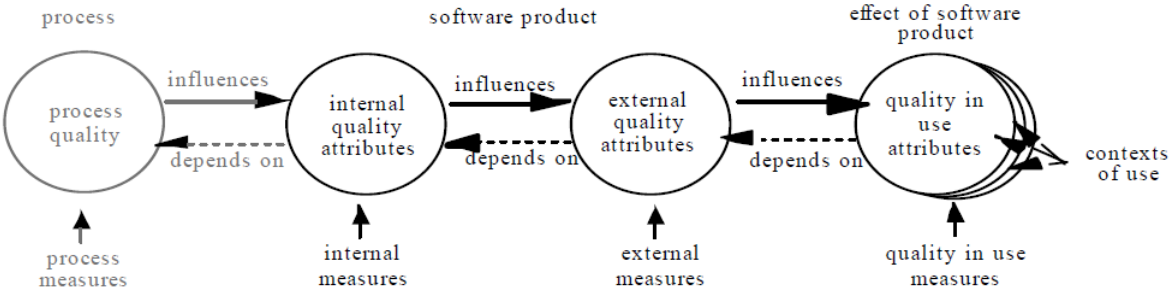


Figure - 1. ISO/IEC 9126-Model of quality. Source: [Suryn et al., 2003]

ISO/IEC-9126 classified software quality into six characteristics and multiple sub-characteristics. Each of the sub-characteristics can be further divided into attributes that can be quantified employing multiple metrics. However, the ISO standard doesn't include any information about the attributes and metrics as the standard is generic for all type of software

products whereas, these two criteria tend to be software product specific as mentioned in the standard. The six characteristics include the following:

i. Functionality: This characteristic includes the set of attributes that verifies the existence of required or specified functions or functionalities within the software product.

ii. Reliability: Set of attributes that are used to test the performance of the software product under stated conditions verifying its reliability.

iii. Usability: This characteristic is related to evaluating the software with respect to the easy with which it can be learned and used.

iv. Efficiency: This includes the attributes to evaluate the level of performance with respect to the usage of resources under stated conditions.

v. Maintainability: It includes the attributes to evaluate the efforts needed to modify the software product.

vi. Portability: This characteristic includes the attributes to evaluate the software product for its transferability among multiple environments.

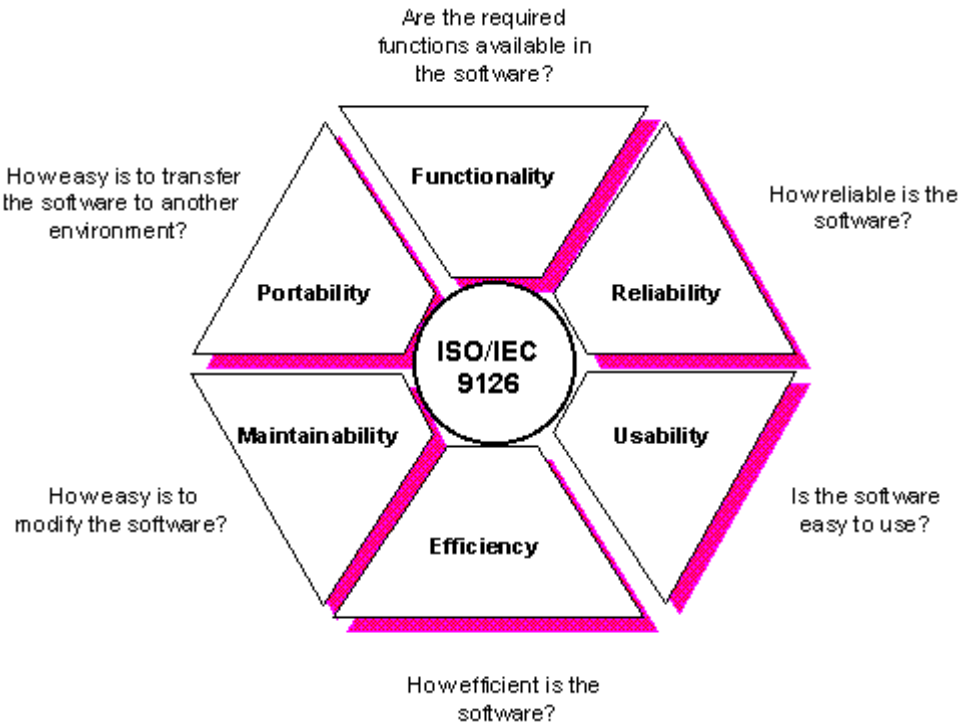


Figure - 2. Proposed characterstics in ISO-9126. Source: [ISO9126]

Figure - 2 briefly explains each of the above listed characteristics using simple questions. Whereas, Figure - 3 lists the proposed characteristics and sub-characteristics available in ISO/IEC-9126.

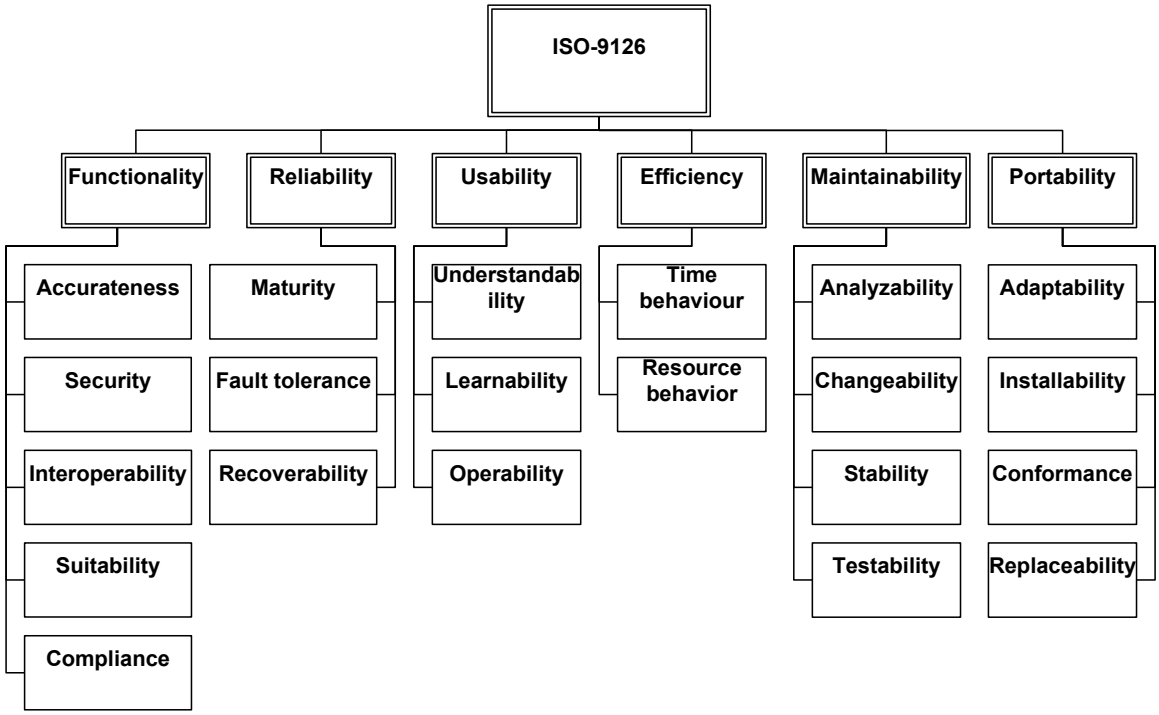


Figure - 3 Characteristics and sub-characteristics proposed in ISO-9126.

[Andreas et al., 2007] applied and extended the ISO/IEC-9126 standard to evaluate the quality of software components. The Table - 1 shows their proposed quality model. The authors have identified multiple attributes against each sub-characteristic of the model. Similarly, they have formulated numerous metrics to quantify attributes. Their suggestions and experimental modifications to ISO/IEC-9126 improve the understandability of the ISO quality model. They have proposed this new quality model for software components only. However with some efforts, this model can be generalized for quality of software in general. This model can serve as a good example to apply and extend the standard to other types of software products.

Table - 1. Proposed quality model for software components. Source: [Andreas et al., 2007]

Characteristics	Sub-characteristics	Attributes
Functionality	Interoperability	Platform Independence
		OS Independence
		Hardware Compatibility
		Data open-format compatibility
	Completeness	User satisfaction
		Service Satisfaction
		Achievability
	Security	Access Control
		Resistance to privilege
		Auditing
		Data Encryption
Reliability	Service Stability	Error Prone
		Error Handling
		Recoverability
		Availability
	Result Set	Correctness
		Transactional
Usability	Learnability	Time to use
		Time to configure
		Time to administer
	Help tools	Help completeness
		User Manual
		Installation and Administration
		Documentation
		Support Tools
	Operability	Operation effort
		Customizability effort
		Administration effort
	Identifiability-Reachability	Directory Listing
		Search & Retrieve
		Categorization
		Explainability
Efficiency	Response Time	Throughput
		Capacity
		Parallelism
	System Overhead	Memory Utilization
		Processor Utilization
		Disk Utilization
Maintainability	Changeability	Upgradeability
		Debugging
		Backward compatibility
	Testability	Trial version
		Test Materials
	Customizability	Parameterization
		Adaptability
		Priority

Similarly, there have criticisms to ISO/IEC-9126 standard as well. For example, [Cherfi et al. 2007] regarded it as a poor standard for effective quality assessment. They argue that the quality characteristics defined by the standard have different meanings for every life-cycle phase. Thus they should use different metrics for every characteristic at each lifecycle stage for evaluating the quality. [Kilidar et al., 2005] performed some experiment and found ISO/IEC-9126 ambiguous in meaning, incomplete with respect to quality characteristics and overlapping with respect to measured properties. They considered the standard unsuitable for measuring design quality of software products.

Another important stream of literature in the field of computer science, on the notion of quality, involves the literature on data quality. The researchers in data quality domain regards the above mentioned quality evaluation approaches to be very general for their domain. They formulated their domain specific quality frameworks for evaluating data quality. In the next section, we discuss some of the existing quality evaluation frameworks for data quality. We also discuss the [ISO25012, 2008] standard as it defines a general quality model for data retained in a structured format within a computer system.

2.2 Data Quality

Data quality can best be defined as "fitness for use" implying that the concept of data quality is relative. Thus, data with quality appropriate for one usage might not possess sufficient quality for another usage .Therefore, data quality should be evaluated along multiple dimensions and go beyond the famous quality measure of "data accuracy" [Tayi et al., 1998]. Bad data quality leads to issues such as relevancy, granularity, accuracy, consistency, currency, completeness, privacy and security [Redman98]. He identified numerous impacts inherent to bad data quality and classified them into three types: Operational Impacts such as reduced customer satisfaction, increased cost, lowered employee satisfaction, etc.; Typical Impacts such as poor decision making, more difficult to reengineer, increased organizational mistrust etc; and Strategic impacts such as difficulty to set and execute strategy, issues of data ownerships, etc.

[Wang et al., 1996] categorized data quality into four categories and identified quality dimensions for each one of them. [Wang 98] employed the same categories and dimensions for information quality:

i. Accuracy of data: Dimensions include Accuracy, Objectivity, Believability and Reputation

ii. Accessibility of data: Dimensions include Access and Security

iii. Relevance of data: Dimensions include Relevancy, Value-Added, Timeliness, Completeness and Amount of data

iv. Representation of data: Dimensions include Interpretability, Ease of understanding, Concise representation and Consistent representation

[Nelson et al., 2005] proposed four dimensions of information quality: Accuracy of information, Completeness of information, Currency of information and Format or presentation of information. [Pipino et al., 2002] took a broader picture and proposed an approach employing 16 data quality dimensions: Accessibility, appropriate amount of data, believability, completeness, concise representation, consistent representation, ease of manipulation, free-of-error, interpretability, objectivity, relevancy, reputation, security, timeliness, understandability and value-added.

Another stream of literature proposes different quality attributes and metrics for evaluating data quality. For example, [Bouzeghoub et al., 2004], [Peralta et al., 2004], [Peralta 06b] regards data freshness to be the most important attribute of data quality for data consumers. They classified data freshness into two factors and used multiple metrics to measure them. Their factors include currency and timeliness. They have employed metrics such as currency, obsolescence and freshness rate to measure the currency factor and timeliness metric to measure timeliness quality factor. Similarly, [Peralta 06a] used surveys and empirical studies to prove that data freshness is linked to information system success. They regard data freshness and data accuracy (correctness, reliability and error-freeness of the data) to be the two main dimensions of data quality and provide a review of both quality criteria from multiple perspectives and identified multiple metrics for their quantification.

[Peralta 06a] and [Peralta 06b] employed semantic correctness, syntactic correctness and precision factors to evaluate data accuracy. Each of these three factors utilizes multiple quality metrics such as semantic correctness ratio, syntactic correctness ratio, granularity, etc. to calculate data accuracy. [Cherfi et al., 2002a] found attributes such as accuracy, timeliness, precision, reliability, currency, completeness, accessibility and relevancy to be extensively studied for data quality evaluation. [Wang 98] presented a Total Data Quality Management methodology, and illustrated how it can be applied in practice. They developed concepts, principles, and procedures for defining, measuring, analyzing, and improving information products. Their methodology is based on the notion that organizations must treat information as a product that moves through an information manufacturing system, much like a physical product. Similarly, [Mecella et al., 2002]

proposed a framework to support data quality management in cooperative information systems. This framework includes the design of an infrastructure service for brokering and improving data quality. They used factors such as accuracy, completeness, currency and internal consistency to evaluate data quality.

[Bouzeghoub et al., 2004], [Peralta 06] analyzed different definitions and metrics of data freshness that evolved over time in addition to factors that influences it. This taxonomy is based on the nature of data, type of application and synchronization policies underlying the multisource information system. [Peralta et al., 2004] employed their proposed framework to evaluate data quality in data integration systems to evaluate data freshness in different scenarios. [Pipino et al., 2002] presents a subjective and objective assessment of data quality. They employed simple ratio, min-max operators and weighted average to develop multiple metrics to evaluate data quality. They also demonstrated how their approach can be applied in practice.

2.2.1 Standards

[ISO25012, 2008] is a first version of a new standard and defines a general quality model for data retained in a structured format within a computer system. It can be used to establish data quality requirements, define data quality measures, or plan and perform data quality evaluations. ISO/IEC-25012 considers two view points (inherent and system dependent) and classifies quality attributes into fifteen characteristics.

[Moraga et al., 2009] extended the ISO/IEC-25012 and proposed a quality model, SPDQM (SQuaRE-Aligned Portal Data Quality Model), for web portal data. Their model includes 42 quality characteristics classified under the two proposed viewpoints of ISO/IEC-25012 and four categories of PDQM (Portal Data Quality Model) i.e. “Intrinsic”, “Operational”, “Contextual” and “Representational”. Proposed SPDQM is illustrated in Table - 2.

Table - 2. SPDQM for web portal data. Source: [Moraga et al., 2009]

Point of view	Category	Characteristic	Sub-Characteristic
Inherent	Intrinsic: This denotes that data have quality in their own right	Accuracy	
		Credibility	Objectivity
			Reputation
		Traceability	
		Correctness	
		Expiration	
		Completeness	
		Consistency	
		Accessibility	
		Compliance	
		Confidentiality	
		Efficiency	
		Precision	
		Understandability	
		Availability	
	Operational: This emphasizes the importance of the role of systems that is, the system must be accessible but secure	Accessibility	Interactive
			Ease of operation
			Customer Support
		Verifiability	
		Confidentiality	
		Portability	
		Recoverability	
		Validity	Reliability
			Scope
			Applicability
System Dependent	Contextual: This highlights the requirement which states that data quality must be considered within the context of the task in hand	Value-added:	Flexibility
		Relevancy	Novelty
			Timeliness
		Specialization	
		Usefulness	
		Traceability	
		Compliance	
		Precision	
	Representational: This denotes that the system must present data in such a way that they are interpretable, easy to understand, and concisely and consistently represented	Concise Representation	
		Consistent Representation	
		Understandability	Interpretability
			Amount of data
			Documentation
			Organization
		Attractiveness	
		Readability	
		Efficiency	
		Effectiveness	

2.3 Conceptual Model Quality

Systems quality was initially thought to have achieved by improving the programming quality and productivity. Later it was revealed that these two dimensions have very marginal impact on systems quality [Akoka et al., 2007] proposed as compared to design quality that accounts to 72% errors in systems development activity [Thiagarajanet al., 1994]. [Avison et al., 1993] argued that the evaluation of information systems should be done at every stage of the lifecycle to improve its quality. He has also emphasized the need of evaluation at a broad range of factors including those of social and organizational. Similarly, [Akoka et al., 2007] proposed interesting notion of interdependencies between model quality and data quality. They formulated a quality meta-model encompassing both data quality and model quality. They propose a three level evaluation model for quality consisting of dimensions, factors and metrics for quantification. [Bansiya et al., 1999] argued that most of the existing available metrics can only be applied on the completed systems and there is a huge need for designing quality metrics that can be used early in the stages of requirements and design to improve the quality.

[Booch 91] have outlined four steps involved in Object-Oriented (OO) Design process:

i. Identification of different objects or classes

ii. Identification of the semantics of those objects or classes

iii. Identification of relationships among those objects or classes

iv. Implementation of those objects or classes

Thus, it can be hypothesized that if all of the four steps of OO design process are carried out with care and caution and hold a certain degree of quality then perhaps the resulting system be of good quality.

2.3.1 Conceptual Models (CM)

Conceptual Models (CM) are the abstraction of the universe of discourse under consideration [Cherfi et al., 2002b]. They are designed as part of the analysis phase and serve as a communicating mediator between the users and the development team. They provide abstract descriptions and hide the implementation details. CM are widely used in organizations to design information systems. [Davies et al., 2006] studied the conceptual modeling in different organizations. They identified different modeling techniques employed by them and measured the practitioners' interest in conceptual modeling.

Within the context of this thesis we will be using the term conceptual models to denote the following:

i. Unified modeling language (UML) Diagrams such as class diagram, use case diagram, etc.

ii. Entity Relationship Diagrams (ER).

2.3.1.1 Unified Modeling Language (UML)

Unified modeling language (UML) was proposed by Booch, Rumbaugh and Jacobson [RSC 1997] and has become a standard in the IS industry for object oriented analysis and design models [Marchesi 98]. UML 2.0 proposes 14 types of diagrams to design a system. These diagrams can be classified into three categories:

i. Structure Diagrams: they include class diagram, component diagram, composite structure diagram, deployment diagram, object diagram, package diagram and profile diagram.

ii. Behavior Diagrams: they include use case diagram, activity diagram and state machine diagram.

iii. Interaction Diagrams: they include sequence diagram, communication diagram, interaction overview diagram, and timing diagrams.

However, UML diagrams have received some criticism on the basis of their inherent complexity. [Siau et al., 2001] employed complexity metrics to evaluate the complexity of UML diagrams with respect to other object oriented methods. Their investigation concluded that the UML diagrams are approximately between 2 and 11 times more complex than other object oriented diagrams.

2.3.1.2 Entity Relationship Diagrams (ER)

Entity-Relationship (ER) diagrams were originally proposed by Peter Chen [Chen 76] to model data. ER-diagrams are widely used by researchers as well as practitioners to formulate a conceptual model or semantic data model of a system. They consist of entities and associations among entities.

Different researchers have proposed evaluation models to evaluate and improve ER-diagrams. For example, [Batini et al., 1992] can be considered as pioneers for introducing the first structured approach for conceptual schema evaluation mainly for databases. They have identified completeness, correctness, minimality, expressiveness, readability, self explanation, extensibility and normality as the criteria to evaluate the schemas. However, their approach doesn't include

any metrics for precise quantification of these criteria whereas their approach encompasses some transformations for improving the conceptual schemas. [Moody 98] extended the work of [Batini et al., 1992] by identifying a set of 25 metrics to quantify eight quality factors for entity relationship models. He categorized each of the eight quality factors into four types of actors: business users (understandability, flexibility, integrity, and completeness), data analysts (correctness, simplicity), data administrators (integration) and application developers (implementability). However, these metrics have never been implemented in any tool nor validated by some research.

Similarly, [Assenova et al., 1996] identified a set of seven quality criteria for evaluation in addition to providing a set of transformations for improving the quality of conceptual schemas. Their evaluation criteria include homogeneity, explicitness, size, rule simplicity, rule-uniformity, query-simplicity and stability. In [Cherfi et al., 2003b], the authors have proposed quality criteria for multidimensional database models. They defined six metrics to quantify analyzability and complexity in these models. Their main objective was to propose quality criteria to increase the analyzability and reduce the complexity of these multidimensional database models. [Genero et al., 2005] concentrated on ER-Diagram complexity and proposed a set of automatable metrics for its evaluation. [Garcia et al., 2007] proposed a meta-model driven measurement process and uses relational models as an example to evaluate the quality. They used measures such as number of tables, number of attributes, tables maintenance index, depth of relational tree, number of foreign keys, schema connectivity index, etc. to evaluate the quality of relational models. However, they claim that their approach and method can be used for other type of conceptual models as it is generic and based on UML's MOF (Meta Object Facility) standard. In [Cherfi et al. 2007], the authors conducted an experiment with a sample of 120 participants and have identified a strong relationship between measured quality and perceived quality. They have used quality metrics such as clarity, minimality, expressiveness and simplicity to quantify the measured quality of the models. They provided 8 models to the participants and ask them to rank those 8 ER models on the same quality criteria used for measurement purpose.

2.3.2 Conceptual Modeling Quality

Although a CM may be consistent with the universe of discourse, it might not necessarily be correct. Since CM are designed before the actual implementation of the system, therefore errors in them are propagated throughout the development cycle and thus heavily impact the development and quality of an information system [Lausen et al., 2001]. This suggests that there is a strong urge for a quality-oriented approach that can help in ensuring the consistency and correctness of

the conceptual models. Research in software quality is rather mature and produced several standards such as ISO 9126 and ISO 25030:2007 whereas, in the domain of CM, research on quality evaluation is rather young. The first structured approach dates back to the contribution of [Batini et al., 1992]. They were the pioneers in proposing quality criteria relevant to CM evaluation. In [Lindland et al., 1994], the quality of models is evaluated along the three dimensions: syntax, semantics and pragmatics. [Kaiya et al., 2004] compared different use diagrams to deal with non functional requirements and [Yu et al., 2004] proposed a method and tool to refactor use case models.

Another approach on the evaluation of CM quality puts light on the importance of aesthetics. For example, [Eichelberger 02], [Purchase et al., 2002], [Purchase et al., 2001b], [Purchase et al., 2000] have insisted on the importance of aesthetics within a model. [Cherfi et al. 2007] and [Cherfi et al., 2002a] have also employed some aspects of aesthetics such as clarity, legibility to evaluate the understandability of their models. [Purchase et al., 2002], [Purchase et al., 2001b], [Purchase et al., 2000] have identified criteria such as minimization of bends, minimization of edge crossing, orthogonality, etc. to improve the aesthetics of UML diagrams or ER diagrams. Their approach evaluates the aesthetics and provides algorithms or transformations to improve it. [Eichelberger 02] also provides an implementation of their approach by proposing a utility that helps in the evaluation of these aesthetics criteria automatically. However, they haven't formally defined any metrics for the evaluation purpose [Cherfi et al. 2007] and [Cherfi et al., 2002a] provided clear definitions of metrics to evaluate some aspects of model aesthetics.

Similarly, another research stream consists of proposing automatable approach or utility driven evaluation approach to ease the evaluation process by an automatic computation of metrics. For example, [Ali et al., 2007a], [Ali et al., 2007b], proposed software driven automated methodologies to evaluate different aspects of UML class diagrams such as structure, correctness and syntax. Their work was inspired from the automated tool presented in [Forsythe et al., 1965] to evaluate the different diagrams designed by students. Similarly, they have also taken ideas from [Shukur et al., 2004] who have proposed computer-aided marking systems for engineering drawings. However, the major shortfall in [Ali et al., 2007a] and [Ali et al., 2007b] approach is due to the fact that they evaluate the models with respect to one model designed by an expert. Thus, their approach or utility can only be applied on class diagrams that have a version designed by an expert. Similarly, the criteria they have used for evaluation is not exhaustive for example, they compare number of attributes in a class designed by an expert to the class designed by non-experts to evaluate the completeness of a model. Thus, their approach could yield wrong results if non-experts have captured the missing information in some other class.

Another big problem in the area of CM quality is due to the presence of autonomous quality models. Most of the research done in this area is independent and doesn't draw their thesis from other work or doesn't extend what has already been done in the field. This has led to two issues:

i. Most of the work done in CM quality evaluation is concentrated on model complexity and its maintenance.

ii. There exist multiple definitions of the same concept and different names for semantically same concepts. For example, [Nelson et al., 2005] identified different definitions of the same quality concepts e.g. there exist nine different definitions for quality attribute "completeness". Similarly, there exist numerous definitions for the same quality concept and identical names for some semantically different metrics [Purao et al., 2003]. Such issues have restricted the adoption of the existing quality frameworks in practice [Moody 05].

The existing work on CM quality classified the evaluation criteria into dimensions, attributes or metrics. Therefore, we will be discussing CM quality criteria for each of these types to have a broader and crisper picture.

2.3.2.1 Quality Dimensions

Different researchers have classified CM quality into different dimensions based on their viewpoint. For example, in [Lindland et al., 1994] the quality of CM is evaluated along three dimensions: syntax, semantics and pragmatics. [Cherfi et al., 2002a] proposed a three dimensional (specification, usage and Implementation) quality framework for conceptual models. They have regarded model quality through users' point of view and demonstrated that conceptual models should be supported by facilities for accessing, developing, analyzing, changing and maintaining concepts used in their construction. [Bajaj 02] zoomed within the different dimensions and defined readability in CM along three dimensions: Effectiveness, efficiency and learnability.

2.3.2.2 Quality Attributes

Most of the evaluation approaches in CM classify their quality criteria into multiple quality attributes that can be quantified employing multiple numeric metrics. For example, [Cherfi et al., 2002a] [Cherfi et al., 2002b] divided their three dimensional quality framework into the following quality attributes:

i. Legibility (the ease with which a conceptual schema can be read)

ii. Expressiveness (representation of requirements in a natural way so that it can be easily understood without additional explanation)

iii. Simplicity (A schema is said to be simple if it contains the minimum possible constructs)

iv. Correctness

v. Completeness (degree of coverage of user requirements within the model)

vi. Understandability (ease with which the data model can be interpreted by the user)

vii. Implementability (amount of effort needed to implement the model)

viii. Maintainability (the ease with which a model can evolve)

Similarly, we performed a thorough literature review and identified multiple quality attributes for CM quality evaluation. These attributes include: structural complexity, modularity, modifiability, understandability, readability, etc. Quality attributes are not independent from one another and thus they can affect other quality attributes. For example in [Cherfi et al., 2008], the authors mentioned that expressiveness quality attribute can affect simplicity quality attributes as increasing the expressiveness of the model will lead to the inclusion of numerous model elements for explicit knowledge addition. Thus the model will contain more elements which can increase complexity that in turn will influence the understandability and maintainability as shown by [Genero et al., 2002a], [Genero et al., 2001b], [Genero et al., 2001c], [Genero et al., 2000b], [Manso et al., 2003].

2.3.2.3 Quality Metrics

Most of the research done in the field of CM quality evaluation was devoted to the definition of numeric metrics for quantifying different characteristics of model. A metric is a specific instrument that can be used to measure a given quality factor. There might be several metrics for the same quality factor [Bouzeghoub et al., 2004]. The aims of metrics are essentially to provide hints about the quality such as to estimate development and maintenance cost [Marchesi 98]. Some of these metrics can be calculated automatically whereas some can't because the definition of these metrics (non automatable metrics) is not based on the structural characteristics of the model or those semantic characteristic that are easy to calculate. In the literature, there exist numerous metrics to evaluate UML class diagram, use-case diagrams and ER-diagrams. For example, [Chidamber et al., 1994] have developed and empirically tested a set of six metrics to measure the three non-implementation deliverables (Identification of different objects/classes, Identification of the semantics of those objects/classes, Identification of relationships among those

objects/classes) identified by [Booch 91]. These metrics include: weighted methods per class, depth inheritance tree, number of children, coupling between objects, responses for a class and lack of cohesion in methods. The development of these metrics received huge appreciation from the researchers and triggered a stream of research on using these metrics to evaluate complexity at different levels and models of design. Similarly, several empirical studies were carried out to evaluate the efficacy of these metrics. However, these metrics received some critiques as well. For example, [Churcher et al., 1995] argued about the level of abstractness these metrics carry and failure to provide implementation details, such as which components should be included in the calculation of these metrics. They take an example of number of methods metrics and argued that the metric doesn't provide details about what should be included in its calculation and thus can lead to multiple interpretations of the same model.

[Cherfi et al., 2002a] and [Cherfi et al., 2002b] have proposed following quality metrics for quantifying their quality attributes:

i. Clarity: computed as a ratio between number of line crossings to the total links in the schema

ii. Minimality: calculated as the ratio of non-redundant concepts to the total concepts

iii. Concept expressiveness: ratio between the expressive concepts (e.g. Inheritance link as it is more expressive than association) and all the concepts present in the model

iv. Schemas expressiveness: compares model expressiveness with respect to other models representing the same reality

v. Syntactic Correctness: A Schema is syntactically correct if the concepts are properly defined in the schema

vi. Semantic Correctness: A Schema is semantically correct if the concepts are used according to their definition (grammar).

[Siau et al., 2001] employed complexity metrics to evaluate the complexity of UML diagrams with respect to other object oriented methods. They proposed quantitative measures to compute UML complexity. [Cherfi et al., 2006] proposed a set of metrics to measure entropy and lack of cohesion in use cases. These metrics are use case specific and cannot be generalized to other models within the UML. Moreover, they also propose a set of rules that can be used by model designers to decrease complexity in use cases. Similarly, [Cherfi et al., 2003a] proposed a documentation degree metric to evaluate the understandability of models.

In the next sub-sections, we have classified some of the existing metrics into automatable metrics or non-automatable metrics. Automatable metrics are usually based on structural characteristics, or some semantic characteristics that are easy to automate, and thus can be measured using some software utility. Non-automatable metrics represents all the metrics that require manual input for computation and thus can't be computed using a software utility.

2.3.2.3.1 Automatable Metrics

[Ojha et al., 1994] proposed some really good metrics to evaluate different aspects of code complexity such as number of classes, number of attributes, etc. Most of these metrics are transferred to CM quality domain and have been used by multiple researchers for automatic evaluation of CM. For example, In [Genero et al., 2004], [Genero et al., 2003], [Genero et al., 2002a], [Genero et al. 2002b], [Genero et al., 2001a], [Genero et al., 2001b], [Genero et al., 2001c], [Genero et al., 2000a], [Genero et al., 2000b], [Manso et al., 2003] the authors have used two sets of automatable metrics (which they referred to as size and structural complexity metrics) to evaluate different quality attributes in UML Class diagram. These sets of metrics are:

i. Size Metrics such as: Number of Classes(NC), Number of Attributes(NA), Number of Methods(NM)

ii. Structural Complexity Metrics such as: Number of Associations (NAssoc), Number of Aggregations (NAgg), Number of Aggregation Hierarchies (NAggH), Number of Generalizations(NGen), Number of Generalizations Hierarchies(NGenH), Number of Dependencies(NDep), Maximum Depth Inheritance Tree(Max DIT) and Maximum Aggregation Hierarchies(Max AggH).

The authors have used these metrics and applied different research methodologies and conducted different sorts of experimentation to conclude the following:

i. There is a significant correlation between the structural complexity metrics and the three maintainability sub-characteristics (understandability, analyzability and modifiability).

ii. There is a significant correlation between structural complexity metrics and maintenance time.

iii. The structural and size metrics of class diagrams can be used as good predictors of class diagram maintainability.

[Marchesi 98] have identified multiple metrics for use-case diagrams and class diagrams that can be automated. For example, he proposed simple metrics such as number of use cases, number

of communications among use cases and actors, etc. whereas sophisticated metrics include a metric to calculate the total number of communications among use cases and actors but without the redundancies that are introduced due to 'extend' and 'use' relationships. Similarly, his proposed metrics for class diagrams include:

i. Total number of classes, total number of inheritance hierarchies

ii. Weighted number of responsibilities of a class (inherited or not)

iii. Weighted number of dependencies

iv. Percentage of inherited responsibilities with respect to total number, etc.

However, from the above metrics we can notice that [Marchesi 98] emphasizes more on the inheritance and dependency relationships than on associations, aggregation, composition, etc. Similarly, the proposed metrics are related to the complexity of conceptual models, thus narrowing the scope of quality evaluation to one dimension. [In et al., 2003] also employed metrics such as total number of classes, total number of inheritance relationships, total number of use relationships, total number of parameters etc to calculate the architectural complexity of the models in the early stage of development lifecycle.

[Rufai 03] has used multiple criteria to evaluate the similarity between a pair of UML models. He proposed two interesting metrics Shallow Semantic Similarity Metric (SSSM) and Deep Semantic Similarity Metrics (DSSM) to compare the names of the classes (SSSM) and the attributes and methods (DSSM) of two UML models representing the same reality. He also proposed to match the signatures of the classes to find the similarity between the classes of two models. Likewise [Zhou et al., 2003] have proposed an entropy based structure complexity metrics to evaluate the complexity of class diagrams. This metric employs the structural complexity metrics defined in [Genero et al., 2002a], [Genero et al., 2000a], [Manso et al., 2003] to calculate the entropy.

[Yi et al., 2004] provides a limited review of the available metrics for evaluating the complexity of UML class diagrams. The authors have compared some of the above mentioned metrics from different viewpoints and found that most of the chosen metrics have their shortcomings while being effective or efficient for some special characteristics of systems. The acceptance of metrics in practice depends on its consistency with their view of complexity.

2.3.2.3.2 Non-Automatable Metrics

Another set of proposed metrics in the domain of CM evaluation cannot be automated due to the following reasons:

i. Inherent complexity of the metrics.

ii. Model properties that aren't exported in XMI (XML metadata interchange). For example, XMI doesn't contain layout information about model elements and thus metrics related to aesthetics (line crossings, etc.) can't be automated.

iii. Absence of technology to automate parts of the metrics (lack of sophisticated natural language processing (NLP) tools to extract important information from textual documents).

Some of the metrics that are not automatable (now, perhaps possible in the future) include the following metrics proposed by [Cherfi et al., 2003a] for quantifying their quality attributes:

i. Requirements coverage degree: Comparison between the concepts covered by the modeling element of the conceptual schema and the ones expressed by the users through the requirements.

   Reasons: The automation of this metrics is significantly difficult as it is difficult to identify if the mapped concept is the same concept depicted in user requirements. Perhaps by employing advanced NLP techniques we can have some confidence on the result of this metrics.

ii. Cross modeling completeness: Compares completeness among several schemas modeling the same reality i.e. ratio between the number of concepts present in the model and the union of all the distinct concepts present in all the schemas representing the same reality.

   Reasons: Difficult to design multiple models for same problem.

iii. Documentation degree: Every model element (classes, attributes, etc.) should have comments associated with it.

   Reasons: Most of the model elements have documentation available as a separate document. For example, entities are modeled in ER-Diagram whereas described in High Level Documents.

iv. User vocabulary rate: Users can make easy correspondence between the modeling elements contained in the model and the requirements in the textual description.

   Reasons: Difficulty in identifying which model element corresponds to which textual description.

v. Cohesion & Coupling: These metrics are usable only in case of multiple modules of conceptual models. It is deemed to have high cohesion for every module and low coupling among modules.

   Reasons: There exist some metrics to calculate cohesion and coupling of modules and some of them might be calculated but most of them are very complex and require manual input.

In the next section, we assess some of the leading software applications that propose quality evaluation for conceptual models. We selected Objecteering, Rational Rose and StarUML modeling software for assessment as all they are widely used in the industry for designing different CMs and also offers functionalities for CM evaluation. Moreover, we selected UMLQuality as it is the only application that is dedicated to CM evaluation alone.

2.4 Software Tools for Modeling and Quality Evaluation

There exist numerous modeling tools for designing different types of conceptual models based on different notations/standards such as UML, Entity Relationship, etc. These tools include Enterprise Architect, Objecteering, Rational Rose, Star UML, Visio, etc. However, only a handful among them provides any means to evaluate the quality of the models designed through them. In this section we will assess some of these modeling tools and the evaluation methodology proposed by them. We will only consider the evaluation methodology proposed for conceptual models and thus will not take into account those for codes or object-oriented programs.

In addition to assessing the above mentioned modeling tools, we will also assess a tool called UMLQuality. This tool doesn't provide modeling capabilities and was conceived for model evaluation only. Some of the literature used in this section is adapted from [Kersulec 08].

2.4.1 Objecteering

Objecteering is a commercial modeling tool widely used in the industry. It supports UML (Unified Modeling Language) and MDA (Model Driven Architecture). It can be used to design UML diagrams such as use case diagrams, class diagrams, sequence diagrams, state transition diagrams, etc. In addition to its modeling capabilities, Objecteering also provides an evaluation methodology for static elements such as classes, packages, etc. However, most of the evaluation criteria are based on syntactic quality of the models. Following are some of the short comings in Objecteering's evaluation method:

i. It doesn't provide any evaluation methodology for dynamic diagrams such as use case diagrams, sequence diagrams or state transition diagrams.

ii. The evaluation metrics can't be defined or edited by the user. Thus, the user is constrained to use the existing set of metrics.

iii. The user can't choose the criteria important for his/her particular needs. All the metrics will be calculated automatically whether required or not.

iv. Users have to interpret the metrics results by themselves and have to imagine the ways to improve the model.

v. There is no post evaluation guidance process or mechanism for model improvement.

2.4.2 Rational Rose

Rational Rose can be regarded as one of the oldest and widely used modeling tool in the industry. It supports UML diagrams such as use case diagrams, class diagrams, sequence diagrams, state transition diagrams, collaboration diagrams, etc. However, as compared to Objecteering's evaluation capabilities, Rational Rose provides a very limited set of metrics for the verification of models. Following are some of the short comings in Rational Rose's evaluation methodology:

i. It doesn't provide any evaluation report.

ii. It doesn't provide an evaluation method for dynamic diagrams.

iii. The evaluation metrics can't be defined or edited by the user.

iv. Users can't choose the metrics with respect to their needs. All the metrics are calculated automatically.

v. There is no post evaluation guidance process or mechanism for model improvement.

2.4.3 Star UML

StarUML is an open source modeling tool designed to replace commercial applications such as Objecteering and Rational Rose. It supports UML diagrams such as use case diagrams, class diagrams, sequence diagrams, state transition diagrams, collaboration diagrams, etc. However, it doesn't provide support for object diagrams and package diagrams. Similar to Rational Rose, StarUML provides a very limited set of metrics for the verification of models. Following are some of the short comings of StarUML evaluation methodology:

i. It doesn't provide any evaluation report.

ii. It doesn't provide an evaluation method for dynamic diagrams.

iii. The evaluation metrics can't be defined or notified by the user.

iv. Users can't choose the metrics with respect to their needs. All the metrics are calculated automatically.

v. There is no post evaluation guidance process or mechanism for improvement.

2.4.4 UMLQuality

UMLQuality est un outil puissant qui s'adresse essentiellement aux experts qualité ou bien encore aux responsables désireux d'améliorer au plus tôt la qualité des produits qu'ils construisent.UMLQuality is a powerful tool designed to work with existing modeling tools such as Rational Rose, etc. to evaluate the quality of models instead of designing the models. It is intended for quality experts aiming to target the quality of their models. UMLQuality utilizes XMI to evaluate models designed using other modelers. However, following are some of the shortcomings in UMLQuality:

i. Absence of any interface for metrics definition

ii. Absence of adequate level of abstraction. Users are left with metrics results and thus it gets difficult for them to interpret.

iii. There is no guidance process for the users enabling them to choose the metrics with respect to their requirements. Either the user selects the metrics by himself/herself or all the metrics are calculated automatically.

iv. Two models can't be compared to each other

v. Recommendations are not incorporated within the tool. A plug-in must be installed in order to have an access to the recommendations.

Despite the above mentioned short-comings, UMLQuality is the best existing tool for evaluating the quality of models as mentioned in [Kersulec 08]. Table - 3 summarizes the above mentioned points about the four evaluated tools.

Table - 3. Comparison between evaluation methodologies proposed in different tools

Criteria	Objecteering	Rational Rose	StarUML	UMLQuality
Evaluate Static Diagrams	Yes	Yes	Yes	Yes
Evaluate Dynamic Diagrams	No	No	No	Yes
Granularity of evaluation criteria	Metrics	Metrics	Metrics	Metrics
Possibility to Add/edit evaluating criteria	No	No	No	Yes
Interface for defining/modifying the evaluation criteria	No	No	No	No
Guidance process for selecting the requirement/project specific evaluation	No	No	No	No
Comparison of multiple models	No	No	No	No
Provision of evaluation report	Yes	No	No	Yes
Provision of post evaluation recommendations	No	No	No	Yes (limited with plug-in)

In the next section, we classified the existing literature on conceptual model quality into the different types of qualities (such as syntactic quality, semantic quality, pragmatic quality, physical quality, etc.) proposed in [Krogstie et al., 1995]. We chose to use Krogstie's framework for conceptual modeling quality for the following reasons:

i. It is an extended version of the famous quality framework proposed by [Lindland et al., 1994] and so can be considered a bit matured.

ii. It is richer than the preceding quality frameworks as it identified additional types of qualities in conceptual models such as physical quality, social quality, empirical quality, etc.

iii. It is well known among the CM quality community as it has been employed by multiple researchers such as [Cherfi et al., 2007], [Maes et al., 2007], [Nelson et al. 2005], [Schuette 91], etc.

2.5 Towards an Instrumented Approach for Quality Management

Considering the literature review presented above, we could summarize the situation as follows:

i. On the one hand we have frameworks. Their main advantages are their global vision of quality assessment and their ability to structure the reasoning about what to assess and how to do it. However, they lack agreement about the definition and the meaning of the quality concepts they use. These frameworks are also cross grained and contain very few

details on how to use them. This is why they are difficult to understand and even to use for quality assessment.

ii. On the other hand we have quality assessment approaches defining quality characteristics and/or metrics. Their main advantage is the fact that they are fine grained and could be operationalized for quality assessment. However, as they propose no global vision of the quality, the exploitation of the assessment results is difficult to analyze and to generalize. As for frameworks, they also lack agreement on the quality concepts they define.

In view of the above, we propose to combine the two above mentioned visions of quality in an attempt to exploit the advantage of both. We propose to enrich a quality framework with guidelines and measurement methods to make the framework usable for quality understanding, quality measurement and quality improvement. We have chosen the generic quality framework proposed in [Krogstie et al., 1995]. This work will first provide a synthesized vision of the existing literature and second by enrich the framework by proposing suitable metrics for the evaluation of conceptual modeling quality facets.

2.5.1 Krogstie's Framework for Quality of Conceptual Models

Krogstie's framework for conceptual modeling quality extends the framework proposed by [Lindland et al., 1994]. Krogstie pointed out some deficiencies in the original framework concerning the difficulty of quality evaluation based only on the model and introduced the consideration of participant's domain knowledge. The resulting framework is depicted in Figure - 4.

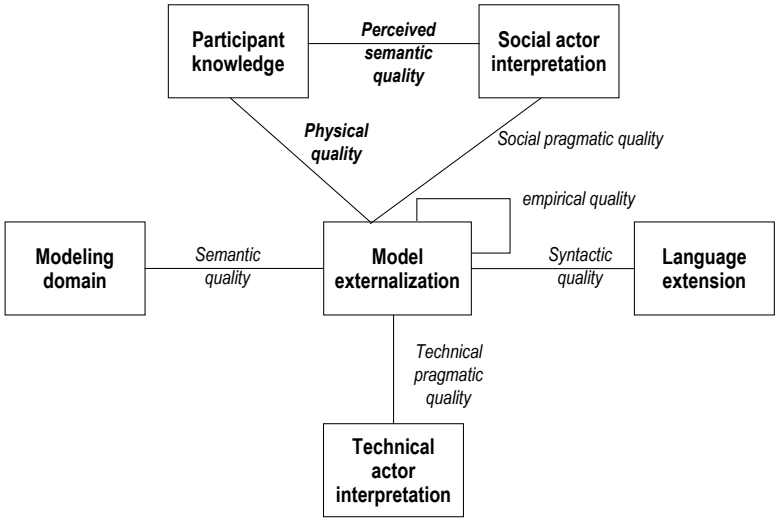


Figure - 4. [Krogstie's et al., 1995] Framework for quality of models

In Figure - 4 quality aspects are described as the correspondence between two statements represented by boxes. Modeling domain refers to the set of statements describing the problem in hand. Language extension contains all the statements that could be expressed given a modeling language. Model externalization is the conceptual model representing the domain. Social actor interpretation is the knowledge perceived by the audience about the model. Technical actor interpretation is the interpretation of the model by the tools. Finally, participant knowledge is related to the statements made by persons involved in the modeling process to represent the domain.

The framework defines also seven quality dimensions defined as the correspondence between pairs of statements. For example, semantic quality checks the model and the domain by verifying the validity of the represented knowledge and its completeness regarding the domain.

2.5.2 Instrumentalisation of the Conceptual Modeling Quality Framework

In this section we will present for each quality dimension:

i. A clear and precise description of means associated to quality dimensions. Means could be guides, methodological advices, tools or any other kind of knowledge aiming to facilitate both the dimension understanding and the measurement of quality values;

ii. A set of references from the literature to quality attributes and metrics containing both the detail of attributes description and metrics definition enabling a precise characterization of quality dimensions as well as their assessment.

2.5.2.1 Syntactic quality measurement

Syntactic quality requires a correspondence between the notation used and the model produced. The quality attributes related to this quality dimension deal with correctness regarding the concepts and constraints of the notation. In the literature this dimension is measured through syntactic correctness (the model is syntactically correct), syntactic completeness (the model is syntactically correct regarding the notation) and eventually normalized (when the notation requires normalization). To achieve this quality we methods and tools dedicated to the notation should develop mechanisms for error prevention, detection and correction. For example, an entity relationship diagrams editor should not allow the definition of a relationship among relationships and should enforce the completion of cardinalities and identifiers definition.

Quality means: Error prevention, detection and correction	
Quality attributes	**Proposal**
Syntactic Correctness	[Ali et al., 2007a], [Ali et al., 2007b], [Cherfi et al., 2002a], [Cherfi et al., 2002b], [Moody et al., 2003], [Moody et al., 2000], [Moody 98], [Moody et al., 1998], [Shanks et al., 1997] , [Zamperoni et al., 1993], [Zhou et al., 2003]
Syntactic completeness	[Briand et al., 1997], [Cherfi et al., 2006], [Cherfi et al., 2003a], [Chidamber et al., 1994], [Harrison et al., 1998], [Lange et al., 2004], [Li et al., 1993], [Marchesi 98]
Normality	[Batini et al., 1992]

2.5.2.2 Physical quality

Physical quality refers to the possibility to access the model. The model should be visible somewhere and in a given form. This requires two things. Firstly, the language or the notation used should have a mean for model externalization such as the possibility to display or to print a graphical or a textual description of the model. Secondly, the produced model should be available and accessible in the adequate form for the audience.

At the language level, this requires an adequate choice of the notation used. This is captured by language expressiveness language adequacy and suitability quality attributes that enable the measurement of externalization capabilities of a language. For internalization evaluation, implementability allows measurement of the effort needed to implement a model in a target technology (database, web pages, programming language etc).

Quality means: Externalization : language implementability, model implementability Internalization : models availability	
Quality attributes	**Proposal**
Implementability	[Cherfi et al., 2002a], [Cherfi et al., 2002b], [Moody et al., 2003], [Moody et al., 2000], [Moody 98], [Moody et al., 1998], [Shanks et al., 1997]
Model expressiveness	[Batini et al., 1992], [Cherfi et al., 2002a], [Cherfi et al., 2002b]
Language expressiveness	[Cherfi et al., 2002a], [Cherfi et al., 2002b]
Language adequacy	[Schuette et al., 1998]
Suitability	[Kesh 95]

2.5.2.3 Semantic quality measurement

Semantic quality deals with the adequacy of the model and the domain. This includes both the actual statements coverage and the further extension implying the extensions possibilities of the model. This requires the measurement of requirements coverage, the relevance of the model representations, the completeness of the model that could be measured directly if comparison to the domain is possible or indirectly using other models or views related to the same domain. It also required the semantic correctness of the modeled statements based on ontology and reuse of domain knowledge representation or meta-models.

Quality means: Consistency Checking, Completeness Checking, Relevancy Checking	
Quality attributes	**Proposal**
Completeness	[Batini et al., 1992], [Cherfi et al., 2002a], [Cherfi et al., 2002b], [Kesh 95], [Lange et al., 2005], [Lange et al., 2004], [Moody et al., 2003], [Moody et al., 2000], [Moody 98], [Moody et al., 1998], [Shanks et al., 1997], [Simsion 94], [Solheim et al., 2006]
Compliance To Meta-model	[Solheim et al., 2006]
Cross Modeling Completeness	[Cherfi et al., 2003a]
Extensibility	[Batini et al., 1992], [Kesh 95]
Flexibility	[Levitin et al., 1995], [Moody et al., 2003], [Moody et al., 2000], [Moody 98], [Moody et al., 1998], [Shanks et al., 1997], [Simsion 94]
Maintainability	[Cherfi et al., 2002a], [Cherfi et al., 2002b], [Genero et al., 2005], [Genero et al., 2003]
Modifiability	[Solheim et al., 2006]
Relevance	[Levitin et al., 1995], [Solheim et al., 2006]
Requirements Coverage	[Cherfi et al., 2003a]
Reusability	[Simsion 94]
Semantic Correctness	[Ali et al., 2007a], [Ali et al., 2007b], [Batini et al., 1992], [Cherfi et al., 2002a], [Cherfi et al., 2002b], [Moody et al., 2003], [Moody et al., 2000], [Moody 98], [Moody et al., 1998], [Shanks et al., 1997], [Zamperoni et al., 1993]
Semantic Robustness	[Levitin et al., 1995]
Soundness	[Kesh 95]

2.5.2.4 Pragmatic Quality Measurement

Pragmatic quality is related to the understanding of models by audience. There have been several empirical studies on the factors having a direct impact on understandability. These studies demonstrated that there are several factors impacting directly the understandability of models. The most cited one is complexity related to both structure and size of models. However the understandability could also be impacted by the usage of simple concepts, the documentation, the naming conventions or simply by choosing model elements names from a vocabulary close to the audience vocabulary (domain vocabulary for example).In order to help pragmatic quality improvement some means or techniques such as visualization at different levels of abstraction or detail, animation techniques, prototyping, translation, etc. could be used.

Quality means: Inspection, Visualization, Filtering/Views, Explanation Generation, Simulation, Animation, Reporting, Execution/Prototyping	
Quality attributes	**Proposal**
Complexity	[Cherfi et al., 2003b], [Chidamber et al., 1994], [Garcia et al., 2007], [Genero et al., 2005], [Genero et al., 2003], [Genero et al., 2002a], [Genero et al., 2002b], [Genero et al., 2001a], [Genero et al., 2001b], [Genero et al., 2000a], [Genero et al., 2000b], [Gray et al., 1991], [Lange et al., 2005], [Lorenz et al., 1994], [Manso et al., 2003], [Marchesi 98], [Poels et al., 2000], [Zhou et al., 2003]
Comprehensiveness	[Cherfi et al., 2007], [Levitin et al., 1995]
Essentialness	[Levitin et al., 1995]
Conciseness	[Boehm et al., 1978], [Boehm et al., 1976], [Kesh 95], [Lange et al., 2005]
Self-descriptiveness	[Batini et al., 1992], [Boehm et al., 1978], [Boehm et al., 1976], [Lange et al., 2005]
Documentation Degree	[Cherfi et al., 2003a]
User Vocabulary Rate	[Cherfi et al., 2003a]
Explicitness	[Assenova et al., 1996]
Size	[Assenova et al., 1996], [Genero et al., 2005], [Genero et al., 2003], [Genero et al., 2002a], [Genero et al., 2002b], [Genero et al., 2001a], [Genero et al., 2001b], [Genero et al., 2000a], [Genero et al., 2000b], [Li et al., 1993]
Simplicity	[Assenova et al., 1996], [Cherfi et al., 2007], [Cherfi et al., 2002a], [Cherfi et al., 2002b], [Moody et al., 2003], [Moody et al., 2000], [Moody 98], [Moody et al., 1998], [Shanks et al., 1997]
Minimality	[Batini et al., 1992], [Cherfi et al., 2007], [Cherfi et al., 2002a], [Cherfi et al., 2002b]
Understandability	[Assenova et al., 1996], [Cherfi et al., 2002a], [Cherfi et al., 2002b], [Moody et al., 2003], [Moody et al., 2000], [Moody 98], [Moody et al., 1998], [Shanks et al., 1997]

2.5.2.5 Social Quality Measurement

The social quality underlying hypothesis is that a model is the result of a stakeholders agreement about the model. Social quality requires the measurement of the degree of agreement. However as the collaborative process is not captured in the model direct measurement of this quality is impossible. However, as this collaborative process could generate several versions, models, views, documents comparison techniques should provide means for indirect measurement by capturing similarities and differences.

Quality means: Agreement, Cross modeling comparison	
Quality attributes	**Proposal**
Cross Modeling Completeness	[Cherfi et al., 2003]
Integration	[Moody et al., 2003], [Moody et al., 2000], [Moody 98], [Moody et al., 1998], [Shanks et al., 1997]
Model Similarity	[Rufai 03]

2.5.2.6 Empirical Quality Measurement

An empirical quality measures how easy to read the model is. It is related to aesthetics.

Quality means: Expressive economy, Use of emphasis, Graph and document layout, use of color	
Quality attributes	**Proposal**
Language Aesthetic	[Eichelberger 02], [Lange et al., 2005], [Lange et al., 2004]
Minimization Of Bends	[Purchase et al., 2002], [Purchase et al., 2001a], [Purchase et al., 2001b], [Purchase et al., 2000]
Minimization Of Edge Crossing	[Purchase et al., 2002], [Purchase et al., 2001a], [Purchase et al., 2001b], [Purchase et al., 2000]
Orthogonality	[Purchase et al., 2002], [Purchase et al., 2001a], [Purchase et al., 2001b], [Purchase et al., 2000]
Clarity	[Cherfi et al., 2007], [Cherfi et al., 2002a], [Cherfi et al., 2002b], [Schuette et al., 1998]
Legibility	[Cherfi et al., 2007], [Cherfi et al., 2003], [Cherfi et al., 2002a], [Cherfi et al., 2002b]
Communicativeness	[Boehm et al., 1978], [Lange et al., 2005], [Lange et al., 2004]
Readability	[Batini et al., 1992]
Structure	[Ali et al., 2007a], [Ali et al., 2007b]

2.6 Conclusion

One of the major problems in the domain of CM Quality is the existence of independent and disparate quality frameworks. Most of the existing quality frameworks propose their vision of CM quality and emphasize on their identified characteristics as pertinent to quality. Thus a reader (or may be user) is left with a list of different frameworks each proposing different quality criteria for evaluation and he/she has to rely on his cognition to identify the relevant quality criteria among that list for his problem. But the quality of CMs can't be improved by employing just one or two perspectives leaving all other perspectives. Quality is multidimensional problem and thus must be

addressed through multiple perspectives. This requires that the user must know all the existing literature to find a better solution for his/her quality problems. But this requirement will restrict the evaluation and improvement activities to quality experts only. However, if some guidance process can be proposed to users that helps them in identifying the relevant quality criteria for their problem and then guides them through the evaluation and improvement of the CMs then perhaps non-experts users might be able to integrate evaluation and improvement activities as part of designing phase. In the following chapters, we present our solution for the above mentioned problems. Our solution includes the following:

i. Federation of existing quality frameworks to formulate a comprehensive quality approach incorporating different evaluation criteria.

ii. Identification of quality patterns, a concept similar to design patterns but dedicated to quality, to encapsulate past experiences and good practices. We describe the concept of quality patterns in details along with all of its components such as quality attributes, metrics and recommendations.

iii. Description about our quality model including the descriptions about each of its components such as goal (including details about formulating structured goals), questions and quality patterns.

iv. Details about the guidance process helping the users to evaluate their CM with the least possible efforts. This process includes the processes to formulate quality goal, mapping of relevant quality criteria (quality patterns, quality attributes) with the formulated goal, evaluation of CM and finally propositions or recommendations for CM improvement.

v. Designing of the software utility automating our proposed approach along with all the processes for guiding a user.

Chapter 3
Proposed Solution

A lot of researchers have proposed numerous metrics to quantify the different aspects of conceptual modeling such as [Cherfi et al., 2002a], [Cherfi et al., 2002b], [Genero et al., 2004], [Genero et al., 2002a], [Genero et al., 2001a], [Genero et al., 2001b], [Genero et al., 2000a], [Marchesi 98], [Moody et al., 2003], [Moody et al., 2000], [Moody et al., 1998], etc.. These quantifying metrics tends to help the modelers in identifying the sensitivity of the problem. Some of these metrics can be computed automatically such as Depth inheritance tree, cohesion, coupling, and numerous size and structural complexity metrics as defined in [Genero et al., 2004], [Genero et al., 2001a], [Genero et al., 2001b], [Genero et al., 2000a], [Moody et al., 2003], [Moody et al., 2000], [Moody et al., 1998], etc. Similarly, some of the metrics are difficult to automate and require human interference or manual input, such as to calculate the number of line crossings or to compute the requirements coverage within a model as proposed in [Cherfi et al., 2002a], [Cherfi et al., 2002b]. However, the common problem among all of these metrics is that they are at a very low level implementation and thus their understanding alone is a cumbersome and time consuming task. On the one side, the mathematical formulation tends to complicate their understanding while on the other side their manual calculation is regarded as repetitive and fastidious task. Metrics can be compared to low level programming module (such as modules written in assembly language). They don't carry any abstraction and thus are difficult to understand and compute manually. It is due to this that their adoption is not widely acknowledged in practice. Similarly, it gets difficult for inexperienced modelers to choose the relevant metrics for evaluating their models from the list of numerous metrics proposed by the researchers. For example consider the following list of metrics: shallow semantic similarity metric, deep semantic similarity metrics, total number of classes, total number of inheritance hierarchies, weighted number of responsibilities of a class, weighted number of dependencies, percentage of inherited responsibilities, weighted methods per class, depth inheritance tree, number of children, responses for a class, coupling between objects, lack of cohesion in methods, rule simplicity, query-simplicity, rule-uniformity, etc. Now if the modeler is interested in checking if his/her model is easy to maintain or not, it gets very difficult for him/her to identify the relevant metrics from this list. He/she would require additional support and documentation to choose the relevant metrics.

Thus, he/she will only be interested in employing the set of few metrics supported by some modeling tool such as Objecteering.

In reply to these issues, researchers introduced a level of abstraction and proposed quality attributes that employ different metrics for quantification. For example, [Cherfi et al., 2002a] and [Cherfi et al., 2002b] have defined quality attributes such as: clarity, legibility, readability and maintenance and employed different metrics for their quantification. Similarly, [Genero et al., 2002a], [Genero et al., 2001b], [Genero et al., 2001c], [Genero et al., 2000b], [Manso et al., 2003] have used numerous metrics to calculate complexity related to size and structure of the model. [Moody et al., 2003], [Moody et al., 2000], [Moody et al., 1998], have also proposed different attributes and metrics for evaluation. However, despite the existence of different attributes or metrics for quality evaluation, there are no generally accepted guidelines for evaluating the quality of the conceptual models and little agreement exists among the experts as to what makes a "good" conceptual model [Moody 05].

[Moody 05] performed a review of the existing quality frameworks (complete and partial) on conceptual models, his findings can be summarized as Table - 4.

Table - 4. Summary of Findings by [Moody2005]

	Research[1]	**Practice**[1]	**Collaboration**[1,2]
Number of proposals	29	8	2
Percentage of Total	74 %	21 %	5 %
Empirically Validated	6	0	1
Percentage	20 %	0 %	50 %
Generalizable[3]	5	0	0
Percentage	17 %	0 %	0 %
Non Generalizable	24	8	2
Percentage	83 %	100 %	100 %

Following are some of the findings inferred from Table - 4:

i. Researchers did not converge towards one quality framework (due to the proliferation of quality frameworks).

[1] Research, Practice and Collaboration represent the source of the framework.

[2] Collaboration means that the researchers and practitioners formulated the framework in mutual agreement.

[3] Generalizable: This implies that the framework can be applied on to conceptual models in general and is not specific to a particular class of models (e.g. data models) or a particular notation (e.g. ER models).

ii. Practitioners are not actively involved in evaluating the quality of the conceptual models (due to the scarcity of quality proposals originating from the practice).

iii. There is a lack of collaboration between researchers and practitioners (Just 5% of the quality frameworks were the result of mutual efforts from the researchers and the practitioners).

iv. There are few frameworks that have been empirically validated (Approximately 18% of the total).

v. There is a lack of generalization since there exist only 5 frameworks that can be generalizable while others are specific to some class of models (e.g. data models) or to any particular notation (e.g. ER models).

Moreover, the literature review on the quality of the conceptual models suggests that the researchers have a very little agreement on a "standardized" set of quality criteria for conceptual models [Moody 05]. Therefore, there is abundance of quality frameworks for conceptual models and only few of them inherit the ideas from the other frameworks. This has resulted in the existence of several definitions for the same concept. [Nelson et al., 2005] have identified different definitions of the same quality concepts e.g. there exist nine different definitions for "completeness". Similarly, there exist numerous definitions for the same quality concept and identical names for some semantically different metrics [Purao et al., 2003]. Such issues have restricted the adoption of the existing quality frameworks in practice [Moody 05].

Thus the task to evaluate a conceptual model gets difficult for a non-expert due to the absence of any standardized set of criteria. Moreover, as mentioned above, the existence of similar concepts with different names or same names for semantically different concepts worsen the situation. In order to reply to the above evidences and to provide a common yet comprehensive basis for quality evaluation, we have relied on the proposition by [Moody 05] and considered synthesizing existing concepts proposed by researchers and adding the new concepts to formulate a comprehensive quality approach for conceptual models.

3.1 A Multi-Faceted Quality Approach for Conceptual Modeling

The goal of above mentioned enrichment activity was to propose a multi-faceted quality approach for conceptual modeling that should be generic, flexible and remains valid for different types of conceptual notations (ER models, UML diagrams, etc.). This proposition aggregates the existing quality proposals and provides some suggestions to complete missing elements or

concepts. We identified a set of 21 quality attributes through this activity. The approach encompassed theoretical, practical and epistemological foundations.

3.1.1 Theoretical Foundations

Information systems represent a perceived real-world system and conceptual models are the first step in their development as they model these systems. In order to create a CM, we need a set of constructs to model these systems. To determine which constructs should be needed, different researchers have proposed different approaches as theoretical guidelines. These approaches include the use of ontology (for ordering and structuring the reality), classification theory (for categorizing knowledge) [Wand et al., 1995], etc. There are reviews on understanding the use of CM and their constructs. Similarly, a lot of researchers talk about employing ontology for helping the creation of realistic models for real-world information systems.

Likewise, in the field of conceptual modeling quality evaluation, there exist methodologies/approaches for evaluation. But the problem lies in their disparity and non-converging solutions. The existing work on CM quality is independent of one another and thus it gets difficult to have a comprehensive and complete picture.

In order to evaluate a CM, we need a set of criteria and a mechanism to structure and classify these criteria so that they can be identified for usage in future. As mentioned above, researchers have proposed different criteria for evaluation but they are independent from one another. Moreover, there doesn't exist any approach (or an ontology) that can help in the identification of these evaluation criteria. Thus it is left on analyst/designer to identify and use the relevant criteria individually. The absence of consolidated and agreed quality criteria for CM has demotivated the acceptance and adoption of evaluation based strategies for CM. We have shown that analysts/modelers acknowledge the importance of implementing an evaluation strategy for CM but most of them don't know if any of such material existed despite their existence. This gap between existing literature on CM evaluation and its usage in practice is due to the fact that neither a standardized set of criteria exists in the literature nor a consolidated quality approach has been proposed and diffused on a wide level.

Two streams of literature can be witnessed within the CM evaluation domain:

i. Evaluation literature on a higher level of abstraction such as identifying different types of qualities, etc. For example, [Lindland et al., 1994] identified and proposed three different types of quality for CM. Similarly, [Krogstie et al., 1995], [Siau et al., 2001], etc. extended his framework and identified additional types of qualities.

ii. Literature proposing different evaluation criteria at different levels of abstraction and granularities such as proposing different quality concepts, attributes, characteristics, sub-characteristics, metrics, etc.

The main problem with these two independent streams is that they don't converge at a point. For example, there doesn't exist any literature classifying the quality criteria into the quality types proposed by [Krogstie et al., 1995], [Lindland et al., 1994], etc. All the criteria proposed by researchers have been classified by themselves into their self identified dimensions or quality types, etc. This has led to several issues, for example:

i. Same criteria have been placed by different researchers at different levels of abstraction. For example, completeness for some researchers is a quality attribute whereas for some it is a dimension or even a metric.

ii. Everyone defines the narrower version of these quality criteria to accommodate his/her vision of it and thus the same concept has been defined numerous times by different researchers differently.

iii. Similarly, the widely accepted quality types by [Krogstie et al., 1995] and [Lindland et al., 1994] have pre-defined and fixed boundaries. And thus, if existing criteria are classified into these types then most of the criteria would be left unclassified. For example, [Krogstie et al., 1995] version of pragmatic quality takes into account only the concepts related to the fact that the model is being understood and not understandable. Thus, all the concepts that are related to improving the understandability of the models couldn't be included in this dimension. Whereas, [Siau et al., 2001] considers pragmatic quality to be related to the fact that only one meaning of the model can be extracted with the least possible cognitive efforts. Thus, implicitly incorporating all the concepts that improve the understandability of the model within this dimension. We adopted this extension of [Siau et al., 2001] to [Krogstie et al., 1995] pragmatic quality and included all the concepts that improve the understandability of the model to be related to pragmatic quality as well. For example, in Section-2.5.2.4, we included quality attributes such as user vocabulary rate, documentation degree, etc. to the pragmatic quality as they help in the understandability of the model whereas if we would have remained within the boundaries laid by [Krogstie et al., 1995] then such attributes have been left unclassified despite their importance.

In view of the above issues, it becomes imperative that the existing literature should be consolidated and classified accordingly employing some existing framework such as that of

[Krogstie et al., 1995] and [Lindland et al., 1994] as was done in conceptual modeling domain or any other domain.

Thus, in order to formulate a consolidated set of criteria for CM quality evaluation, we used existing literature on CM as its theoretical foundation to formulate the following:

i. Identify the hierarchy of evaluation criteria such as dimensions, attributes, metrics, etc.

ii. Define each identified evaluation criteria clearly and comprehensively such that there should be one and only one definition associated to it. Moreover, these criteria can be classified to only one place at a hierarchy. For example, completeness must fit only to the definition of one of the following: dimension, attributes, metrics, etc.

iii. Devise a mechanism to incorporate or merge different flavors of the same concepts within the newly formulated criteria. For example, a way to merge nine different definitions of completeness into one.

iv. Identify existing or formulate new quantifiable measures for higher level concepts such as attribute, etc. so that their impact can be calculated.

In order to achieve all of the above, different quality criteria, from the previously existing quality frameworks or literature, were extracted and filtered. This aggregation activity used the philosophy behind conceptual modeling and quality as its basis and enriched the model by extracting different concepts from the previously existing literature. The process consists of the following steps:

i. Selection of various attributes from the literature (details are discussed in Section-3.5.1).

ii. Identification and classification of relevant metrics into respective quality attributes for measurements. For example, metrics such as number of classes, number of attributes, etc. are used for measuring complexity quality attribute.

iii. Grouping of quality attributes with respect to commonality

iv. Selecting generic quality attributes (quality attributes that are generic to every conceptual model)

v. Merging non-generic attributes into generic attributes that are closest with respect to semantics

This process resulted in the selection/identification of a set of quality attributes that were generic and represent different aspects of the conceptual models such as complexity, maintainability, etc. Moreover, the advantage of this process was the elimination of redundant

concepts in addition to unification of different frameworks and identification of grey areas. This can be regarded as an important step in our approach. This enrichment activity contributed in the literature by providing a more comprehensive and flexible set of quality criteria for conceptual models. We proposed 21 quality attributes that incorporate a wide range of quality criteria already existing in the literature. Moreover, this comprehensive view helped in the identification of uncovered areas of conceptual modeling quality.

3.1.2 Practical Foundations

The above mentioned strategy to formulate a consolidated and comprehensive quality evaluation approach is incomplete without incorporating the insights from the practice and can be questionable without exercising a proper validation. Most of the work done in the field of CM quality evaluation has originated from research and only a handful of the proposals have been initiated from the practice [Moody 05]. Software Quality Assurance (SQA) activity is regarded as of utmost importance in any organization developing or implementing software commodity. Similarly, the strategic importance of SQA operations can be witnessed by the following two facts:

i. SQA team works in the same fashion as that of auditors isolating themselves from other teams involved in the development activities.

ii. SQA team is headed by the manager of managers or senior executives. Thus, SQA can influence decision process.

It has been widely accepted in research and practice fields that the quality of the CM has a severe impact on the quality of the final product. Similarly, [Avison et al., 1993] also emphasized on the extension of SQA scope to all the activities of the software development life cycle. We conducted a survey to study the modeling practices of different populations (including practitioners) of IS domain and also to validate the selection of quality criteria from the literature. Almost all the participants from the practice responded that their conceptual models are evaluated and checked by either of the following: analyst, designer, software engineer and even project manager. This implies that the evaluation strategy for CM is an integral part of testing (could be within SQA) yet there exist only a handful of proposals originating from the practice. Following can be inferred from the above findings:

i. There is no formal mechanism of CM evaluation in practice

ii. If there exist some formal mechanisms, then either they are confidential or proprietary

However, the commonality in both of the above mentioned cases is that there is knowledge out there in practice that has not been solicited, formalized and published in the research. Similarly, these practices have never been studied in depth and communicated. Thus, we planned to study those practices and to incorporate them into our consolidated quality approach.

Our approach involves practitioners' viewpoint as its practical foundation. The basic idea was twofold: one to study the evaluation strategy employed in practice and second to validate our approach. We involved professionals including practitioners using surveys, interviews, etc. For example, in order to be sure that the resultant set of quality attributes (identified from the literature or defined as new concepts) represent most of the important aspects (if not entirely) in the evaluation of CM, an interim validation exercise was planned and performed having professionals including practitioners as the respondents. This validation exercise tried to collect the responders' views on the holistic quality of the conceptual models in addition to their feedback over the identified/selected set of quality criteria. Their feedback was evaluated and modifications were made to select a set of evaluation criteria (Details about this experiment can be consulted from the Chapter 7). Their feedback/viewpoint can be considered as a practical foundation to our approach.

Similarly, we also tried to extract knowledge about their practices by asking them feedback questions such as to identify the quality aspects that are important to them in a conceptual model. Such questions enabled us to study their practices and also to find the quality criteria that have been used in practice but are unknown to theory.

Another approach in this regard involved a set of experiments conducted on post graduate students over the efficiency of employing our approach to improve the conceptual models. We tried to study the cognitive efforts put in by these students and the criteria employed by them to evaluate and improve the CM without any prior knowledge about existing CM evaluation methodology. All such activities serve as practical foundations to our approach.

3.1.3 Epistemological Foundations

Epistemology is the branch of philosophy concerned with knowledge (nature and its sources), and the acquisition of knowledge [Hirschheim 85]. It can be considered as the theory of knowledge seeking answers to questions such as what is knowledge and how is it acquired? What differentiates between adequate and inadequate knowledge? etc.

Many studies in the domain of conceptual models evaluation address the problem of miscommunication between business and IT actors. One of the research directions aiming to

understand this problem considers an epistemological point of view based on well-founded assumptions [Ribbert et al., 2004] , [Schütte 99]. We studied these approaches as a source for devising the selection of quality criteria for CM evaluation. For example, in order to extend the horizon of our methodology towards epistemological foundations, we employed [Becker et al., 2007] epistemological framework. Their framework is fuelled by a set of the following five questions crucial to building epistemological foundation:

i. What is the object of cognition? (Ontological aspect)

ii. What is the relationship between cognition and the object of cognition?

iii. What is true cognition? (Concept of truth)

iv. Where does cognition originate?

v. By what means can cognition be achieved? (Methodological aspect)

Similarly, within the field of Conceptual modeling, [Recker et al., 2008] have discussed the following three questions to be crucial when discussing epistemological theories:

i. What does it mean to engage in conceptual modeling? It refers to the epistemological implications towards the perception of the concepts “model” and “modeling”.

ii. What does it mean to judge the outcome of conceptual modeling? This aspect of consideration refers to epistemological implications towards the evaluation methodology, i.e. as to how evaluation can be conducted.

iii. What does it mean to achieve quality in conceptual modeling? This aspect refers to epistemological implications towards the perception of quality.

Within our approach, we tried to find the answer to the above mentioned questions through the literature review to achieve a strong epistemological ground. One of the important problems that exist now is that the researchers don’t take into account the epistemology behind the modeling. It is very important to understand the logic behind the modeling and different types of conceptual models. We dig down the classics of modeling and conceptual models to identify the characteristics, properties and practices that are deemed important for modeling. This has helped us in identifying and highlighting the errors in the CM. Similarly, we have also consulted the literature and detailed meta-models of the important conceptual models to formulate metrics for the identification of errors and recommendations to improve them. We translated [Becker et al., 2007] and [Recker et al., 2008] frameworks into the following sets of questions to guide our way towards achieving epistemological basis of our approach:

i. What are conceptual models (CM)?

ii. Why do we make CM?

iii. How do CM originate?

iv. What was the rationale behind CM origin?

v. What are the alternatives to CM?

vi. Why do people use their cognition while designing CM?

vii. How do people translate their cognition into CM?

viii. What is the notion of quality for CM?

ix. Why do we need quality for CM?

x. How can we distinguish between good and bad models?

xi. How can we prevent bad modeling? etc.

All of the above questions (or similar types of questions) helped us in identifying the epistemological foundation of our approach that in turn enabled us in devising effective evaluation and improvement approach for conceptual modeling quality. For example, we tried to seek the answer to question "Why do we make CM?" We identified all the reasons that led to the employment of CM for designing the system such as CMs are used to translate end-users requirements to developers. Thus this leads us to identify two important things about CMs:

i. CMs communicate users requirements to developers (or any other recipient) and thus they should be complete otherwise the missing requirements will not be included in the final system.

ii. Since CMs are designed for subsequent stages of development and very often for developers so that they can know about the users' requirements. Thus if CMs are not understandable then the developers might not interpret them correctly or their interpretation might be wrong.

In view of the above findings, we identified the existing literature that talked about completeness and understandability aspect of CM and included them in our approach. This enrichment process is described in detail in Chapter 7

3.2 Quality Model Overview

Our approach encompasses methods and techniques to evaluate and improve the conceptual models with respect to a certain aim or more precisely a goal and thus this goal oriented approach relies partially on the famous Goal Question Metric (GQM) approach proposed in [Basili et al., 1994] and [Basili et al., 1984] can be regarded as pioneers to employ goal based evaluation methodology. [Basili et al., 1988] developed an improvement-oriented software engineering process model that employs the goal question metric paradigm to integrate the constructive and analytic aspects of software development. They defined GQM to be a mechanism for formalizing the characterization, planning, construction, analysis, learning and feedback tasks. Moreover, GQM represents a systematic approach for setting need-specific project goals of an organization and defining them in an operational and tractable way. [Basili et al., 1987] found goal oriented approach to be feasible and beneficial. Goals are refined into a set of quantifiable questions that can use multiple metrics for quantification. [Basili et al., 1994] provides more details about how goals are formulated and how the GQM approach can be employed. They aim to specify a measurement model for GQM at the following three levels:

i. Conceptual level (Goal): A goal can be defined for an object (such as product, process and resource) for any reason such as with respect to quality, or different points of views, etc.

ii. Operational level (Questions): In GQM, set of questions are employed to characterize the assessment or achievement of a specific goal. Questions characterize the object of measurement with respect to a selected quality issue from a selected view point. Similarly, questions can also be used to elaborate the vague goals.

iii. Quantitative level (Metric): a quantitative measure is required to answer the questions related to a goal using a set of data associated to it.

[Wernick 00] employed GQM and formally elaborated the four steps in a GQM-based study:

i. The definition of goals

ii. Posing of relevant, objective questions to determine the attainment of goals

iii. The definition of collectable metrics which relate to questions

iv. The analysis of the results to determine the answers to the questions and their relationship to the goals.

There are several research papers that have used GQM approach for evaluation. For example, [Cherfi et al., 2008] and [Cherfi et al., 2002b] employed GQM approach to evaluate different dimensions of quality in conceptual models. [Bouzeghoub et al., 2001] used GQM as a basis to construct a quality model for data warehouse. Similarly, [Vassiliadis et al., 1999] extended GQM to capture the interrelationships between different quality factors with respect to a specific quality goal to evaluate and improve the quality in data warehouse. [Nick et al., 2001] and [Nick et al., 1999] use GQM technique to systematically develop a measurement program for the evaluation of an experience base (an organizational memory for software engineering knowledge). They also demonstrated the practical benefit of GQM through a case study where GQM was applied to an existing case-based reasoning system/application. [Deprez et al., 2007] applied GQM to create an assessment methodology specifically tailored to evaluate the evolvability and robustness of Free and Open-Source Software (F*l*OSS) endeavors. Similarly, [Wernick 00] used GQM to derive relevant metrics from their FEAST (Feedback, Evolution and Software Technology) goals to be used as the basis for data collection programs. [Bouzeghoub et al., 1999], haven't explicitly employed GQM approach but have used quality goal based evaluation and improvement approach for data warehouse.

GQM has been widely used in the industry for different evaluation tasks. We employed GQM, as our approach is based on an analyst/designer specific evaluation i.e. an evaluation method adopted for a particular requirement or formally a particular goal. Moreover, our approach encompasses different evaluation criteria at different levels of abstraction and thus we require a method to map these evaluation criteria to the analyst/designer specific needs or goals. However, our adoption of GQM is slightly different from the traditional GQM adoption as in the original version Goals are translated into metrics via questions whereas in our approach metrics are numerous and are at the lowest level of abstraction. Thus we need to map these goals to quality criteria that are at a higher level of abstraction. Another main reason to link goals with some higher abstraction criteria is due to the fact that our approach is applicable to all types of conceptual models and thus there can exist numerous metrics for different aspects of different types of conceptual models. However, the same aspect might hold for a particular quality concern for all types of models. For example, in order to evaluate the complexity of any model, we can evaluate the structural complexity (complexity related to the structure of the model) of the model. This aspect of structural complexity will hold for every type of conceptual models. If we would have opted for direct mapping of goals to metrics then the resolution of this complexity goal would differ for every type of conceptual models as most of the metrics are specific to model types.

Our approach also employs questions, as proposed by GQM, to map goals to quality criteria as sometimes analysts/designers specified goals are vague statements and it is difficult to predict the domain of goals. Our approach lets analysts/designer evaluate conceptual models with respect to their desired quality goal. These goals can be vague and thus, as proposed by GQM, questions are used to transform these goals into more concrete statements. These questions help in narrowing the domain of the evaluation. In our adoption of GQM, goals are translated into quality patterns through questions. These quality patterns are at the higher level of abstraction and are responsible for finding answers to the questions raised in the goal. Quality patterns are discussed in detail in the following sections.

Figure - 5 depicts the adoption of GQM to our approach. It can be seen that different goals are formulated for evaluating different aspects of conceptual models. These quality goals are generally vague and need to be précised in order to operationalize their achievement. Even if goals are not vague then it is important to interpret them in the same way as was deemed by the analyst/designer. Thus in order to map the goal into relevant quality criteria that is relevant to the analyst's vision (or any other who formulated the goal) of quality goal, our approach employs questions. These questions help in identifying the relevant quality patterns with respect to formulated goal. Our approach maps the quality goal on to quality patterns rather than metrics. The identified quality patterns are responsible for evaluating the CMs and later help in their improvement. The next sections describe each of the components depicted in Figure - 5.

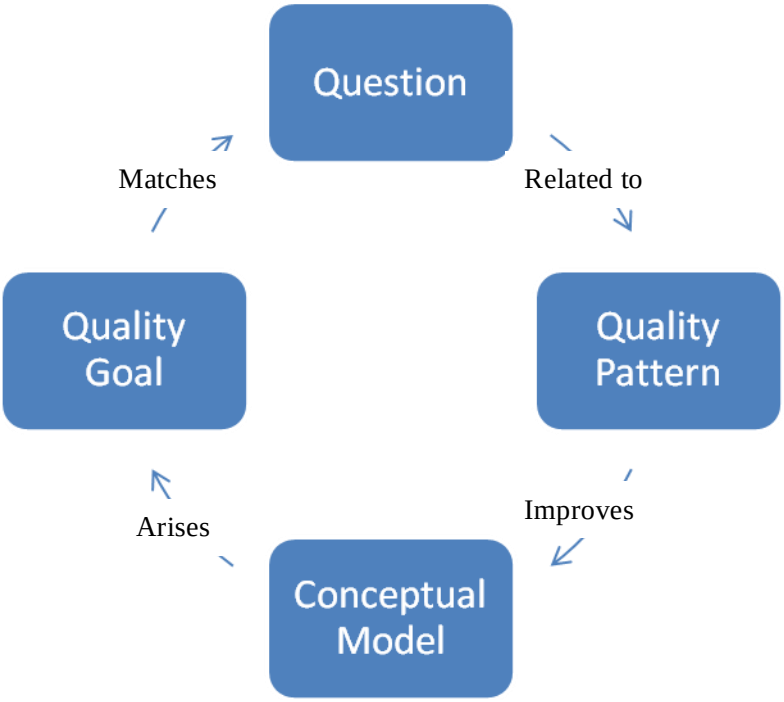


Figure - 5. An iterative quality improvement based approach

3.2.1 Quality Goal:

Quality goal is the objective desired by an analyst/designer to attain for the object of interest. As mentioned above, quality goals may be defined for any object, for a variety of reasons, with respect to various quality models, from various points of views and relative to a particular environment. Goals can be defined for the following types of objects [Basili et al., 1994]:

i. Products: Artifacts, deliverables and documents such as specification documents, conceptual models, design diagrams or documents, programs, test suites, etc.

ii. Processes: Time constrained activities related to software such as specifying, designing, developing, testing, etc.

iii. Resources: Items used by processes in order to produce their outputs such as personnel, hardware, software, etc.

For example, an analyst/designer might be interested to check his/her conceptual model for its correctness, thus the goal in this scenario is correctness and the object of interest is the conceptual model. This goal can be used to evaluate and improve the object under consideration (conceptual model in this case).

However, sometimes a goal statement could be vague and thus needs to be translated into more concrete statements. Thus, in order to obtain these concrete statements from the goal, we propose to employ a Goal Question Metrics (GQM) approach proposed by [Basili et al., 1988] and [Basili et al., 1984] can be regarded as pioneers to employ goal based evaluation methodology. They categorized goals into two categories:

i. Goals that may be used to evaluate a particular software development methodology relative to the claims made for it;

ii. Goals common to all methodologies.

GQM represents a systematic approach for setting need-specific project goals of an organization and defining them in an operational and tractable way. Similarly, [Basili et al., 1987] employed the notion of goals to implement the improvement process by setting project improvement goals, characterizing those goals and the environment via defect profiles in a quantitative way, choosing methods and tools to evaluate the actual behavior and refining the project goals based on the evaluation results. Goals are refined into a set of quantifiable questions that can use multiple metrics for quantification.

[Basili 93], [Basili 92], [Basili et al., 1988] proposed a set of templates for formulating goals and a set of guidelines for deriving questions and metrics for non-experience analyst/designer as the process of setting goals and refining them into quantifiable questions is a complex task and requires adequate experience. The authors proposed that every goal should have purpose, perspective and is valid for an environment. The purpose of the goal is to define the object(s) of study. There can be several object(s) of study from multiple perspectives within a same goal but it might be wise to break such complex goals into several simpler goals. Similarly, perspective of a goal is meant to position it for evaluating the object(s) of study at a particular angle or set of angles. The purpose of environment is to define the context of study by defining all aspects of the project. The environment should include all those factors that may be common among all similar projects and must be stored for future comparison. However, in the absence of any storage mechanism or for independent goals, this aspect can be ignored.

The scope of each of the above mentioned components for formulating a goal are as follows (

Table - 5), formally defined by [Basili 93]. These categorizations or guidelines can be used to structure goals or help the analyst/designer in formulating their goals effectively and efficiently:

Table - 5. Goal formulation template

Purpose	to analyze	objects such as products, processes, resources
	for (or why)	characterization, evaluation, prediction, motivation, improvement
Perspective	with respect to (focus)	cost, correctness, defect removal, changes, reliability, effectiveness, user friendliness, etc.
	from the point of view of (who)	user, developer, manager, customer, corporation, etc.
Environment	in context of	process factors, people factors, problem factors, resource factors, methods, tools, constraints, etc.

For example, the goal to evaluate the completeness of conceptual models can be structured using the above guidelines in the following way:

Purpose	to analyze	Conceptual model
	for	Evaluation
Perspective	with respect to	Completeness
	from the point of view of	Analyst

In the above example, we can notice that an analyst/designer specific goal in natural language can easily be transformed into structured goals using the guidelines proposed in [Basili 93].

Next step in our approach involves the employment of GQM's questions to translate vague goals for evaluation.

3.2.2 Questions:

Quality goals are translated into questions. These questions help analysts/designers in narrowing the scope of goals yet specifying its domain and increasing the details about it. Moreover, these questions also help in identifying the evaluation criteria with respect to the formulated goal. If the goal is clearly formulated, then this translation process could be effective and easy. However, if the goals are vaguely defined then the introduction of questions will enhance its mapping onto the appropriate evaluation criteria for quality estimation and possible improvement.

The process of setting goals and refining them into quantifiable questions is a complex task and requires adequate experience. [Basili 93], [Basili 92], [Basili et al., 1988] identified guidelines to formulate product and process related questions from the formulated goal. For each

target product/process there are three major sub goals that need to be addressed: definition of the product/process, definition of the quality perspectives of interest and the feedback related to the quality perspectives of interest. The summary of each of these guidelines are presented at Table - 6. Since we are interested in formulating questions for conceptual models, therefore we adopted only the propositions with respect to models.

Table - 6. Guidelines to formulate questions related to conceptual models

Sub-goals	Type of Questions (Specific to Conceptual Models)
Definition	It includes questions related to: i. Physical attributes such as size, complexity, etc. ii. Modifiability or maintainability of the model iii. Defects such as errors, missing requirements, etc. iv. Context of the model
Quality Perspectives of Interest	It includes questions related to the following: i. Readability, understandability, etc. ii. Aesthetics of the model iii. Conformance to the syntactic requirements of the modeling language iv. Validity of the model for a target domain (semantic validity) v. Semantic completeness of the model vi. Model effectiveness vii. Substantiation of the model (i.e. whether results are reasonable from various perspectives)
Feedback	It includes the questions related to improving the model relative to the quality perspective of interest and suggestions for improvement

For example, the following set of questions can be generated through the above mentioned guidelines for the quality goal presented in the previous section about model completeness:

i. Is completeness related to syntax?

ii. Is completeness related to semantics?

iii. Is completeness related to requirements coverage? Etc.

Each of the questions helps in the identification of evaluation criteria relevant for the quality goal in context. In the above set of questions, if the answer to the three questions is "yes", then it means that the model must be evaluated for completeness with respect to:

i. Syntactic requirements by the modeling language

ii. Semantics requirements by the modeled domain and

iii. The user specified requirements.

In our approach, questions help in the identification of relevant quality patterns for model evaluation and improvement. These quality patterns are at a higher level of abstraction as compared to metrics. Quality patterns are described in the next section.

3.2.3 Quality Pattern:

As mentioned in Section 3.1.1, we performed a thorough review to capitalize knowledge and we formulated a set of 21 quality attributes. This process of knowledge capitalization involved a thorough literature review and identification of new quality attributes for the gray areas. However, the selection of the above mentioned quality attributes for any evaluation project can be trickier for a non-expert analyst/designer. Even though it will be much simpler if compared with the direct selection of employing metrics for evaluation due to the following reasons:

i. There exist numerous metrics to measure diverse aspects of different types of conceptual models. Thus it is difficult to remember all the metrics and finding the relevant metrics from the directory of metrics can be a difficult task and might incur errors.

ii. Attributes serve as an abstraction and consolidate a set of all metrics relevant to a particular aspect of conceptual modeling. For example, "structural complexity" attribute will contain all the metrics relevant to the complexity of every type of models due to their structure.

The process for selecting the relevant quality attributes with respect to desired goal remains trickier for a non-expert analyst/designer and thus requires in-depth knowledge about each of these attributes and what they propose. We found that there is a lack of methodologies putting together the evaluation of conceptual models and their improvement through a real guidance process. Often the readers are left with a proposed set of evaluation criteria (dimensions, attributes, metrics, etc.) that can be used for evaluation. And since these evaluation criteria are independent of other proposed criteria, as mentioned above, thus the reader can only think of employing the proposed set of criteria in hand. This can lead to three problems:

i. Either the readers find an incomplete solution due to the limited amount of information provided by propositions in hand, as most proposals tend to be autonomous.

ii. The reader finds a non-optimal solution to a problem for which perhaps a better solution is proposed by some other proposal.

iii. It gets difficult for the readers to interpret the evaluation results in order to improve their models, as most of the proposals fail to provide post evaluation improvement guides [Moody 05].

From the above problems, it can be noticed that the domain of conceptual modeling quality lacks a consolidated approach that capitalizes existing knowledge and past experiences and fails to provide a guidance process incorporating both evaluation and improvement aspects.

The above mentioned problem in conceptual modeling can be compared to problems incurred by programmers in the early days of software development discipline as it lacked capitalizations of knowledge, sharing of experiences, etc. back then. Thus, everyone sought his/her particular solution to a common set of problems indulging into recurring and redundant activities. The main shortfall in their autonomous effort was the absence of reusing existing experiences i.e. devising a not-so-good solution for a problem where a better solution existed. The same scenario holds for design activity. The remedy to this was the proposition of design patterns addressing recurring problems by proposing a fairly good solution and most importantly devising an approach to capitalize experiences. Design patterns encapsulate valuable knowledge in the form of established and better solution to resolve design problems for addressing design quality [Hsueha et al., 2008]. However, design patterns don't explicitly target the quality but propose an established solution to a common problem. In order to incorporate the notion of quality evaluation or improvement within the design patterns, a new concept (named as quality patterns) has recently emerged. It uses the epistemology of design patterns and includes criteria to guide the evaluation of conceptual models and suggestions to improve them. The concept of quality patterns was first proposed by [Houdek et al., 1997] and it targets the software engineers.

[Cherfi et al., 2008] argues for employing quality patterns to guide the evaluation process. They proposed a quality pattern meta-model and a three phase evaluation process. Their proposed phases include, quality specification phase, quality measurement phase and quality improvement phase. They have also tried to find a relationship between design patterns and proposed quality patterns. Their work can be regarded as a ground breaking for quality pattern driven modeling process. We adopted this concept of quality patterns, to incorporate the guidance process in the selection of the relevant and related quality attributes for evaluation process. Thus, next portion of our approach is based on the idea proposed by [Cherfi et al., 2008]. We extend their approach and present a more comprehensive quality pattern driven evaluation and improvement process for conceptual models.

3.3 Example of approach:

We will use a simple example to demonstrate each of the four components of our approach, For example, consider an analyst/designer interested in evaluating and improving his/her conceptual model. He/she defines the following goal: "Is my model easy to change?" We can

structure this goal by employing the guidelines specified in [Basili 93] and demonstrated in the above sub-section. In this goal, we can identify that the purpose of the defined goal is to analyze the CM for evaluation and the context of the goal is to target the problems related to future extension and evolution of the CM from the analyst's point of view.

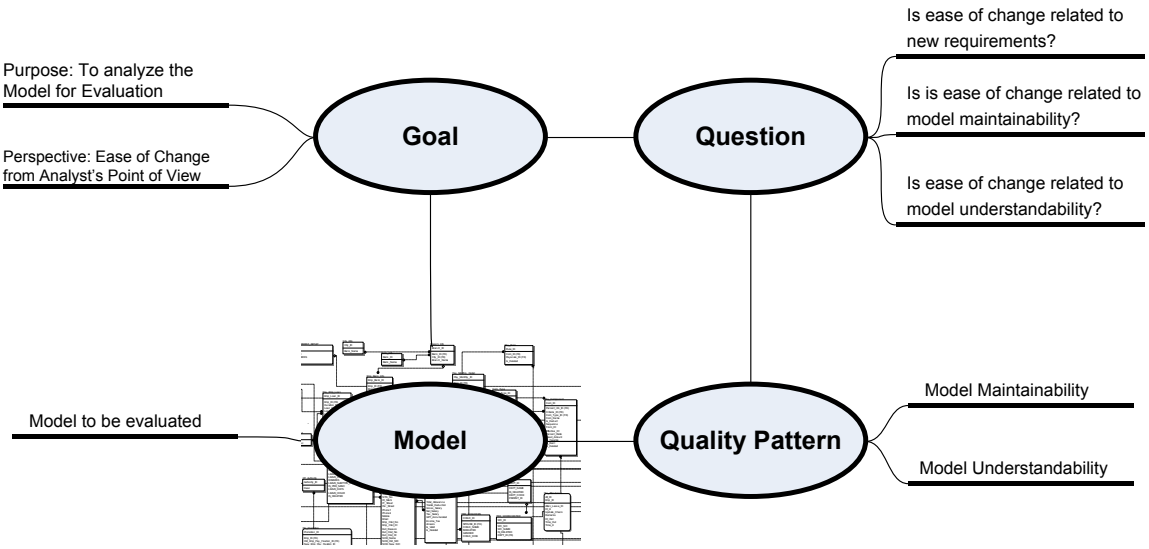


Figure - 6. An example of our quality improvement approach

However this defined goal could lead to multiple solutions. To precise the analyst's/designer's requirement, we can employ the following questions to narrow the scope yet précising the exact requirements:

Q1: is ease of change need related to new requirements considerations?

Q2: is ease of change need related to model maintainability?

Q3: is ease of change need related to understandability of the model?

It can be noted from the above questions that Questions 1 and 2 are directly related to change with respect to incorporating and/or modifying the existing requirements, whereas question 3 is related to understandability of model that is indirectly related to the ease of change. Thus by answering to these questions, the direction or domain of the goal can be narrowed to modifiability

and/or understandability. The final decision will help the analyst/designer in choosing the respective quality patterns for evaluation.

In this example, we can see from the Figure - 6 that the analyst/designer is interested in both aspects of the goal i.e. modifiability and understandability of the model. Thus, only those quality patterns will be employed for evaluation and improvement that are related to these two aspects of the model.

3.4 Quality Pattern Meta-Model

Quality patterns can be identified and formulated using the generic and simple quality pattern meta-model presented in Figure - 7. A Quality pattern uses multiple quality attributes for quality evaluation. Each of the quality attributes can employ multiple metrics for quantification. These metrics can be dependent on model type (ER-diagram, class diagram, etc.) or model element (entities, classes, etc.). For example, "Number of class" metrics can only be applied on the classes (model element) of UML class diagram (model type). However, similar or equivalent metrics can be devised for other model elements of different types of model. For example, an equivalent of "Number of class" metric for ER-diagram would be "Number of entities" metric so on and so forth.

The strength of our approach lies in the post evaluation feedback in the form of predefined transformations, textual recommendations and/or appropriate design patterns for improvement.

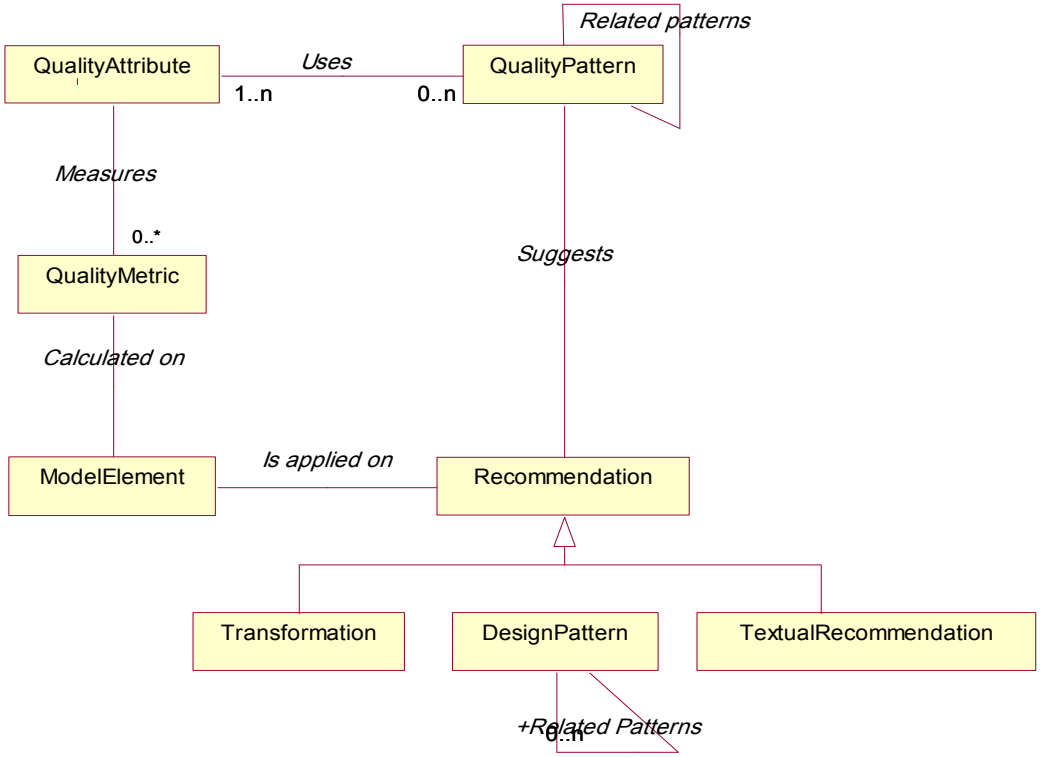


Figure - 7. Quality Pattern Meta-Model

3.5 Quality pattern

From the above quality pattern meta-model (Figure - 7), it can be noted that a quality pattern can use multiple quality attributes to solve a problem within a context. Similarly, a quality attribute can be used by multiple quality patterns. A Quality attribute in turn employs multiple metrics for quantification. All quality attributes are generic and thus remain valid for all model types. However, the metrics are dependent on elements (classes, entities, etc.) of different conceptual models (Class diagram, ER-diagram, etc.). For example, "Structural Complexity" attribute can be used for class diagrams, ER-diagrams, etc. However, the selection of metrics will depend on model type. In case of class diagram, this attribute will use metrics such as number of associations, number of aggregations, etc. whereas in case of ER-diagram the metrics will be the number of identifying relationships, the number of many-to-many relationships, etc.

Based on the results of different metrics, numerous recommendations are proposed for improvement. These recommendations could be in the form of textual recommendations, transformations (automatable or non-automatable) and/or design patterns. As visible from the

model, a metric can propose multiple recommendations. Similarly a recommendation can be proposed by multiple metrics.

Quality patterns capitalize the experience and provide an established solution to a recurring problem. In order to define the structure of quality patterns, we merged the propositions of [DeLano et al., 1998] and [Gamma et al., 1995] for design patterns and add additional information for helping the automatic searching. Quality patterns are composed of:

i. **Name:** A significant name summarizing the pattern objective. The name is very important as it is used to communicate the usage of the quality pattern to analysts/designers. If the name doesn't clearly identify the quality pattern then it might not be found and employed by the implementer.

ii. **Context:** Characterization of the situation in which the pattern applies. The context must be defined clearly in order to apply the pattern on the situations it is deemed for. Every quality pattern can't be applied to all the situations. Most patterns are specific to a situation or a class of situations.

iii. **Problem:** Description of the problem to solve or the challenge to be addressed. Problems should be mentioned clearly so as to help the implementer in identifying the problems that can be solved using this pattern. The problem definition is an important part of quality patterns as it educates the implementers about the types of problems and how such problems can be solved.

iv. **Solution:** The recommendation to solve the problem. The solution should be well explained so that the problem can be rectified with ease by the implementer. If a quality pattern proposes a better solution for a recurring problem and if the solution is well defined then it can be deemed that this quality pattern will be employed frequently for improving the quality.

v. **Keywords:** A list of keywords related to the pattern content. These sets of words are included in the quality pattern so as to ease the efficient searching of quality patterns. Every quality pattern should have relevant, self explanatory and as many keywords as possible so that the quality pattern be found by the implementer or software utility efficiently and with ease.

vi. **Related Patterns:** Patterns that are closely related to the one described. The identification of related patterns can bring significant improvement in the quality process as the scope of evaluation can extend after including the relevant related quality patterns to the

evaluation process. Similarly, related patterns can also help the implementers in understanding the different problem dimensions and other types of problems related to the one they are targeting.

3.5.1 Quality Attributes

Quality attributes can be defined as the group of properties observable over the product lifecycle [Preiss et al., 2001] or the group of properties of the service delivered by the system to its users. The service delivered by a system is its behavior as it is perceived by its user(s) [Barbacci et al., 1995]. Similarly, [SEI, CMU] defined quality attributes to be the benchmarks that describe system's intended behavior within the environment for which it was built. The quality attributes provide the means for measuring the fitness and suitability of a product. Within system engineering domain, quality attributes can also be regarded as the non-functional requirements for evaluating the performance of the system. These attributes are also referred to as "ility" due to suffix of many of the quality attribute such as "compatibility, extensibility, modifiability, etc." [Manola 91] defines "ility" as a characteristic or quality of a system that applies across a set of functional or system requirements.

There exist numerous definitions of quality attributes specific to different domains and applications. Similarly, the semantically equivalent concept of term 'quality attribute' has been synonymized into different terms such as characteristics (as in ISO-9126, etc.), dimensions, factors, etc.

Quality attributes provide an abstraction to a set of closely related and similar metrics. In our approach they are at the second level of abstraction after quality patterns. Different aspects of conceptual modeling quality are identified and classified into multiple attributes. Each attribute has to be generic and should remain valid for all types of conceptual models. Thus attributes related to some specific notation (UML, ER, etc.) can't be selected. Different researchers have placed attributes at different levels of abstraction and thus there exist numerous attributes in the literature that are specific to a particular notation.

Similarly, the existing work on CM quality has classified the evaluation criteria into dimensions, attributes and/or metrics. There is a clear distinction between metrics and other classification categories due to the widely accepted format of metrics. However, there exists a huge confusion among the definitions of attributes and dimensions. Some researchers have defined a concept as a dimension whereas some other researchers have used the same definition and called this concept an attribute. Consider the following table (Table - 7) listing numerous dimensions proposed by different researchers:

Question: What are Quality Attributes?

Answer: *Quality attributes are the group of properties observable over the product lifecycle [Preiss et al., 2001] or the group of properties of the service delivered by the system to its users. The service delivered by a system is its behavior as it is perceived by its user(s) [Barbacci et al., 1995]. Similarly, [SEI, CMU] defined quality attributes to be the benchmarks that describe system's intended behavior within the environment for which it was built. Within system engineering domain, quality attributes can also be regarded as the non-functional requirements for evaluating the performance of the system. For us quality attributes provide an abstraction to a set of closely related and similar metrics relevant to some property or characteristic of CM evaluation. Every quality attribute must be generic i.e. it should remain valid for all types of conceptual models.*

Table - 7. Dimensions proposed by researhers

Proposal	Dimensions
[Bajaj 02]	Effectiveness, efficiency, learnability
[Unhelkar 05]	syntactical correctness, semantic correctness and consistency, and aesthetics
[Moody et al., 2003], [Moody et al., 2000], [Moody et al., 1998]	Flexibility, integration, implementability, correctness, completeness, integrity, simplicity and understandability
[Levitin et al., 1995]	Relevance, unambiguous definition, obtainability of value, comprehensiveness, essentialness, attribute granularity, domain precision, naturalness, occurrence identifiability, homogeneity, semantic consistency, structural consistency, robustness, flexibility
[Ballou et al., 1985]	Accuracy, timeliness, completeness and consistency
[Pipino et al., 2002]	Accessibility, appropriate amount of data, believability, completeness, concise representation, consistent representation, ease of manipulation, free-of-error, interpretability, objectivity, relevancy, reputation, security, timeliness, understandability and value-added
[Wang et al., 1996]	Identified four categories, each having multiple dimensions: i. For data accuracy: Dimensions include Accuracy, Objectivity, Believability and Reputation ii. For data accessibility: Dimensions include Access and Security iii. For data relevance: Dimensions include Relevancy, Value-Added, Timeliness, Completeness and Amount of data iv. For data Representation: Dimensions include Interpretability, Ease of understanding, Concise representation and Consistent representation

The above mentioned dimensions can be directly quantified employing metrics. For example, completeness can be easily quantified using metrics such as requirements coverage degree, semantic completeness, etc. Thus these dimensions are not at the same level of abstraction as being the quality dimensions/types proposed by [Lindland et al., 1994] (syntactic, semantic, pragmatic), [Krogstie et al., 1995] (syntactic, semantic, pragmatic, perceived semantic, social) or [Cherfi et al., 2002a] (specification, usage, implementation), etc.

In our approach, we combine all the dimensions in Table - 7 (and similar dimensions) as attributes. However, the dimensions proposed by [Lindland et al., 1994], [Krogstie et al., 1995], [Cherfi et al., 2002a], etc. are not at the same level of abstraction as the above mentioned dimensions and thus can't be considered as attributes. Moreover, these dimensions are just a way of classifying different criteria.

Similarly, ISO-9126 standard classified the quality criteria into characteristics (such as maintainability) and sub-characteristics (such as changeability, testability, customizability). However, these quality characteristics are variously called quality dimensions, factors, principles, criteria, categories, goals, etc. Curiously, none of the proposals uses the ISO terminology [Moody 05]. In our approach ISO sub-characteristics are equivalent to quality attributes and thus we have also merged some important concepts from this standard into our attribute set such as maintainability.

Another problem in the area of CM quality is the presence of independent and autonomous quality frameworks. These frameworks does not position and contrast themselves with existing frameworks or use them as basis for extension. Thus the literature on CM quality evaluation is not converging to a set of agreed concepts and this divergence has resulted in the existence of multiple definitions for the same concept and different names for semantically same concepts. [Nelson et al., 2005] have identified different definitions of the same quality concepts e.g. they have identified nine different definitions for quality attribute "completeness". Similarly, there exist numerous definitions for the same quality concept and identical names for some semantically different metrics [Purao et al., 2003]. Such issues have restricted the adoption of the existing quality frameworks in practice [Moody 05]. Our approach also incorporates these issues and includes these concepts as attributes and their different definitions as metrics. For example, as per our approach completeness is equivalent to a quality attribute and thus we combine all the definitions of completeness within a single quality attribute named as "completeness" and formulated different metrics to cater the dissimilar requirements of the existing nine definitions. Thus, completeness will have different meaning in different contexts.

Summing up, a quality attribute in our approach aggregates all the dimensions that are at the lower level of abstraction (as explained above), attributes, characteristics or sub-characteristics, criteria, etc. However, all the high level criteria (those that can't be directly quantified by metrics such as specification) are accommodated as goals.

As mentioned in Section 3.1.1, we performed a review and formulated a set of 21 quality attributes from a thorough literature review and identification of new quality attributes for the gray areas. We also employed a web-based survey to validate the selection of these quality attributes from professionals including practitioners. Details about selected attributes and their definitions can be consulted from Appendix-A, whereas the details about validation can be consulted from the Chapter 7.

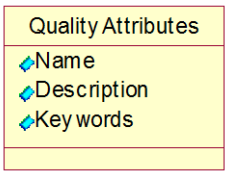


Figure - 8. Quality Attributes

In our model, each attribute has a name and description associated to it. We have also kept the keywords along with every attribute to help the automatic searching during the implementation phase (Figure - 8 depicts the structure of a quality attribute). As mentioned above, concepts such as sub-characteristics, characteristics, factors, properties etc are all quality attributes in our approach.

Following are some of the selected quality attributes (the details about all the selected attributes can be consulted from Appendix-A).

Name	Completeness
Description	This quality attribute evaluates the model completeness with respect to both syntactic and semantic completeness. Syntactic completeness relates to the notation used (e.g. verifying that multiplicities are defined for associations in a class diagram). Semantic completeness is related to the coverage of user requirements. It could be checked by verifying conformance between concepts depicted in the conceptual model and the ones expressed by the users through the requirements or even by comparing the concepts appearing in several specifications related to the same reality).
Keywords	Completeness, requirements coverage, semantic completeness, syntactic completeness

Name	Structural complexity
Description	This attribute represents the model complexity due to the existence of different relational elements within the model. These elements can include associations, aggregations, generalizations, dependencies for class diagram and number of transitions, etc. for state diagrams and number of identifying and non identifying relationships, etc. for ER diagrams. This attribute contains several metrics that are proposed in literature and have been tested for their efficacy in model complexity and maintainability.
Keywords	Complexity, structural complexity, maintainability

3.5.2 Quality Metrics

Measurements provide data or basis for comparable evaluations to assess the static and operational qualities of software or application artifacts. Metrics are the measures or evaluation processes that assign comparable numeric or symbolic values to entities in order to characterize selected qualities or features of the entities. Each metric has a scope, the set of entities/objects to which it is applicable; a range, the set of possible measurement results; and the measurable property or feature or behavior which the measure characterizes. For example, programming code line count has software applications as one of its scope with line length as one of its measurable feature. Explicitly representing the scope and the measurable property/feature/behavior allows for the consideration of different metrics which characterize the same attribute for the same set of entities. Each measurable property/feature/behavior may have multiple, identifiably distinct metrics [ADM-OMG, 2009]. Similarly, [SPEM-OMG, 2008] defines metrics to be an instrument containing one or more constraints to provide measurements for any model element.

Most of the work done in the field of conceptual modeling quality is based on the formulation or proposition of different sets of metrics. Metrics in conceptual models are the measures of their properties, features, behaviors, characteristics or other important aspects. It is a specific instrument that can be used to measure a given quality attribute. There might be several metrics for the same quality attribute [Bouzeghoub et al., 2004]. Researchers started devising metrics to

quantify the impact due to the existence of different properties, characteristics, etc. of models so that these aspects can be controlled to improve the quality. Some of these metrics can be calculated automatically whereas some can't. In the literature, there exist numerous metrics to evaluate various types of models such as UML class diagrams, use-case diagrams, ER-diagrams, etc. Table - 8 lists some of the existing automatable metrics.

Table - 8. Some of the existing automatable metrics

Proposal	Target	Metrics
[Genero et al., 2002a], [Genero et al., 2001b], [Genero et al., 2001c], [Genero et al., 2000b], [Manso et al., 2003]	Complexity for class diagram	Number of Attributes, Number of Methods, Number of Associations, Number of Aggregations, Maximum Depth Inheritance Tree(Max DIT), etc.
[Marchesi 98]	Complexity metrics for use case diagram	Number of use cases, Number of communications among use cases and actors, Non-redundant number of communications among use cases and actors
[Marchesi 98]	Complexity metrics for class diagram	Number of classes, Number of inheritance hierarchies, Weighted number of responsibilities of a class, etc.
[Rufai 03]	Similarity between UML models	Shallow Semantic Similarity Metric (SSSM), Deep Semantic Similarity Metrics (DSSM).

Question: What are Quality Metrics?

Answer: *Metrics are the measures or evaluation processes that assign comparable numeric or symbolic values to entities in order to characterize selected qualities or features of the entities. Each metric has a scope, the set of entities/objects to which it is applicable; a range, the set of possible measurement results; and the measurable property or feature or behavior which the measure characterizes. Explicitly representing the scope and the measurable property/feature/behavior allows for the consideration of different metrics which characterize the same attribute for the same set of entities. Metrics in conceptual models are the measures of their properties, features, behaviors, characteristics or other important aspects. It is a specific instrument that can be used to measure a given quality attribute. A quality attribute can employ multiple metrics to measure different aspects of CMs.*

Similarly, some of the non-automatable metrics include requirements coverage degree, Cross modeling completeness, documentation degree, user vocabulary rate, etc. [Cherfi et al., 2003a] or

aesthetics metrics such as minimization of bends, minimization of edge crossing, orthogonality [Purchase et al., 2002], [Purchase et al., 2001b], [Purchase et al., 2000].

In our approach, we have used metrics to quantify different quality attributes. We employed both automatable and non-automatable metrics to measure the different aspects of an attribute. Based on the values of those metrics, different recommendations can be proposed for improvement.

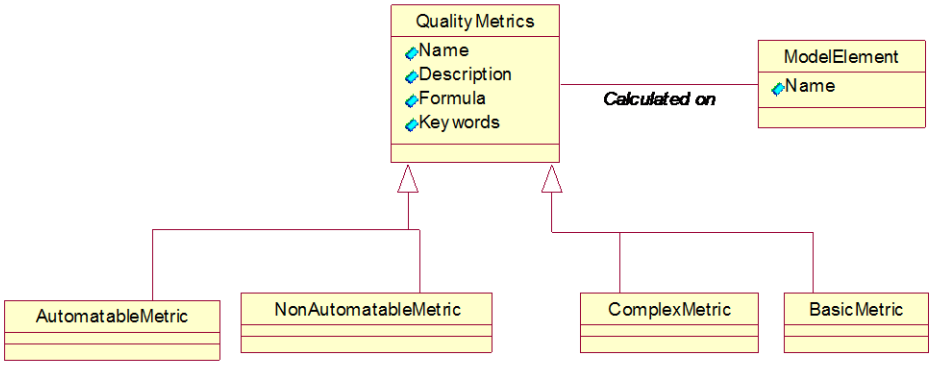


Figure - 9. Model for metrics

Figure - 9 presents the formal model for metrics. Each metric has a name, description and measurement formula associated to it. A Measurement formula represents the algorithm to compute the metrics. We have also kept the keywords along with every metrics to help the automatic searching during the implementation phase. It can be seen that every metrics is calculated on model elements such as classes, entities, attributes, etc. Moreover, our model proposes the following two types of metrics:

i. Basic Metric: It is an atomic metric i.e. a basic metric is a metric that doesn't employ other metrics for measurement. For example, the metric to calculate "number of classes" in a class diagram is a basic metric.

ii. Complex Metric: These types of metrics use at least one additional metric for measurement i.e. a metric depending on other metrics for measurement is a complex metric. For example, the metric to calculate "number of model elements" in a class diagram is a complex metric as it is dependent on other metrics such as number of classes, number of associations, number of association classes, etc. for measurement.

Similarly, we classify each of the metrics (basic or complex) to be either automatable, i.e. those that can be calculated automatically without requiring human input, or non-automatable. For example, a metric to calculate "number of line crossings" in a class diagram is a non-automatable metric since we can't calculate the line intersections automatically as this information is not available in the exported model file. Whereas, metrics such "number of classes", "number of associations", etc. can be calculated automatically and are thus automatable metrics.

We have performed a thorough literature review and classified the different concepts into a set of quality attributes and classified different existing metrics into each of those attributes for quantification. Similarly, we also identified the grey or left-over areas and thus have also formulated some new metrics to quantify those left-over areas. Some of the newly formulated metrics includes the following:

i. Degree of defined multiplicities: This metric calculates the ratio between the total numbers of defined multiplicities within a model to the total number of associations in a model.

Let:

X = Number of defined (or existing) multiplicities or cardinalities;

Y = Number of association links;

Z = Number of composition and aggregation links;

Then:

$$\text{Degree of Defined Multiplicities} = \frac{X}{2 * Y + Z}$$

Range:

Degree of Defined Multiplicities=1, if both ends of the association links, compositions links and aggregation links are defined.

Degree of Defined Multiplicities=0, if no multiplicities are defined in the model.

ii. Degree of named associations: If proper naming is assigned to every relationship or association then it enhances the understandability of the model. This metric calculates the ratio between the number of named associations and the total associations.

Let:

W = Number of named relationships or associations;

X = Number of association links;

Y = Number of association classes;

Z = Number of composition and aggregation links;

Then:

$$\text{Degree of Named Associations} = \frac{W}{X - Y + Z}$$

Range:

Degree of Named Associations = 1, if all the association links, compositions links and aggregation links are defined except those association links that have association classes.

Degree of Named Associations = 0, if no associations are named in the model.

iii. Technical vocabulary rate: It is based on the assumption that the understandability of a model will be enhanced if the reader can make easy correspondence between the modeling elements contained in the conceptual schema and the requirements in the textual description.

Let:

X = Number of technical labels in the model;

Y = Total number of labels in the model

Then:

$$\text{Technical Vocabulary Rate} = \frac{X}{Y}$$

Range:

Technical Vocabulary Rate = 1, if all the employed labels including the associations names are technical terms instead of common language terms.

Technical Vocabulary Rate = 0, if all the employed labels are common language terms instead of technical terms.

iv. Overall model reuse. This metric is adopted from [Basili et al., 1990]. It calculates the aggregated reuse of the whole model by summing the reuse of every individual concept in the model. This metric uses the following formula for calculation:

Let:

X = Any concept present in the model;

Reuse(X) = Count of all the ancestors of the concept "X" and the concepts inherited by concept "X"

I = Number of all the distinct concepts in the model

Then:

$$\text{Reuse (Model)} = \sum_{I} \text{Reuse } (X_I)$$

Range:

Overall Model Reuse = ∞, if all the concepts have multiple ancestors and numerous inherited concepts.

Overall Model Reuse = 0, if none of the concept has any ancestor or any children.

3.5.3 Recommendations

Quality evaluation is only a step to improve the conceptual models but most of the quality frameworks focus exclusively on defect detection (quality evaluation) and ignore the defect correction (quality improvement) aspects. Thus they may help in identifying the problem but the analysts must rely on themselves for the solution [Moody 05].

Question: What are Recommendations?

Answer: *Recommendations are the suggestions, propositions or corrective advices in the form of text, transformations or design patterns for improving the quality of CMs. Analysts/designers can employ the suggested/proposed recommendations for improving the quality of CMs as recommendations are dependent on the evaluation results or more precisely on metrics values.*

For many software development approaches and methods, documentation providing understandable guidance for best practices is more important than precise models [SPEM-OMG, 2008]. SPEM 2.0 combines a guidance mechanism with a process structure. Its architecture allows associating guidance elements with process structure elements. [SPEM-OMG, 2008] provides semantics for the following guidance kinds: Checklist, Concept, Estimate, Example, Guideline, Practice, Report, Reusable Asset, Roadmap, Supporting Material, Template, Term Definition, etc. Figure - 10 provides the guidance model specified in [SPEM-OMG, 2008].

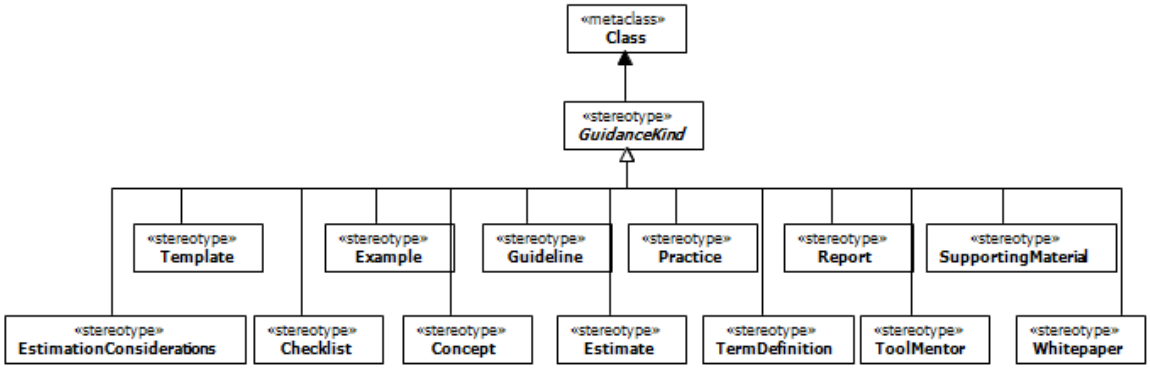


Figure - 10. SPEM 2.0 Guidance Kinds

SPEM 2.0 provides a good mechanism to incorporate the notion of guidance with the process structure elements. However, all the guidance kinds provide textual descriptions and thus they can lead to different interpretations. Moreover, some guidance kinds will be beneficial in some scenarios whereas not so useful in some other. Thus, it can get trickier for an analyst/designer to identify the best set of guidance kinds for the problem in hand.

Corrective actions (quality improvement) are the essence of our proposed solution. The last level of our quality aware approach suggests the recommendations for quality improvement. As quality patterns encapsulated both researcher's and practitioner's quality practices thus they provide good solutions to recurring problems.

The recommendations for improvements are dependent on metrics values. Thus upon metrics calculation, relevant recommendations are proposed to improve the model through a guided process. These recommendations can be in the form of any of the following three types:

i. Textual recommendations (in the form of descriptions)

ii. Transformations (in the form of rules for improvement)

iii. Design patterns (proposing a recommended solution to a recurring problem)

3.5.3.1 Textual Recommendations

Quality patterns can propose recommendations in the form of textual descriptions for quality improvement. Textual recommendations are proposed in situations such as:

i. When the domain of the problem can't be formalized

ii. When the improvement actions can't be formalized into step-wise transformations and require detailed information about the problem and its resolution

For example consider the following problems and their textual recommendations for resolution:

Problem: Missing Requirements
i. Identify all the requirements that are communicated by the user but don't exist in the model. ii. Identify the existing concepts that can accommodate the missing requirements. For example, if date of birth information of an employee is missing then identify if an Employee class exists in the model. If it exists then add this missing requirement within the existing concept. iii. If existing concepts don't exist that can incorporate the missing requirements, then add the new concept(s) to incorporate the missing requirements. For example, if Employee class doesn't exist then add this class and then add the date of birth information within the class. iv. Verify that the model contains all the requirements else post implementation modification will be difficult and expensive.

The following recommendation is applicable only to a class diagram and can be modified for ER diagram.

Problem: Missing Multiplicities
Following steps can be performed: i. Identify proper multiplicities for both ends of the normal associations. ii. Identify proper multiplicities for composition and aggregation relationships. iii. If a many-to-many relationship exists between two classes/entities, verify that an associating class or entity exists for its resolution. iv. Multiplicities must not exist for generalizations.

From the above two examples, it can be noticed that the recommendations are dependent on model types (class diagrams, etc.) and sometimes even model elements (such as classes) as they are associated to metrics and metrics are calculated on model elements (see quality pattern model).

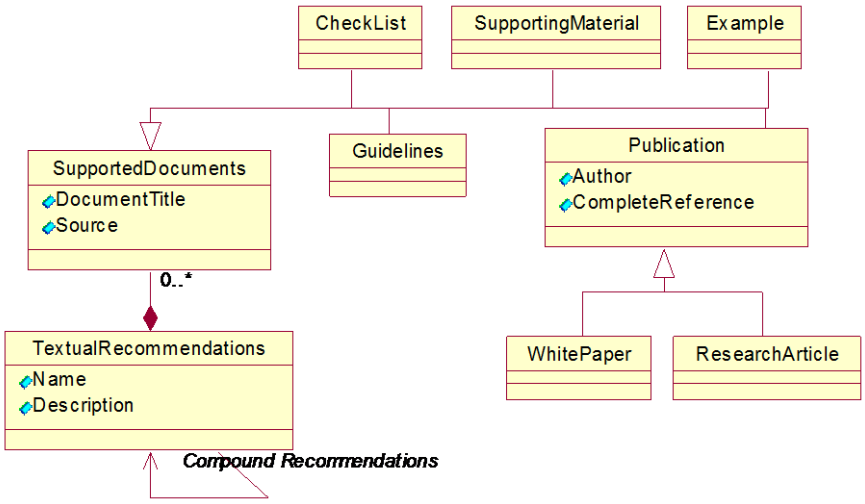


Figure - 11 Model for textual recommendations

Figure - 11 presents the model for textual recommendations. Each textual recommendation has a name and description associated to it. Moreover, a textual recommendation can associate multiple textual recommendations to cater the requirements of a compound recommendation. Each textual recommendation can have multiple supported documents as references. These supported documents can help the analyst/designer in understanding the recommendations easily. Supported documents can be of the following types: checklist, guidelines, examples, publications, etc. Publications can be either a white paper or a research article publication. We have adopted this classification of supported documents from [SPEM-OMG, 2008].

3.5.3.2 Transformations

Quality patterns can also propose recommendations in the form of transformations to be applied on the model for improvement. Some of these transformations can be applied automatically on the model via a software tool while some can't due to complexity or lack of information about the model elements. For example, a transformation to divide a model into small modules can be performed semi-automatically (requiring inputs from analyst/designer) whereas the transformation to reduce the line crossings within a class diagram can't be automated since the information about line intersections is not necessarily available in the exported model.

Transformations can only be formulated when the domain of the problem and solutions can be formalized. Following are some of the examples of the transformations recommended through our approach:

Problem: Model complexity due to the existence of numerous objects (classes, attributes, etc.) within a model.
In order to reduce the structural and relational complexity within a model, they must be divided into smaller modules. Model division can be done in two ways: Structural Division and Semantic Division. Following transformations can be performed: i. **Structural Division** is an easier but non-efficient method. Randomly select the model elements and divide them into multiple modules. But bad selection of elements can lead to low cohesion and high coupling among the resulting modules. ii. **Semantic Division** is a difficult but efficient method. Read the model carefully and classify the model elements with respect to some similarity or relationship. For example, classify the elements with respect to common functionality or interdependency. The elements with a common set of goals or functionalities should be grouped together as a module. Such a division will increase the cohesion and reduce the coupling. iii. Another possible type of division is to identify the complex parts of the model and divide them into multiple modules to reduce the complexity.

The following transformation is applicable only to the class diagrams.

Problem: Complexity in classes
If classes are complex due to the existence of numerous attributes or methods within a class, the following transformations can be performed: i. Identify the attributes or functions that are irrelevant within the scope of the class (to increase cohesion). ii. Try adding these attributes/functions to the existing relevant class. iii. If no class exists that is relevant for these attributes/functions, then add these attributes and functions in a new class and define the associations. iv. If all the attributes/functions are relevant to the class then classify them into mandatory and optional and then split the class into two classes one containing all the mandatory attributes/functions and the other containing all the optional attributes/functions.

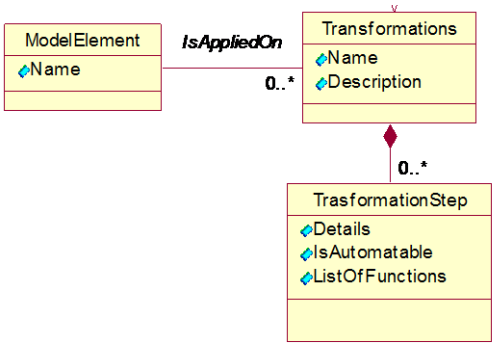


Figure - 12. Model for transformations

Figure - 12 presents the model for transformations. Each transformation has a name and description associated to it. A transformation can be composed of multiple steps. These

transformation steps can be automatable or non-automatable. A transformation is applied on a model element.

3.5.3.3 Design patterns

The use of design patterns to improve the software quality has attracted an increasing attention in the area of software engineering. Design patterns encapsulate valuable knowledge in the form of an established and recurring solution to resolve design problems to improve design quality [Hsueha et al., 2008]. A design pattern can be defined as a particular recurring design problem that arises in specific design contexts, and presents a well-proven generic scheme for its solution to have a certain level of confidence on the reliability of the solution [Buschmann et al., 1996].

In software engineering, patterns are designed to facilitate reusability and capitalize well known and agreed practices. [DeLano et al., 1998] and [Gamma et al., 1995] and proposes the GoF (Gang of Four) and AGCS templates for describing design patterns. Some of the most commonly employed design patterns include Model-View-Controller (MVC), Façade Pattern, Proxy pattern, Singleton, Wrapper Pattern, etc.

Similarly, GRASP (General Responsibility Assignment Software Patterns) patterns also received much attention in object-oriented design as it provides guidelines about assigning responsibilities to classes and objects. GRASP patterns consists of Information Expert, Creator, Controller, Low Coupling, High Cohesion, Polymorphism, Pure Fabrication, Indirection and Protected Variations patterns. There also exist evaluation methodologies to verify the quality of design patterns such as the ones described in [Chatzigeorgiou et al., 2008] and [Hsueha et al., 2008].

In addition to textual recommendations and transformations, quality patterns can also propose design patterns as recommendations for quality improvement. Design patterns provide established solution to recurring problems. However, employing design patterns for model improvement is a manual process. Our approach is unique in a way that, on the one hand, it helps in the identification of relevant design patterns to non-expert analyst/designer as employed by [Berdún et al., 2008] and, on the other hand, the inherent problem in conceptual model is resolved using better solutions.

For example consider the following problems and proposed design patterns for their rectification through our approach:

Problem: Complex classes
i. Use High Cohesion Pattern to reduce the complexity of the source class. As in-cohesive classes are inefficient, large and complex. Thus perform the following tasks: a. Assign class the responsibilities related to other responsibilities of the class. b. Find if the class contains methods that this class shouldn't be responsible for and delegate the responsibility of this method to the suitable class. ii. Use High Polymorphism Pattern to reduce the complexity and increase the cohesion of the class. Following tasks can be performed: a. Check if a class contains responsibilities that vary by class type. If yes, then these responsibilities should be assigned polymorphically to the specialization classes. For example, different shapes can use overrided polymorphic Draw() function to draw their shapes by themselves instead of one complex generic function to draw all types of shapes.

From the above examples, it can be witnessed that even though the design patterns are identified and proposed, their application is a manual process and requires knowledge about design patterns.

3.5.4 An example of quality pattern: Model Complexity Quality Pattern

Pattern Name: Model Complexity

Context:

i. To check the overall complexity of the model with respect to the number of instances of different elements (number of classes/entities/attributes etc) present in the model. This pattern is suitable for models containing numerous elements.

Problem:

i. Sometimes models contain several classes/entities/uses-cases, etc. This can hamper the understandability of the model. Miller ("The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information", 1956) proved that adults can hold 7 ± 2 objects in their working memory.

ii. Similarly, the existence of numerous elements can induce complexity.

iii. This induced complexity can hamper the maintainability as complex models are difficult to maintain.

iv. Calculate the following metrics (following metrics are applicable to class diagrams only) to check if this pattern is relevant for the current problems of the model:

   a. Number of Classes: Total number of classes in a model.

   b. Number of Attributes: Total number of attributes in a model.

   c. Number of Methods: Total number of methods or functions in a model.

   d. Number of cycles: Total number of cycles within a model.

   e. Degree of non-redundancy: This metric calculates the ratio between the non-redundant concepts and the total concepts present in the model.

   f. Number of Associations: Total number of associations in a model.

   g. Number of Aggregations: It calculates the number of aggregation relationships within a class diagram.

   h. Number of Compositions: It calculates the number of composition relationships within a class diagram.

   i. Number of Generalizations: It calculates the total number of generalization relationships in a model.

j. Depth Inheritance Tree: It calculates the longest path from the class to the root of the hierarchy in a generalization hierarchy.

Solution:

i. Models can be made simpler if they are divided into small independent modules, each one with a limited number of concepts and functionalities.

ii. Following transformations can be employed for improvement (details about transformations are on the next page):

   a. Remove redundant elements

   b. Factorize associations to remove redundant associations

   c. Divide the model

   d. Merge classes

   e. Divide a class

iii. The following design pattern can be employed to improve the quality of the model (details about transformations are on the next page):

   a. GRASP high cohesion pattern

   b. GRASP polymorphism pattern

Keywords: Complexity; Maintainability; Modify; Understandability; Size; Number of classes/entities, etc.; Number of concepts; Number of attributes;

Related patterns:

i. Model Maintainability (Complex models are difficult to maintain)

ii. Model clarity (models containing numerous elements can be difficult to read)

3.5.4.1 Details about Textual Recommendations/Transformation/Design Patterns

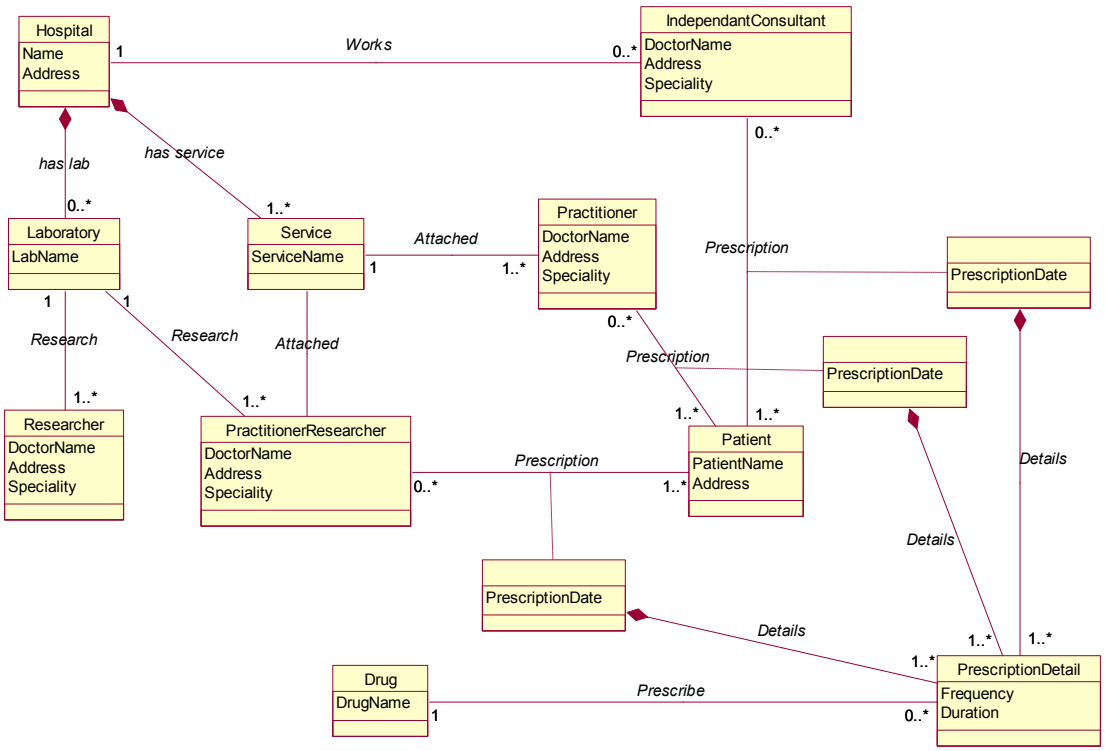
a. Remove redundant elements

i. Check the model to identify redundant elements such as classes, associations etc that have the same names or are semantically equivalent.

ii. Remove the redundant elements in a way that no information is lost.

iii. Similarly, if two associations have the same names then verify if they can be factorized.

iv. For example: In the following model, there are four classes representing different types of doctors (Practitioner, IndependentConsultant, Researcher and PractitionerResearcher). Since there is no generalization, therefore there are multiple redundant associations (three redundant association classes named as "Prescription", three redundant associations named as "Details" and two redundant associations named as "Attached"). However, if a generalization is introduced for these four types of doctors then the redundant associations can be removed.

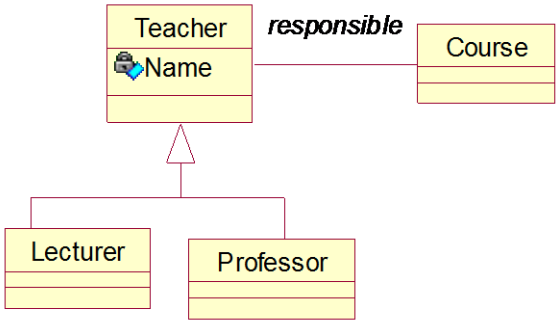


b. Factorize associations to remove redundant associations

i. Check the model to identify same or redundant associations for example associating having same name.

ii. Now if these associations are within the same level of hierarchy and are present for all the classes of that hierarchy then this association can be moved up in the hierarchy i.e. to the parent class.

iii. For example, if Lecturer and Professor have the same relationship with course and since they are the only two children of their parent thus this association can be taken up in the hierarchy i.e. we can remove these two associations and instead relate Teacher with Course (See the model below).



c. Divide the model

i. Model division can be done in two ways: Structural Division and Semantic Division

ii. Structural division is an easier but non-efficient method. It randomly selects the model elements and divides them into multiple modules. But bad selection of elements can lead to low cohesion and high coupling among the resulting modules.

iii. Semantic division is a difficult but efficient method. Read the model carefully and classify the model elements with respect to some similarity or relationship. For example, classify the elements with respect to common functionality or interdependency. The elements with a common set of goals or functionalities should be grouped together as a module. Such division will increase the cohesion and reduce the coupling.

iv. Identify if the model contains functionalities or concepts that can be grouped together or if the model represents two separable modules. If yes then divide them

into individual modules. For example: if the model contains concepts to manage the sale of items and also contains information about the security of the application then they clearly represent two different modules and thus they can be split into two modules, one for sale of items and the other for application security.

v. Another possible type of division is to identify the complex parts of the model and divide them into multiple modules to reduce the complexity.

d. Merge Classes

i. Concepts with similar functionalities can be merged as one or can be removed to reduce redundant concepts.

ii. Sort all the relevant and related attributes/functions among different classes.

iii. Package related attributes and functions within the same class to increase cohesion.

e. Divide a class if it contains numerous attributes and methods

i. If there are numerous attributes within a single class then perform the following steps:

a. Identify the attributes or functions that are irrelevant within the scope of the class (to increase cohesion).

b. Try adding these attributes/functions to the existing relevant class.

c. If no class exists that is relevant for these attributes/functions, then add these attributes and functions in a new class and define the associations.

d. If all the attributes/functions are relevant to the class then classify them into obligatory and optional and then split the class into two classes one containing all the mandatory attributes/functions and the other containing all the optional attributes/functions.

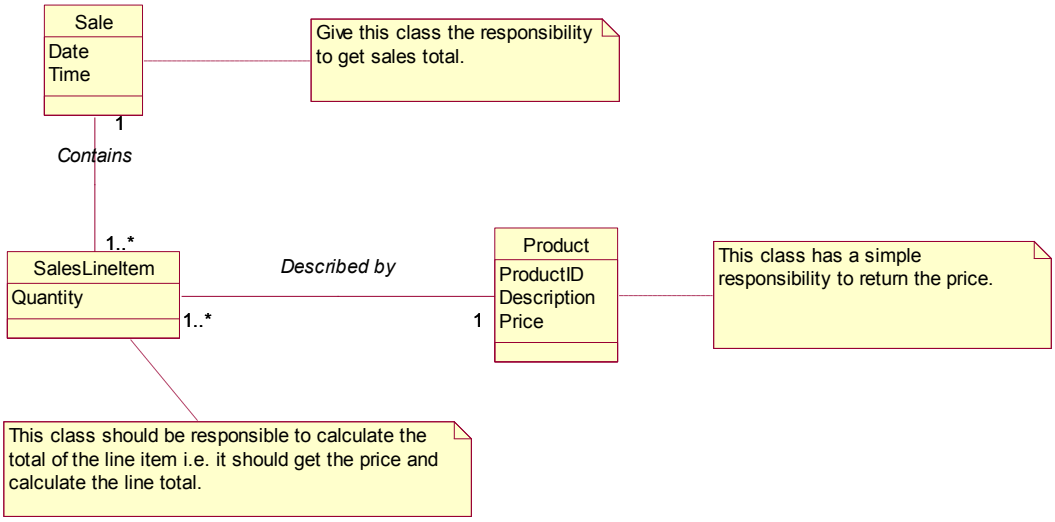
The following design pattern can be employed to improve the quality of the model:

f. GRASP high cohesion pattern

i. Classes must be identified with care such that all the relevant attributes and functions must be packaged within the same class.

ii. Verify that a class contains all the related responsibilities. For example, if a sale contains multiple items then the total of the sale should be calculated by the class sale and not by SalesLineItem class. So check and delegate the responsibilities to the concerned class only (See the figure below).

iii. Incohesive classes are complex to manage and implement



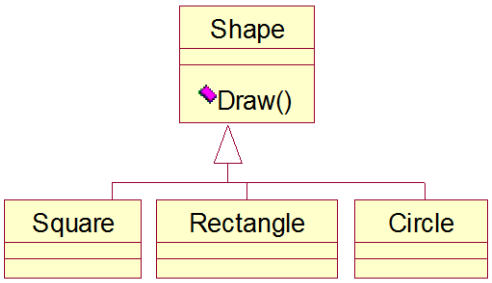
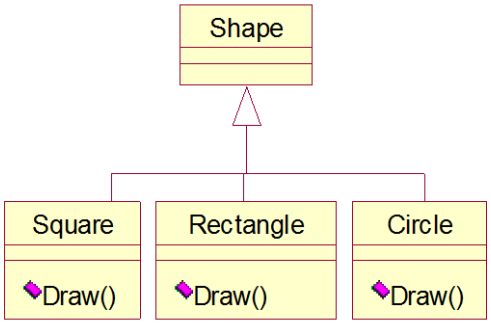
g. GRASP polymorphism pattern

i. When related behaviors vary by class type then the responsibilities should be assigned polymorphically to the specialization classes. Polymorphism Pattern increases the cohesion.

ii. Identify all the hierarchies in the model.

iii. Within each hierarchy, identify if a parent class implements a method that could have different implementations for its children. If yes, then this method should be assigned to all the specialized classes to reduce the complexity of the class.

iv. For example, different shapes can use overrided polymorphic Draw() function to draw their shape by themselves instead of one complex generic function to draw all types of shapes.

Draw() function implemented by the parent and thus will be complex.	
By polymorphism each shape implements its own Draw() function and thus the implementation is simple	

3.6 Conclusion

In this chapter, we presented our proposed solution to evaluate and improve the conceptual models. We define the employed theoretical, practical and epistemological foundations for formulating multi-faceted quality approach. Next, we describe each component of our quality model such as goal, questions and quality patterns. We adopted [Basili 93], [Basili 92], [Basili et al., 1988] propositions to help the analysts/designer in formulating structured goal with least efforts. One of our major contributions includes the identification of quality patterns to guide the evaluation and improvement of CMs. Therefore we presented the concept of quality patterns in details along with all of its components such as quality attributes, metrics and recommendations. Lastly we include a complete quality pattern along with all the relevant details as an example.

In the next chapter, we present the quality driven development process (Q2dP). We describe different processes involved in the identification/creation of the quality concepts such as the processes to identify new quality patterns, quality attributes and metrics. Similarly, we also describe the complete evaluation and improvement process for CMs starting from the formulation of analysts/designer specific quality goals to the evaluation of the CMs and finally to the recommendations/propositions for quality improvement.

Chapter 4
Quality Driven Development Process (Q2dP)

4.1 Introduction

In preceding chapter, we presented our approach for quality evaluation and improvement of conceptual models. The presented concepts could be seen as a set of methodological tools able to help analysts and designers in evaluating the quality of their models and even its improvement. However these concepts require:

i. Expertise for efficient usage

ii. Efforts for selecting a suitable or a set of suitable concepts such as quality pattern, quality attribute or metric

iii. Experience for selecting the relevant concepts under the given situation

Indeed, as the concept of quality is considered as a non-functional goal, the existing development processes and methods do not explicitly consider the quality during the early stages. However, it is widely agreed that mastering quality during the early stages affects, heavily, the quality of the final system. This explains the efforts devoted to the development of good practices (Unified Process (UP) [Jacobson et al., 1999], [Kruchten 00], [Larman 97]; design patterns [Buschmann et al., 1996], [DeLano et al., 1998], [Gamma et al., 1995], [Hsueha et al., 2008]).

We propose to integrate quality as part of the development process. Indeed, we believe that if developers are delegated the sole responsibility of the quality management, we cannot be sure if it is done rigorously and thus we have no guarantee on the quality of the obtained results. This chapter aims to propose a quality driven development process (Q2dP). Our approach could be seen as a transplantation operation with an aim to relocate quality concerns to the existing development processes at a much earlier stage. The approach is illustrated by Figure - 13.

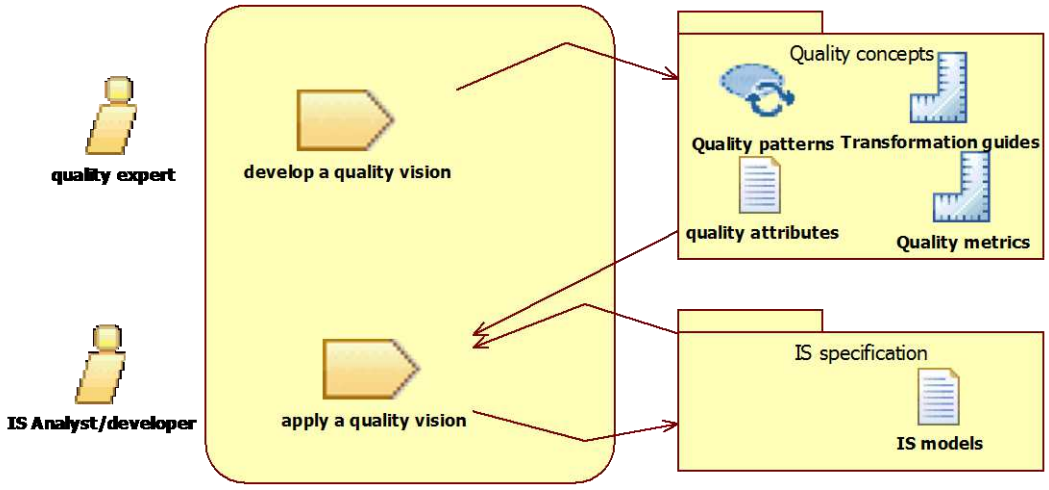


Figure - 13. A quality driven development process

The process encompasses two important phases: the quality vision development and the quality vision application.

The definition of quality concepts is a hard task requiring high level expertise in quality management. To guide this activity, our approach proposes a set of methodological tools to assist the quality expert:

i. A quality meta-model presented in Chapter 3.

ii. A set of structured processes for quality concepts definition (detailed in this chapter).

iii. A knowledge base containing predefined quality concepts and their explanations (detailed in Chapter 6).

iv. And the trace of previous quality guided IS developments as an input for quality vision adjustment and/or correction. Indeed, we believe that the best validation of the concepts and of the whole approach requires its application on several case studies and the analysis of the reaction analysts.

The deliverable of this phase is the set of quality concepts (patterns, attributes, metrics and recommendations) that are used by the second phase devoted to a quality driven IS development process detailed in Section-4.3 of this chapter.

4.2 Constructing a Quality vision

As mentioned in Chapter 3, our quality vision encompasses quality concepts such as quality patterns, quality attributes and metrics. The identification of these concepts requires expertise and knowledge about quality in conceptual models. However, we proposed a set of processes to identify new quality patterns, attributes and metrics to guide the quality experts. These processes are formulated with intent to formalize the identification of these quality concepts. The subsequent sub-sections describe processes to identify different quality concepts.

4.2.1 Identifying New Quality Pattern

Our quality approach is based on the concept of quality patterns. Quality patterns incorporate the guidance process for quality evaluation and improvement of conceptual models. However, identification of quality patterns remains a highly skilled and difficult task. Similar to design patterns, quality patterns are also identified for recurring problems and tend to propose better solutions.

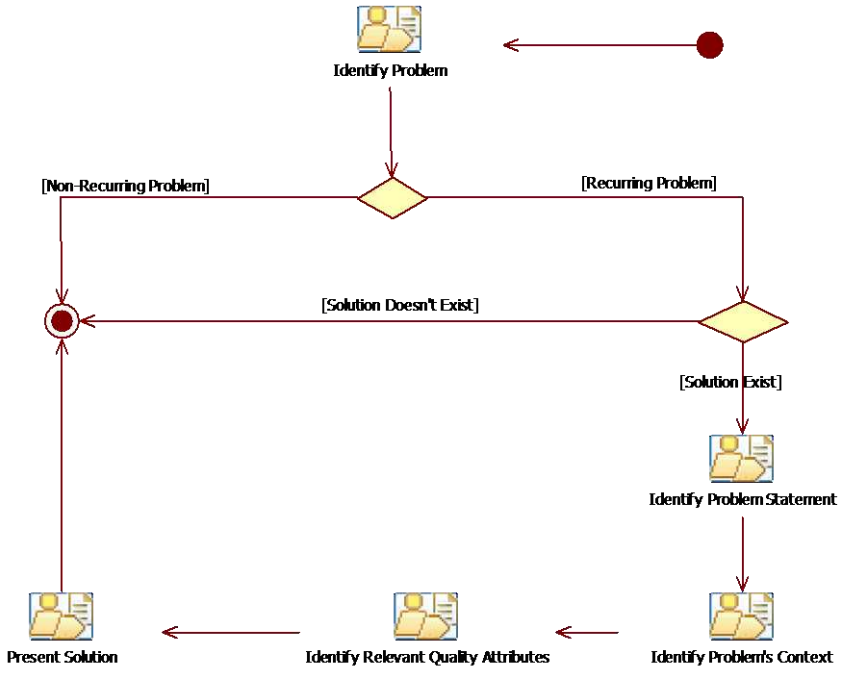


Figure - 14. Process to Identify New Quality Patterns

Despite the difficulties in identifying new quality patterns, we intend to help the quality experts by proposing the following process (depicted as Figure - 14):

i. Quality patterns are identified for recurring problems. Thus, if the problem is recurring then a quality pattern should be identified. For example, complexity in conceptual models is a frequent and common problem. Most of the time complexity exists due to the numerous model elements within a single model depicting a pattern of common and repetitive problems and so quality pattern can be identified for this problem.

ii. Once the problem is identified, it is important to determine if a solution (in the form of quality attribute, metrics or recommendations) can be drawn for this problem. If a solution can't be proposed then a quality pattern can't be identified as a quality pattern must propose a solution.

iii. After the above two initial checks, the detailed problem statement and the context of the quality pattern should be identified.

iv. Respective quality attributes must then be identified to solve the problem. For example, in case of complexity, quality attributes such as structural complexity can be used to solve the problem.

v. Once the quality attributes are identified for the quality pattern, it is important to present the solution. Our proposed quality approach presents the results in two parts: in the first part, the evaluation results are presented and in the second part recommendations are presented to rectify/resolve the problem.

4.2.2 Identifying New Attributes

As mentioned in Chapter 3, quality attributes in our approach stands as a single concept incorporating the existing classification terminologies such as dimensions, attributes, characteristics, sub-characteristics, criteria, properties, etc. Different aspects of conceptual modeling quality are identified and classified into attributes. Each attribute has to be generic and should remain valid for all types of conceptual models. Thus, attributes related to some specific notation (UML, ER, etc.) can't be selected. Different researchers have placed attributes at different levels of abstraction and thus there exists numerous attributes in the literature that are specific to a particular notation only.

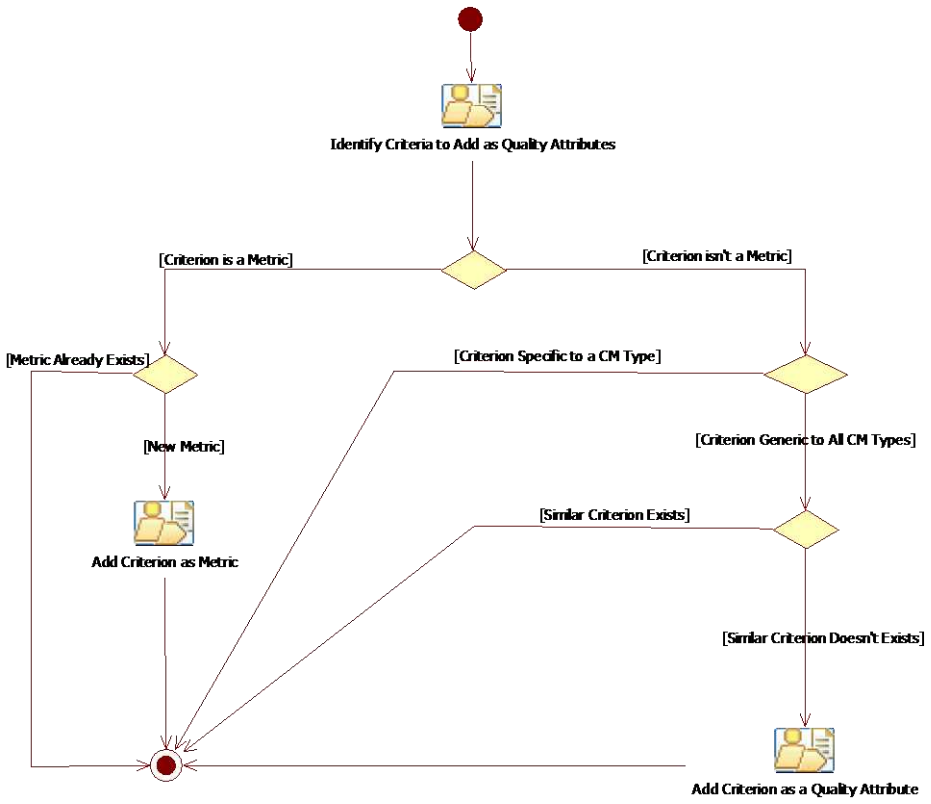


Figure - 15. Process to identify new quality attributes

In our approach, the selection of quality concept (existing or new) as quality attribute must adhere to the following process (depicted as Figure - 15):

i. The concept (or candidate criterion) should be verified if it is a metric or not. A metric is a measure of a particular property or characteristics of the CM. Thus, if the candidate concept is a measurement criterion or a formula then it is a metric and it can't become an attribute as quality attribute is a higher level concept. For example, Cohesion can't be identified as an attribute since it is a measure to calculate the relatedness of various responsibilities of the class or a module.

ii. If the candidate criterion is not a metric then verify if this criterion is valid for all types of conceptual models i.e. it is not limited to a certain notation such as class diagram or ER-diagram. For example, data completeness can't be selected as a quality attribute, despite the fact that it is not a metric, since it is valid for data models only and is invalid for other conceptual models such as sequence diagrams, state diagrams, etc.

iii. If the candidate criterion is not a metric and is valid for all types of conceptual models then it should be verified that a similar or semantic equivalent concept doesn't exist as an

attribute. This check is important in ensuring that different attributes for semantically equivalent concepts must not exist. For example, correctness of requirements, correctness of syntax, and correctness of domain are three different definitions of similar concept Correctness. Thus, there should be just one quality attribute Correctness while its different definitions should be incorporated through different measures or metrics.

4.2.3 Formulating Metrics to Measure Quality Attribute

Quality attributes provides an abstraction to a set of closely related and similar metrics. Moreover, semantically close concepts are grouped within a same quality attribute. Thus their differences must be incorporated by enhancing the domain/definition of the attribute and/or by formulating corresponding metrics. For example, in case of correctness of requirements, correctness of syntax, and correctness of domain, we merged these concepts into one quality attribute as Correctness. Thus, the domain/definition of Correctness attribute should incorporate the above mentioned three types of correctness. Moreover, corresponding metrics should be formulated to measure the respective aspects related to each of the three concepts.

In our approach, quality attributes are associated to a set of metrics for measurement. These metrics could vary with respect to different types of conceptual models and different model elements within the same model type. For example, in case of correctness, there will be a set of metrics to ensure the syntactic correctness of class diagrams and a different set of metrics for ER-Diagrams as the syntactic requirements are different for both types of models.

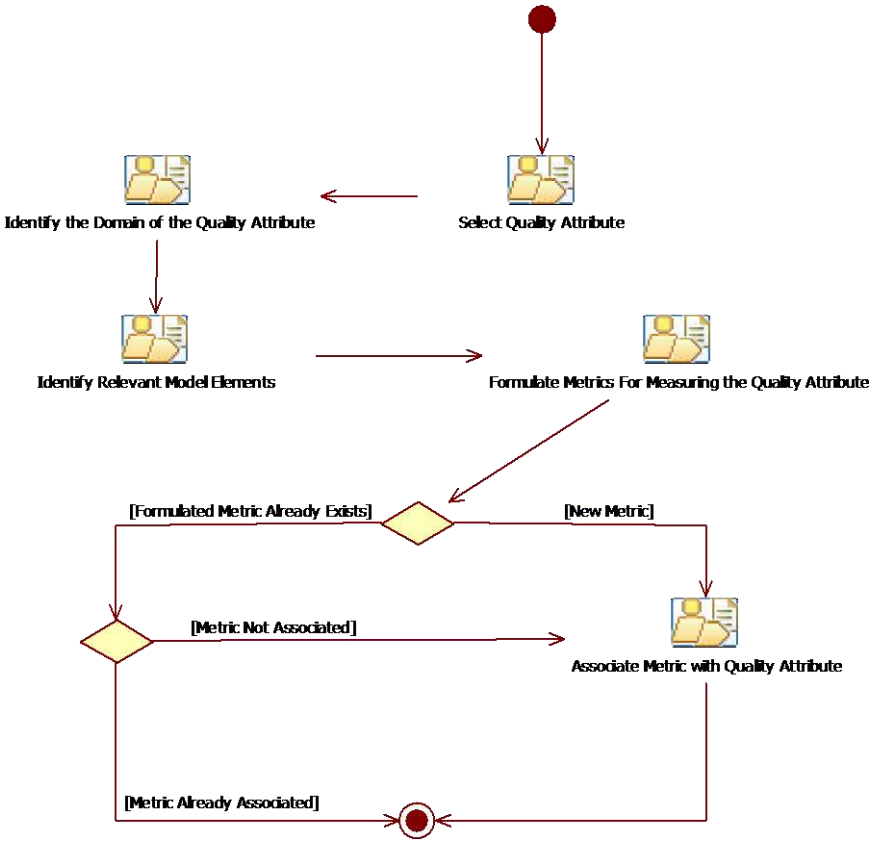


Figure - 16. Process to formulate metrics for measuring quality attributes

In order to identify new metrics or to associate existing metrics to a quality attribute, we propose the following process (depicted as Figure - 16):

i. Domain or definition of the quality attribute must be identified clearly. For example, in the case of three types of correctness, the domain/definition of correctness should encompass the requirements of all the three types.

ii. All the concerned model elements (such as classes, associations, entities, etc.) should be identified for the concerned model type (Class diagram, ER-diagram, etc.). For example in the case of a quality attribute Complexity, researchers have formulated different metrics for model elements such as classes, associations, entities, etc. Similarly for other quality attributes, concerned model elements can be identified for measurement.

iii. Once the model elements are identified, corresponding metrics can be formulated within the domain/definition of the quality attribute. For example, in case of Complexity quality attribute, following metrics were proposed by researchers for class diagrams: number of Classes, number of associations, etc. It can be noted that these metrics depend on model

elements i.e. in this case these metrics are applicable only to class diagram whereas Complexity quality attribute is valid for all types of conceptual models. Thus, metrics should be formulated for model elements of other model types such as ER-diagram. For example the metrics related to the structural complexity of ER-diagrams could include number of entities, number of relationships, etc.

iv. Once the metric is formulated, it must be associated to the target quality attribute for the concerned model type.

4.3 Applying a quality vision

It can be witnessed from Figure - 17, that our proposed process can be integrated to any development process. Our process is generic and thus can be applied to any level of development cycle. However, their adoption requires expertise and thus must be managed by quality experts. This customization results in the selection of suitable quality concepts leading to a more effective quality guidance. The implementation of Q2dP helps the IS analysts in guiding their development process in a quality aware way.

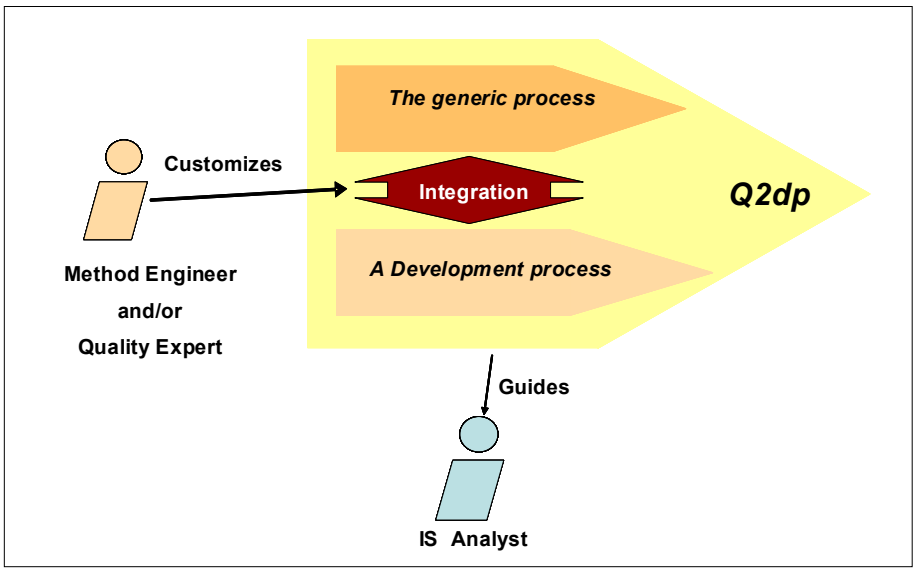


Figure - 17. Quality Driven Development Process (Q2dP): Roles and Aims

The proposed generic quality process has two main characteristics:

i. It could be applied on any IS development step as it is generic.

ii. It is flexible. The quality expert responsible for integration decides about the quality concepts to be used and even how and when to refer to them.

4.3.1 The Generic Quality Process

Our quality driven process encompasses methods and techniques to evaluate and improve the conceptual models with respect to a specific quality goal. As mentioned in the previous chapter, we employ a widely accepted GQM approach, with a slight modification as we map the formulated quality goals to quality criteria that are at a higher level of abstraction then metrics. We propose designer/analysts to formulate quality goals in a structured way but still some goals can be vague and complex. Thus we use questions, as proposed by GQM, to transform these goals into more concrete statements. These questions also help in narrowing the domain of the evaluation and map goals to quality criteria. In our process, goals are translated either into quality patterns or quality attributes through questions. These quality patterns and quality attributes are at the higher level of abstraction and are responsible for finding answers to the questions raised in the goal.

Our proposed quality driven process aims at helping the achievement of a quality goal formulated by an IS designer and encompasses the following steps (as depicted in Figure - 18, details about each step are included later in the chapter):

i. The process starts with the formulation of a quality goal (by the IS designer). We employ the goal formulating templates proposed in [Basili 93] to help the user in formulating their goals with a least amount of efforts in a structured way. For example, a user is interested in evaluating a conceptual model with respect to the ease with which it could be changed. Thus, the quality goal in this case is modifiability with it being the perspective or focus of the goal (refer to goal formulation Section-3.2.1)

ii. As our approach employs GQM, therefore questions are used to translate the formulated goals into relevant evaluation criteria.

iii. These questions help mapping the goal to quality patterns or quality attributes. Thus, once the goal is formulated, different questions are asked from the user to help its translation into the relevant evaluation criteria. If no relevant quality criteria could be identified then the goal should be modified.

iv. The next step involves the identification of quality attributes as we only have a limited set of quality patterns for recurring problems. Thus if relevant quality attributes exist, then they are selected.

v. Target conceptual model is evaluated employing the selected quality patterns and quality attributes.

vi. The interpretation of quality patterns and quality attributes propose a set of recommendations leading to the improvement of the CM according to the formulated quality goal.

vii. These recommendations can propose to use an existing domain ontology for rectifying particular set of problems. For example in order to reduce model complexity, one of the recommendations includes the division of the model into multiple smaller modules. Thus in order to divide the model, the usage of some existing domain ontology can help implementing the recommendations by identifying different clusters or modules from the model. One example using domain ontology during our approach is demonstrated in the next chapter (Section-5.6.2.4)

viii. However, in our approach a goal can be composed of multiple sub-goals or a hierarchy of goals. Thus the same approach, above mentioned, will be followed for all the sub-goals.

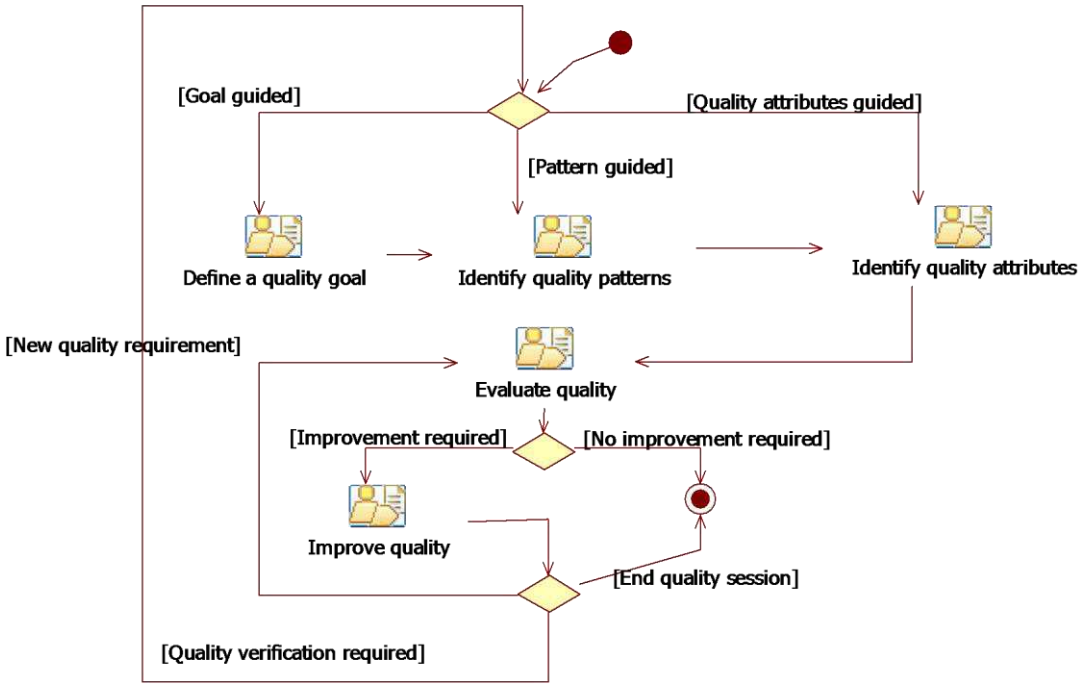


Figure - 18. Quality Pattern Driven Process Workflow

4.3.1.1 Defining a Quality Goal

As mentioned in the previous chapter, quality goal is the objective desired by a user to attain the object of interest. Quality goals may be defined for any object (such as products, processes, resources, etc.), for a variety of reasons (such as characterization, evaluation, prediction, motivation, improvement, etc.), with respect to various quality models (such as cost, correctness, defect removal, changes, etc.), from various points of views (such as analysts, managers, users, etc.). Thus we employ the goal formulating templates proposed in [Basili 93] to help the user in formulating their goals with least amount of efforts in a structured way. This structured process will enable users to clearly identify the purpose, motivation, perspective and point of view behind every quality goal. Moreover, this structured goal formulation process will reduce the vagueness in goal statements written in natural language by the users.

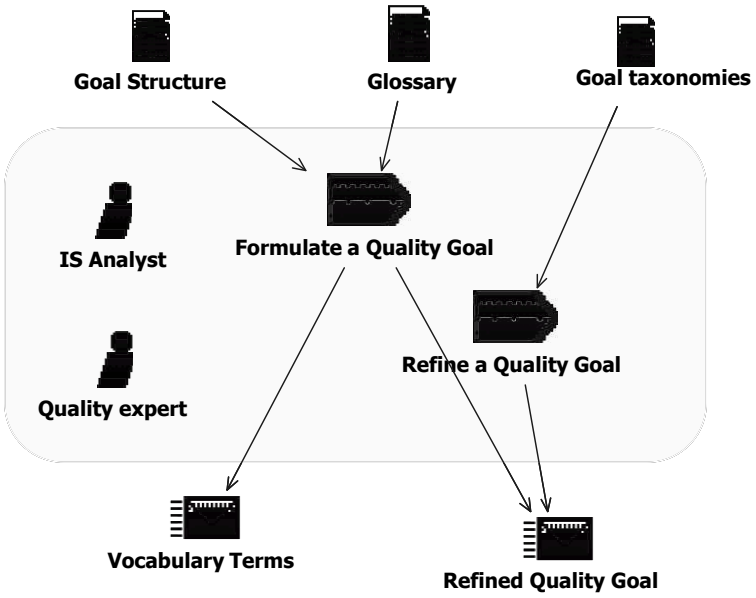


Figure - 19. "Define a Quality Goal" Work definition

In order to formulate a quality goal, we propose to use a set of artifacts such as goal structure artifact, glossary artifact and goal taxonomy artifact.

4.3.1.1.1 Goal Structure Artifact

[Basili 93] suggests expressing measurement goals using five facets of information. Each goal statement explicitly contains these facets. We adopt these facets as per our approach for conceptual models:

i. Object: The product or process under study; e.g., analysis class model, use case model. For example consider the quality goal to evaluate the modifiability of conceptual models, within this goal the object of analysis is conceptual model.

ii. Purpose: Motivation behind the goal (i.e. why we formulate this goal); e.g., better understanding, better change consideration. For example in a quality goal to evaluate the modifiability of conceptual models, the motivation of analysis is evaluation.

iii. Focus: The quality attribute of the object under study (what); e.g., correctness, defect removal, changes, effectiveness, etc. For example the perspective of the above mentioned goal is to focus on the modifiability of conceptual model.

iv. Viewpoint: Perspective of the goal (who's viewpoint); e.g., project manager, programmer, analyst, customer. In the above mentioned goal the target viewpoint is not mentioned. However within the context of conceptual modeling evaluations, the target point of view is that of analysts/designers. However, a goal can be composed of multiple perspectives or can focus on multiple aspects of quality. For example a quality goal "to analyze conceptual model for evaluating correctness, completeness and modifiability" represents three different perspectives or may be decomposed in three different sub-goals. Our approach encompasses such complex goals and users have the possibility to define multiple perspectives or sub-goals with one goal. However, within one goal the object of analysis (such as conceptual models, processes, etc.) and the target point of view (users, analysts, etc.) will remain the same while different motives (evaluation, prediction, etc.) and perspectives (completeness, correctness, etc.) can be defined.

v. Environment: Context or scope of the measurement program; e.g., project X

4.3.1.1.2 The Glossary Artifact

The Glossary gathers predefined terms useful for quality goals expression. These terms correspond to the five facets used for goals expression. They are collected from literature and are organized in a way to help expression of quality goals within a given context.

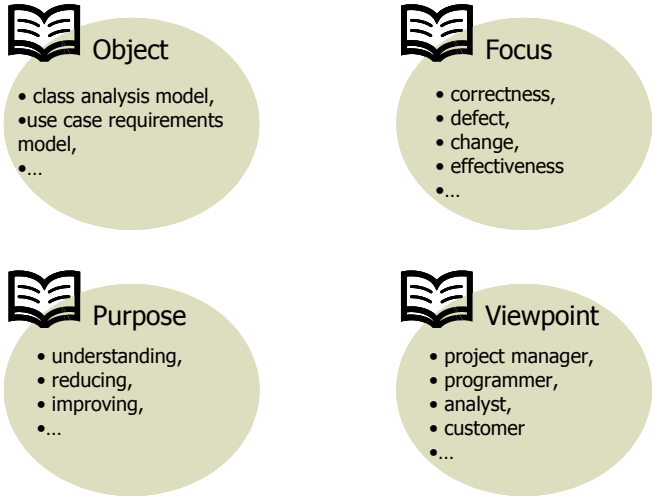
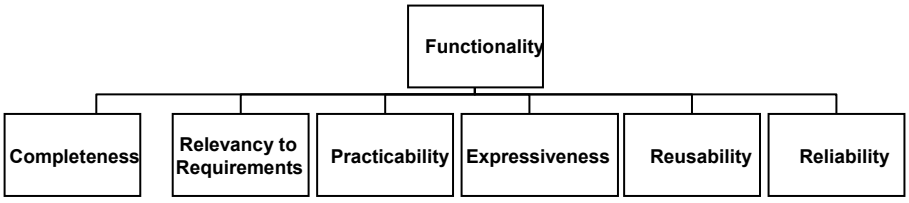


Figure - 20. An Extract from the Glossary

During the goal expression, the glossary content is used to suggest suitable terms. This doesn't mean that only glossary terms are allowed, the analyst/ quality expert can use his/her own terms.

4.3.1.1.3 Goal Taxonomies Artifact

The refinement of a goal aims to precise abstract and high level goals allowing matching with quality patterns, attributes and/or metrics. The refinement process is usually complex and needs to be helped. This guidance is provided in our approach by questions exploring the "Why" of the initial goal. The answer to this question could be assisted by assets of quality goal taxonomies constructed from several sources: quality standards, quality attributes and factors definition, etc. For example, for evaluating the functionality of conceptual models we have built the following taxonomy:



Functionality consists of the set of attributes responsible for evaluating the model quality based on functional aspects. These attributes are, directly or indirectly, related to the functional quality of the future product and address issues that could lead to functional changes in the final

product. Furthermore, these attributes tries to identify the key problems that can hamper the functionality of the final product.

Completeness: This attribute is based on the coverage of user requirements. It evaluates the quality by comparing the conformance between concepts depicted in the conceptual model and the ones expressed by the users through the requirements. Furthermore, this attribute can be used to compare completeness among several schemas modeling the same reality. A schema is considered complete if it covers all the modeling elements present in other schemas representing the same reality. This attribute can use collaboration patterns [Bolloju 04] to enhance the chances of model completeness. Moreover, this attribute can also evaluate whether the number of concepts present in the model corresponds to the number of concepts demanded by the user in their requirements.

Reusability: This attribute has been widely recognized and appreciated in the Object Oriented Paradigm. Reusability is considered as a major opportunity for improving quality and productivity of systems development [Thiagarajan et al., 1994]. We choose this attribute to evaluate the quality of the model in twofold: First, to check whether the model employs the previously developed models (e.g. use of existing modules) and secondly to check whether this model can be reused in future (for example to check if this model is specific or generic). Such an attribute can take into consideration the use of collaboration patterns to reduce the chances of errors [Bolloju 04] and will help in speeding up the process of modeling. Some studies suggest that reusability is feasible only if planned at the design stage because of loss of generalizability at subsequent stages [Thiagarajan et al., 1994]. Reusability is important in our model since it enhances the system's functional reliability since the reused component/module has been tested multiple times; therefore errors and deficiencies would have been rectified during its maturity cycle.

Relevancy to requirements: This attribute is different from "Completeness" in a way that it is employed for finding the relevancy between the concepts present in the model and the ones required by the users. It will help in removing the irrelevant concepts from the model; thus it will implicitly affect the complexity and functionality dimensions.

Practicability: This attribute is based on the notion of feasibility of the model. It verifies whether the model employs concepts or elements that are realistic and can be materialized. For example, there can be some models that require unprocurable sophisticated technology for implementation.

Reliability: A system is reliable if it is not prone to failure. It is important to consider this attribute at the conceptual level as a failure could be a hardware or a software failure. The software failures are generally caused by errors that could result from analysis decisions. Consequently, designers

must design reliability in the system by reusing reliable components, designing integrity constraints to ensure data integrity, facilitating its testability, etc.

Expressiveness: This attribute evaluates the expressiveness of a model. A model is expressive if it represents users' requirements in a natural way and is understandable without additional explanation. This attribute evaluates whether the employed concepts are expressive enough to capture the main aspects of the reality. E.g. an inheritance link is more expressive than an association. So the more expressive concepts are used, the more the schema will be expressive. Furthermore, this attribute evaluates the expressiveness by validating whether the existing notations are used to increase the expressiveness or not. For example, it can verify whether the cardinalities are defined in a model or not.

4.3.1.1.4 Refining Quality Goals

Our approach is based on GQM. Thus we employ questions to help users in narrowing the scope of their goals yet specifying its domain and increasing the details about it. Sometimes goals contain vague statements that are difficult to interpret. It may be due to the fact that perhaps users were unable to clearly translate their requirements into goal statements or may be users are unaware of the proper aspects of the quality in which they are interested in. For example, consider a user interested in evaluating the easiness with which a model can be changed. Thus he/she is interested in modifiability of the model. Similarly, there are multiple factors that are involved in modifiability of the models such as understandability, complexity, modularity, etc. So it gets difficult from the goal statements alone to identify the factor that are important to user. For example, is the user interested in complexity or modularity or understandability or any two or all of the three factors? Thus if we simply try to map this goal onto evaluation criteria then perhaps our perceived domain of the goal might be narrow or might not be in the right path. However, usage of questions can clarify the motives behind the goal. Thus asking users relevant questions at this stage will help us in reducing the gap between our perception of the goal and the requirements of the user. In addition to this, relevant questions will also enable us to clearly define or border the domain of the goal along with identifying the relevant quality criteria with respect to the formulated goal. This process is illustrated in Figure - 21.

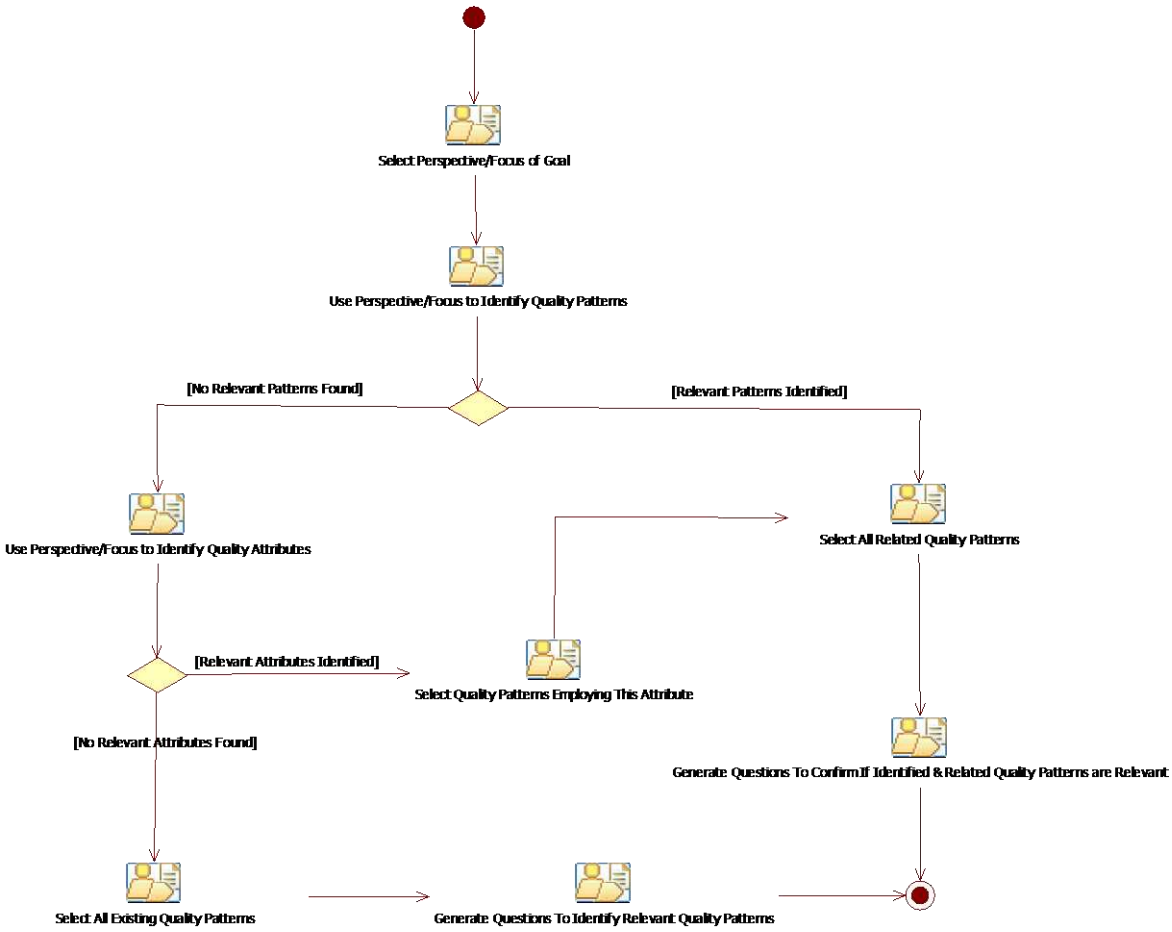


Figure - 21. Mapping Goals to Relevant Evaluation Criteria (through Questions)

Questions are used to refine the quality goal. We employ the perspective or focus from the formulated quality goal to generate questions. We have proposed a structured way to formulate quality goals (refer to Section-4.3.1.1) and perspectives or focus from such goals can be easily identified. For example, perspective or focus of the goal could be correctness, effectiveness, modifiability, defect removals, changes, etc. Questions are generated under the following scenarios:

i. When relevant quality patterns (with respect to perspective or focus of the goal) exist, generate questions for all the relevant quality patterns and their related quality patterns.

ii. When relevant quality attributes (with respect to perspective or focus of the goal) exist but relevant quality patterns couldn't be identified, generate questions for quality patterns employing these quality attributes.

iii. When neither relevant quality patterns nor quality attributes exist. This implies that the goal is difficult to refine employing the defined perspective or focus alone. Thus questions must be generated for all the problems solved by all the existing quality patterns so as to help the user in relating his goal with the existing quality evaluation criteria. However, heuristics can be used to order the quality patterns for formulating questions.

4.3.1.2 Identifying Quality Patterns

Quality patterns can be identified either through the formulated quality goal (goal guided) or quality experts, having in-depth knowledge about evaluation criteria including quality patterns, can directly identify and employ the patterns for evaluation (pattern guided). Pattern guided evaluation process is not complex. Quality experts manually select and employ the relevant quality patterns that they think are important for them. However in a goal guided process, identification of relevant quality patterns is linked to the refining of quality goals through questions. Quality goals are mapped to quality patterns for evaluation and improvement. Identification of quality patterns is possible through the following three ways (Figure - 22):

4.3.1.2.1 Direct identification:

i. Select the perspective/focus of the goal.

ii. Search the selected perspective/focus in existing quality patterns to identify the relevant quality patterns.

iii. Select all the identified quality patterns along with all of their related quality patterns.

iv. For ensuring the consistency between the quality goal and the identified quality patterns, generate questions about every identified quality pattern and all quality patterns that are related to them (quality patterns are related to each other) and query the user.

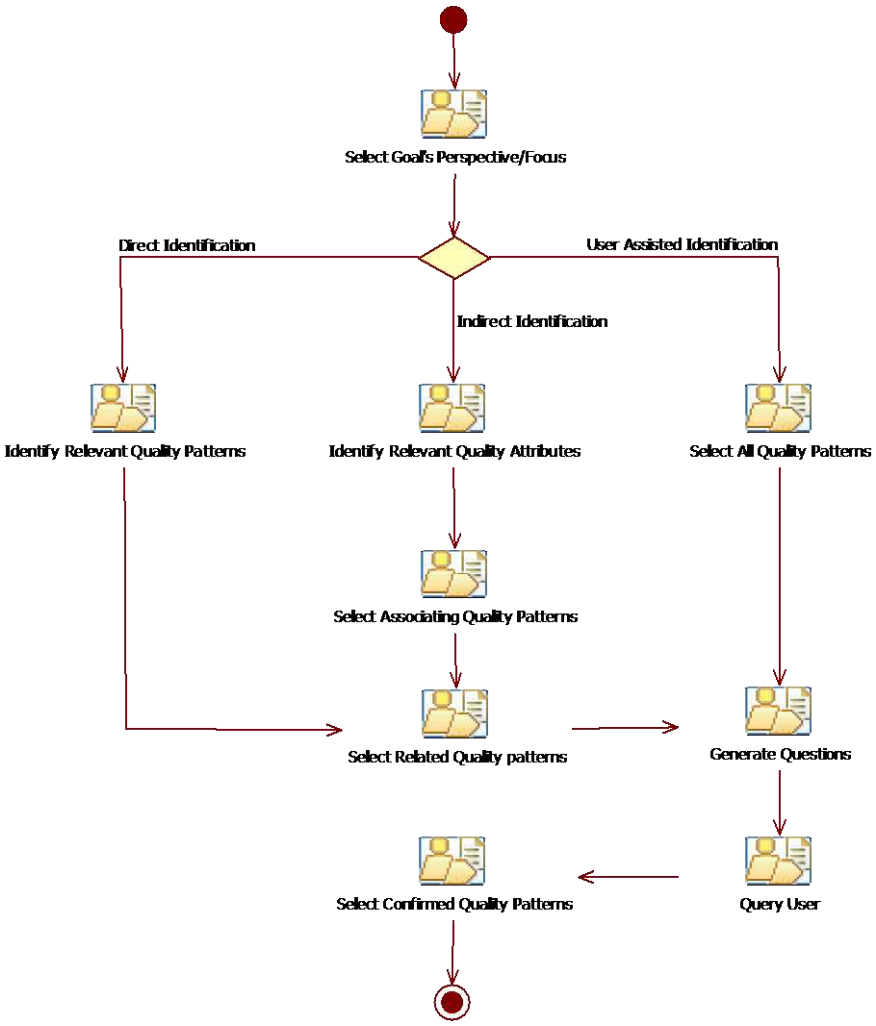


Figure - 22. Process to Identify Quality patterns

4.3.1.2.2 Indirect identification via quality attributes:

i. If no relevant quality patterns are identified then search the relevant quality attributes using the selected perspective/focus (described in the next sub-section).

ii. For all the identified quality attributes, select the quality patterns employing those quality attributes.

iii. Also select all the related quality patterns of the selected quality patterns.

iv. Generate questions regarding every identified and all of their related quality patterns.

4.3.1.2.3 Assisted identification via user:

i. If neither relevant quality patterns nor quality attributes are identified, then generate questions about all the problems solved by all the existing quality patterns and query user.

ii. Identify the relevant quality patterns with respect to users' response to questions.

4.3.1.3 Identifying Quality Attributes

Similar to the identification of quality patterns, there are two ways to identify relevant quality attributes:

i. Direct selection of quality attributes (quality attribute guided). It can only be employed by quality experts as it requires in-depth knowledge about the quality attributes. Quality experts manually select and employ the quality attributes on their discretion for evaluation.

ii. Through the selected quality patterns since quality patterns are linked to quality attributes. Once the relevant quality patterns are identified via the process mentioned in the previous sub-section, different quality attributes are employed by the selected quality patterns for evaluation.

4.3.1.4 Evaluate Quality

As described in the Chapter 3, quality attributes employ multiple metrics for evaluating the quality of the conceptual models. Once quality attributes are identified (following the above mentioned process), the following process (illustrated in Figure - 23) can be employed to evaluate quality:

i. Select all the identified quality attributes.

ii. Select all the associated metrics with respect to the target model type such as class diagram, etc. This includes all types of metrics such as basic/complex or automatable/non-automatable metrics.

iii. Employ the metrics formulae to evaluate desired aspects of quality.

iv. Identify all the relevant recommendations based on measurement results.

v. Present the computed metrics results

vi. Propose recommendations

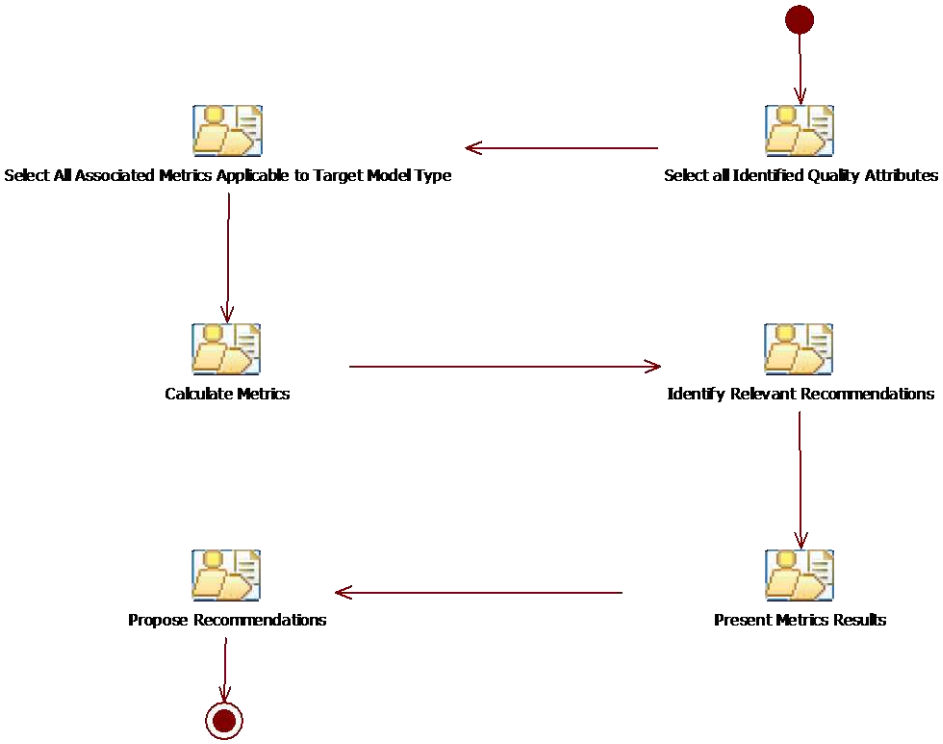


Figure - 23. Quality Evaluation Process

4.3.1.5 Improve Quality

Quality evaluation is only a step to improve quality as it only identifies the problems. However, it's important to find the solution to solve the identified problems. As mentioned in Chapter 3, corrective actions (quality improvement) are the essence of our proposed solution. The last level of our quality aware approach suggests the recommendations for quality improvement. As quality patterns encapsulate both researcher's and practitioner's quality practices thus they provide solutions to recurring problems. Once the metrics are calculated, relevant recommendations are proposed for further improvements through a guided process. These recommendations could be any of the following three types:

i. Textual recommendations

ii. Transformations

iii. Design patterns.

Once the relevant recommendations are identified, the following process can be employed to improve the quality:

i. Follow the guidelines or description provided with all the textual recommendations to improve the model.

ii. For transformations, implement all the steps required to eliminate the identified problems by transforming the initial model into the final model following all the recommended transformations.

iii. Applying recommended design patterns is a manual and difficult process. In order to apply design patterns, we have to manually search the whole model to identify the elements that can be improved by applying those patterns. For example if GRASP's high cohesion pattern is recommended for a model, then we have to manually search for classes lacking cohesion. In order to achieve this goal, we might have to look at the description of the classes, their attributes, methods, etc. to identify the elements hampering cohesion. Similarly for polymorphism design pattern, we have to manually identify the methods that can reduce the complexity by implementing polymorphic functions.

iv. Existing ontologies can also help in implementing the recommendations effectively. For example in Chapter 5, we employ an existing Human Resource Ontology to identify different modules from a complex model in order to implement a recommendation for dividing a complex model.

4.4 Conclusion

In this chapter, we presented our proposed quality driven development process (Q2dP) encompassing methods and techniques to evaluate and improve the conceptual models with respect to a specific analyst/designer requirement or goal. In the first part, we discuss the processes involved in the creation of the quality vision such as the identification of new quality patterns, quality attributes and metrics whereas in the second part, we describe the processes involved in applying our quality vision on the CMs. It includes the processes to formulate analyst/designer specific quality goals (in a structured way), mapping of these goals onto quality patterns, attributes and metrics for evaluation.

The strength of our guided process lies in the fact that every analyst/designer (including experienced and inexperienced) can employ our processes to evaluate and improve the model without any prior knowledge about any evaluation criterion or quality framework.

In the next chapter, we applied our proposed solution and process on a case study to evaluate their efficacy. We executed all the steps of our proposed approach to evaluate and improve the case study CM.

Chapter 5
Case-Study: Goal-Based Evaluation/ Improvement

This chapter applies the quality evaluation and improvement process, discussed in previous chapters, over a conceptual model as a case study. We selected a real world class diagram from an existing Enterprise Resource Planning (ERP) system that was developed for a huge organization in Pakistan. This model is only an extract of the original model on human resource module of that ERP system. The original class diagram (or model) is approximately ten times the size of this model. We selected this class diagram as a case study since we had several difficulties in maintaining the original class diagram due to its complexity and size. Thus we considered testing our approach using this class diagram as the case study. However, we modified the original class diagram and selected only those concepts that are common among different organization and easy to understand. We evaluated this class diagram with respect to a specific goal employing the proposed quality pattern driven evaluation process. The set of proposed metrics, through selected quality patterns, were calculated and all the resulting recommendations were applied on the model. The resulting transformed model was re-evaluated employing the same metrics. Results were compared to highlight the improvements due to the applied evaluation process. The case study is explained in the next section.

5.1 Introduction to the Case Study

The conceptual model (class diagram) for this case study represents information on a human resource management domain. All the concepts represented in this model (Figure - 24) revolve around an organizational employee referred to as “Personnel”. This model is designed for a system capable of managing different aspects of Personnel.

Broadly speaking, this model includes the following type of information:

i. Personnel related information such as name, address, employment date, marital status, etc.

ii. Personnel’s Spouse and children information.

iii. Awards or punishments received by the personnel.

iv. Overtime performed by personnel.

v. Leaves related information such as type and number of authorized leaves.

vi. Bank account information for salary transfer.

vii. Salary related information such as different types of pay scales and their structures, different pay components, etc.

viii. Personnel loan information or advances taken by personnel.

5.2 Formulation of Quality Goal

Consider the following user goal in natural language "check my model if it is complete and easy to understand". In order to better understand this quality goal, we will transform it into the structured goal employing the template proposed by [Basili 93] and described in Section-4.3.1.1. The above mentioned goal is decomposed into fields such as purpose, perspectives, etc. as shown below:

Purpose	to analyze	Conceptual model
	for	Evaluation
Perspective	with respect to	Completeness & Understandability
	from the point of view of	Analyst

The point of view can't be predicted from the goal specified in the natural language. We supposed that the goal was formulated by the Analyst. In any case this information doesn't influence the evaluation process whereas we selected the "purpose for" as "Evaluation" since the goal says "check my model" meaning the analyst is interested in evaluation only.

As demonstrated in Chapter 3, the interpretation of this goal can lead to multiple solutions. Thus to precise the domain of the quality goal, we employ questions. It will help in translating this goal into equivalent sub-goals or concrete statements that can be mapped onto our formulated quality patterns or quality attributes for evaluation and improvement.

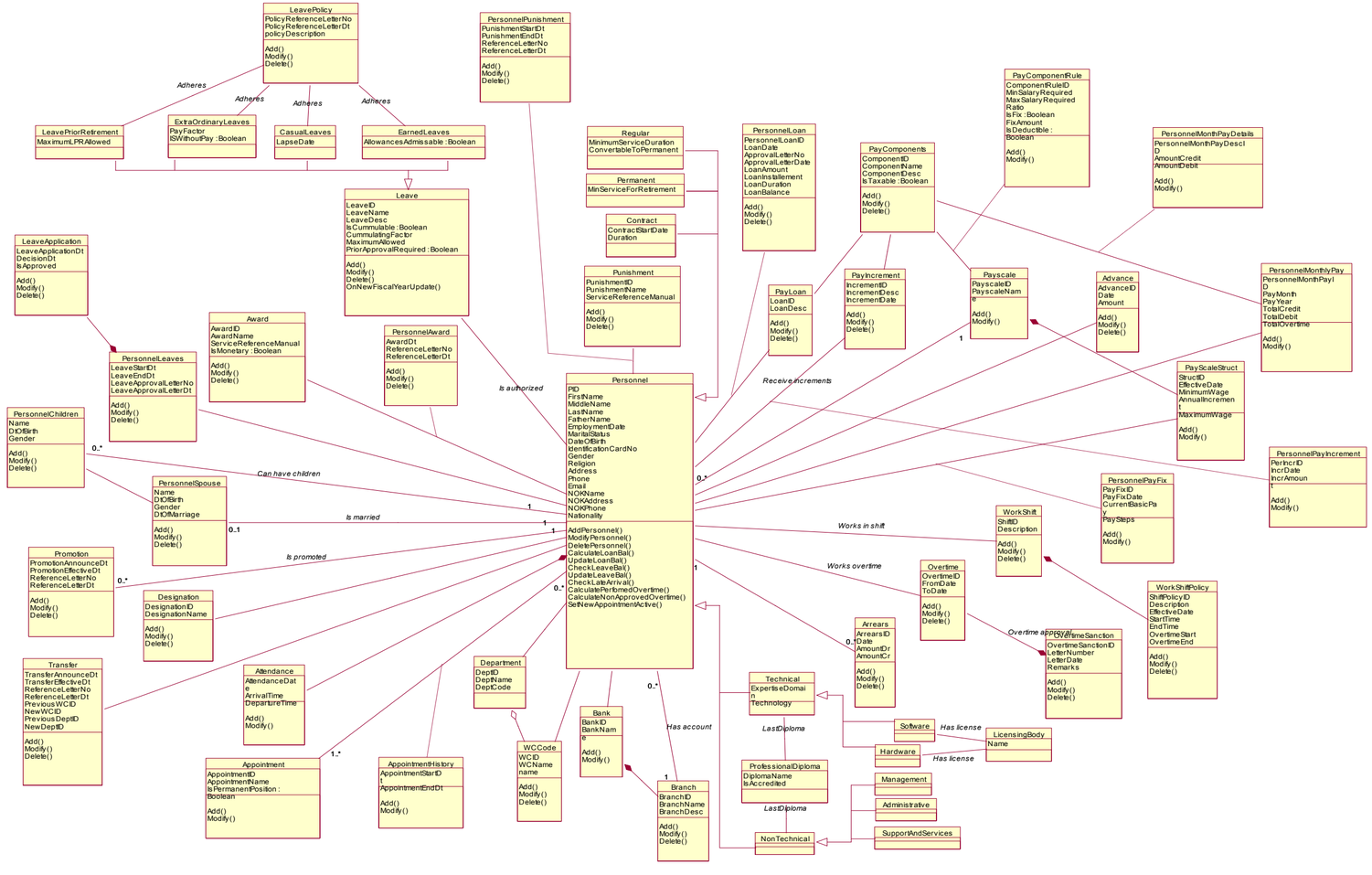


Figure - 24. Model to be evaluated

Following are some of the questions that are generated employing the process described in Section-4.3.1.1.4.

- Q1: is completeness related to syntactic completeness?
- Q2: is completeness related to semantic completeness?
- Q3: is completeness related to requirements coverage?
- Q4: is understandability related to complexity?
- Q5: is understandability related to the absence of documentation?
- Q6: is understandability related to readability difficulties?

Questions 1, 2 and 3 are formulated for completeness whereas questions 4, 5 and 6 are formulated for understandability. For demonstration, we suppose that the user answers the first 4 questions as YES whereas the last two questions as NO. Thus, the domain of evaluation will encompass the directions identified in questions 1, 2, 3 and 4.

5.3 Selection of Relevant Quality Criteria for Formulated Quality Goal

In order to evaluate the case-study, evaluation criteria including quality patterns, quality attributes and metrics should be used. In order to identify the relevant quality criteria with respect to the formulated quality goal and the responses of the asked questions, following steps are performed:

i. Search the perspective/focus of the goal and their related terms (related terms are asked as questions such as completeness is related to syntactic completeness and semantic completeness) in the name, description and keywords of the existing quality patterns to identify the relevant quality patterns. For example, in this case we will search completeness, syntactic completeness, semantic completeness, requirements coverage, understandability and complexity in the above mentioned information of the existing quality patterns to identify the relevant quality patterns.

ii. If no quality pattern is identified then the same set of terms will be used to search through the information contained in the existing quality attributes.

iii. If relevant quality attributes are identified then we will select all the quality patterns that use these quality attributes for evaluation.

The details about searching process are discussed in Section-4.3.1.2. Once the relevant quality patterns are identified, all the associated quality attributes (quality attributes are associated to quality patterns) and their metrics will be selected for evaluation. The mapping process for identifying the relevant quality criteria with respect to the above mentioned quality goal resulted in the identification of the following quality criteria:

5.3.1 Selected Quality Patterns

From the existing quality patterns, the mapping process identified model completeness and model complexity quality patterns to be relevant. Thus these two patterns can be employed to evaluate and improve the given model with respect to the above formulated quality goal. The details about these quality patterns are as follows:

5.3.1.1 Model Completeness Quality Pattern

Pattern Name: Model Completeness

Context:

i. To check if the model is complete with respect to syntactic and semantics. This pattern should be employed to validate and improve the model for its completeness.

Problem:

i. Incomplete conceptual models (CM) pose threats to the later stages of development as they will result in an end system that doesn't provide all the functionalities it was conceived for. So the CM should be evaluated for any missing user requirements.
ii. Similarly, if CM is not syntactically complete then it can hamper the understandability of the model. Syntactic completeness relates to the notation used (e.g. verifying that multiplicities are defined for associations or that associations have a valid name in a class diagram)
iii. Use the completeness quality attribute to identify the exact problem.
iv. The following metrics, associated to complexity quality attribute, can be calculated to check if this pattern is relevant for the current problems of the model (metrics b and c are applicable to class diagrams only):
    a. Requirements Coverage Degree
    b. Degree of defined multiplicities
    c. Degree of named associations

Solution:

i. CM should incorporate all the requirements demanded by users.

ii. CM should contain all the syntactic elements required by the target modeling notation.
iii. Following recommendations can be used for improvement:
a. Incorporate missing requirements
b. Define missing multiplicities
c. Define missing associations labels

Keywords: completeness; syntactic completeness; semantic completeness; requirements coverage;

Related patterns:
i. Model Maintainability (incomplete models need to be modified)

The structure of the completeness quality pattern can be seen from the following Figure - 25. However, this structure is adopted for this case-study alone as it includes only those metrics that are applicable to class diagrams and employed in this case-study for evaluation. For example, completeness quality attribute also contains metrics for ER-diagrams or other conceptual models but are not listed in Figure - 25. The first level contains the name of the pattern, the second level contains the quality attributes employed by the quality pattern, the third level contains the metrics for quantification and the last level contains the recommendations (in the form of textual recommendations, transformations and design patterns).

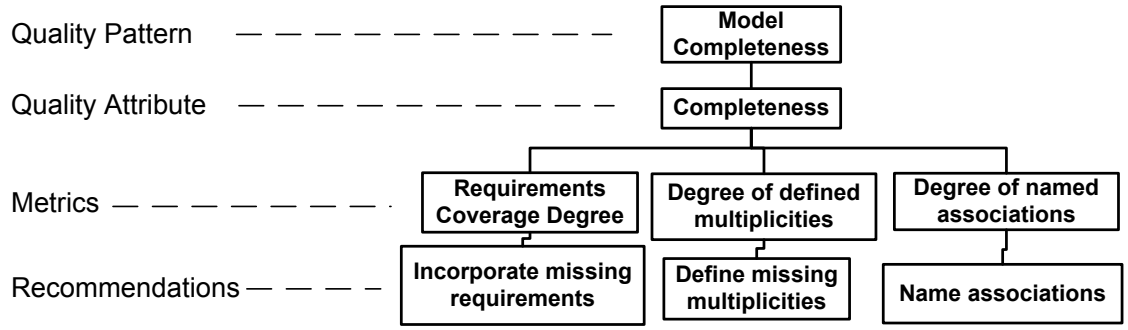


Figure - 25. Structure of Model Completeness Quality Pattern

5.3.1.2 Model Complexity Quality Pattern

The details about model complexity quality pattern can be referred from Section-3.5.4. However, the structure of the complexity quality pattern can be seen from Figure - 26.

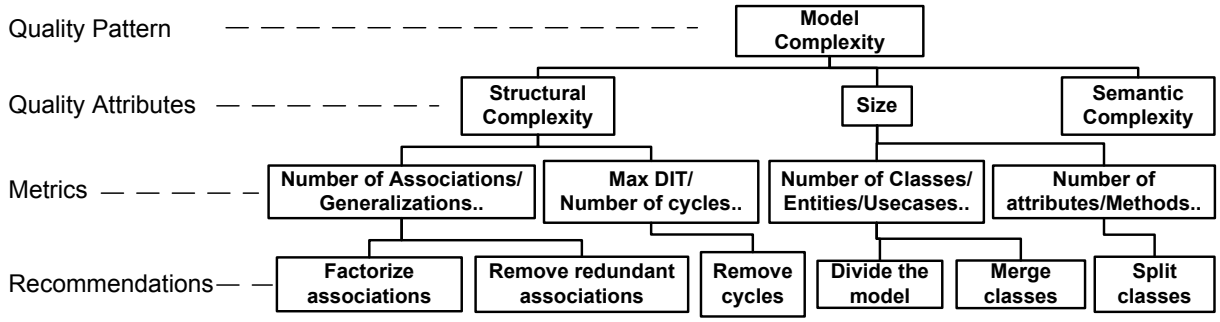


Figure - 26. Structure of Model Complexity Quality Pattern

5.3.2 Associated Quality Attributes for Evaluation Project

The selected complexity and completeness quality patterns employ the following quality attributes for evaluation:

i. Completeness: This quality attribute evaluates the model completeness with respect to both syntactic and semantic completeness. Syntactic completeness relates to the notation used (e.g. verifying that multiplicities are defined for associations in a class diagram). Semantic completeness is related to the coverage of user requirements. It could be verified by checking the conformance between concepts depicted in the conceptual model and the ones expressed by the users through the requirements or even by comparing the concepts appearing in several specifications related to the same reality [Cherfi et al., 2003].

ii. Size: This attribute evaluates the overall complexity of the model with respect to the number of instances of different elements present in the model. It is based on the hypothesis that the more there are structural elements in the model the more it gets complex. These elements can include entities, classes, use cases, actors, attributes, methods, etc.

iii. Structural complexity: This attribute represents the model complexity due to the existence of different relational elements within the model. These elements can include associations, aggregations, generalizations, dependencies, transitions, relationships, etc. This attribute contains several metrics that are proposed in literature and have been tested for their efficacy in representing model complexity and maintainability as shown in [Genero et al., 2002].

iv. Semantic Complexity: In Natural Language Processing, the concept of semantic complexity is related to the number of things to "talk about" in the domain. In our approach, we propose to relate semantic complexity to the variety of "subjects" represented within the same model. Intuitively, a model representing both stock control and clients' accounts information is complex to understand as it refers to two distinct domain subjects.

5.3.3 Associated Quality Metrics for Quantification

The above mentioned quality attributes employ multiple metrics for quantification. Following are some of the metrics that are designed for class diagrams and will be used to evaluate the case study model. However, in case of other types of models (such as ER-models or use cases, etc.), some of the metrics mentioned below might not be applicable and similarly some new or additional metrics can be applied. For example, if we are to evaluate an ER-Model then the metrics such as number of classes, numbers of methods etc are not valid however metrics such as number of entities, number of associations etc can be used.

5.3.3.1 Metrics for Completeness Quality Attribute

i. Requirements Coverage Degree [Cherfi et al., 2003]: This metric is based on the notion of completeness of user requirements. It has been widely accepted that if the requirements errors are detected earlier in the designing phase then the cost of their correction gets much lower. This metric calculates the ratio between the concepts covered by the modeling elements in the conceptual schema and the ones expressed by the users through the requirements.

Let:

X = Number of requirements covered by modeling elements;

Y = Total number of requirements;

Then:

$$\text{Requirements Coverage Degree} = \frac{X}{Y}$$

Range:

Requirements Coverage Degree = 1, if all the requirements expressed by user are covered in the conceptual model.

Requirements Coverage Degree = 0, if none of the requirements expressed by user are covered in the conceptual model.

ii. Degree of defined multiplicities: This metric calculates the ratio between the total number of defined multiplicities within a model to the total number of associations in a model. This metric is described in Section-3.5.2.

iii. Degree of named associations: If proper naming is assigned to every relationship or association then it enhances the understandability of the model. This metric calculates the ratio between the number of named associations and the total associations. This metric is described in Section-3.5.2.

5.3.3.2 Metrics for Size Quality Attribute

Following sets of metrics are proposed in [Assenova et al., 1996], [Genero et al., 2005], [Genero et al., 2003], [Genero et al., 2002], [Genero et al., 2001], [Genero et al., 2000], [Li et al., 1993]:

i. Number of Classes: Total number of classes in a model.

ii. Number of Attributes: Total number of attributes in model.

iii. Number of Methods: Total number of methods or functions in the model.

5.3.3.3 Metrics for Structural Complexity Quality Attribute

Following are the lists of metrics to evaluate the structural complexity of the model. Metrics iii-vii are proposed by [Genero et al., 2005], [Genero et al., 2003], [Genero et al., 2002], [Genero et al., 2001], [Genero et al., 2000]:

i. Number of cycles: Total number of cycles within a model.

ii. Degree of non-redundancy [Cherfi et al., 2002b]: This metric calculates the ratio between the non-redundant concepts and the total concepts present in the model.

Let:

Xi belongs to class, association, inheritance link, association class, aggregation link, composition link;

NB(Xi) = Number of elements of type Xi;

NBR(Xi) = Number of redundant elements of type Xi in the model;

Then:

$$\frac{\sum_{i}\left(NB(Xi) - NBR(Xi)\right)}{\sum_{i} NB(Xi)}$$

Range:

Degree of Non-Redundancy = 1, if the model doesn't contain any redundant concept.

Degree of Non-Redundancy = 0, if the model contains all the concepts that are redundant.

iii. Number of Associations: Total number of associations in a model.

iv. Number of Aggregations: It calculates the number of aggregation relationships within a class diagram.

v. Number of Compositions: It calculates the number of composition relationships within a class diagram.

vi. Number of Generalizations: It calculates the total number of generalization relationships in a model.

vii. Maximum Depth Inheritance Tree: It calculates the longest path from the class to the root of the hierarchy in a generalization hierarchy.

5.3.3.4 Metrics for Semantic Complexity Quality Attribute

To measure semantic complexity, we propose to use domain ontology or a thesaurus. For the given case dealing with Human Resource (HR) management domain, we have used an ontology (attached as Annex-B) extracted from the documentation of the ERP systems (same ERP as mentioned above). This ontology is only an extract of the original ontology used to structure

different concepts of HR management activities. This ontology provides information about different HR areas such as payroll, work time, personnel data, training, skills and competencies, etc.

A thorough and much detailed ontology for HR activities can be created using [OPM 10], [OPM 06] standards and HR-XML vocabularies[4]. But creating an ontology isn't the central point of our thesis. We wanted to demonstrate the feasibility of using existing ontology to improve the model. We propose to measure the semantic complexity as the number of clusters in the model. Thus we relied on the available ontology to identify different clusters from the original model (Figure - 24). Similarly, there are numerous research articles proposing different methods for identifying clusters. We have manually mapped the original model on this ontology to identify different clusters.

5.4 Model Evaluation

The above mentioned selected metrics for this case-study are computed for the original model (Figure - 24). The results are presented in Table - 9. All the metrics employ the computation formulae as defined above. However, in order to calculate the requirement coverage degree metric, we have employed the requirements mentioned in Appendix-D for calculation.

[4] HR-XML Consortium Library, 2007 (http://ns.hr-xml.org/2_5/HR-XML-2_5/index.php)

Table - 9. Computed Metrics for Initial Model

Quality Attribute	Metric	Value
Completeness	Requirements Coverage Degree	0.7
	Degree of defined multiplicities	0.1818
	Degree of named associations	0.5
Size	Number of Classes	46
	Number of Attributes	174
	Number of Methods	120
Structural Complexity	Number of Associations	35
	Number of Association classes	8
	Number of Aggregations	1
	Number of Compositions	6
	Number of Generalizations	14
	Maximum Depth Inheritance Tree	2
	Number of Cycles	7
	Degree of non-redundancy	0.927
Semantic complexity	Number of clusters	2

From Table - 9, we can see that the requirements coverage degree metric is 0.7 since among the set of 10 chosen requirements, following three requirements are not fulfilled in the model (consult Appendix-D for the stated requirements):

i. Software personnel are not further specialized into any of the four sub types (analyst, programmer, tester or documenter).

ii. Hardware personnel are not further specialized to any sub type (network support, hardware maintenance, installations) either.

iii. Requirements states that the leaves are of six types whereas the model classifies the leaves into four types only.

Similarly, only 18% multiplicities are defined and only 50% associations are labeled in the model. Thus, the model is incomplete with respect to all of the three chosen metrics. Furthermore, the size and structural complexity metrics values are very high predicting the inherent complexity of model.

5.5 Post Evaluation Propositions for Quality Improvement

As demonstrated in the Chapter 3, quality patterns propose recommendations for quality improvement. These recommendations are the essence of our proposed solution. Once the metrics are calculated, corresponding corrective actions or transformations can be proposed to optimize the model. Thus, in view of the above metrics results (Table - 9) and their interpretations, the

following recommendations can be applied to improve the model, as proposed by the selected quality patterns:

For improving model completeness:

i. Incorporate missing requirements

ii. Define missing multiplicities

iii. Define missing associations labels

For reducing model complexity:

i. Factorize associations (to remove redundant associations)

ii. Use high cohesion GRASP design pattern (to increase cohesion)

iii. Use polymorphism GRASP design pattern (to increase cohesion)

iv. Divide the model (to reduce semantic complexity)

v. Evaluate all cycles to remove redundant concepts

5.6 Application of Recommendations to the Original Model

All the above mentioned resulting recommendations are applied to the case-study model. The resulting modules (the original model is divided into two independent modules as per the above mentioned recommendation) are placed as Figure - 27 and Figure - 28. The details about how these recommendations are applied to the model are described below.

5.6.1 To Improve Model Completeness

Following recommendations are proposed through the model completeness quality pattern and address the issues related to incomplete models. As recommendations are dependent on metrics, thus some of the recommendations are applicable only to class diagrams. However it must be noted that these are not the only recommendations proposed by the completeness quality pattern. These are the recommendations resulting from to our selection of metrics in the quality pattern.

5.6.1.1 Incorporate missing requirements

Missing requirements pose threats to the success of the developing system. Moreover, it is widely accepted that the earlier identification and the incorporation of the missing requirements reduce the systems correction cost to a greater extent. As we identified that the case-study model was unable to cater three requirements, we incorporated all the missing requirements in the following way.

i. We added four classes (analyst, programmer, tester and documenter) inheriting from the Software class to further classify software personnel into the four sub-types.

ii. Similarly, we added three more classes (network, maintenance and installation) inheriting from the Hardware class to further classify hardware personnel into the required three sub-types.

iii. Requirements state that the leaves are of six types whereas the model classifies the leaves into four types only. Thus we added the missing two types of leaves (Study Leaves and Medical Leaves) as classes inheriting parent Leave class.

5.6.1.2 Define missing multiplicities

Multiplicity defines the number of objects taking part in the relationship. Multiplicities are important to understand the semantics behind the relationship of the related classes. We can notice from the case study model that only 18% of the multiplicities are defined. For example, multiplicities are not defined for the association between *Personnel* class and *WorkShift* class thus the developer will not know if *Personnel* are allowed to work in multiple shifts. We identified the correct multiplicities for this association in the transformed model (Figure - 27) and now developer can see that *Personnel* can work in one and only one work shift. Similarly, we define all the unidentified multiplicities for all the associations.

5.6.1.3 Define missing associations labels

Proper and expressive association names enhance the understandability of the model. These names tend to help the reader in understanding the nature/type of association between the associated classes. In the case-study model, only 50% of the associations are named. For example, the association between *Personnel* class and *Transfer* class is not named thus the reader of the model might not understand the description of this association. He/she can't identify what *Personnel* can transfer or what is transferred? We identified the proper name for this association in the transformed model (Figure - 27) and now reader can understand that *Personnel* can be transferred to other work centers. Thus it is clear now that personnel are the ones who are transferred rather than personnel transferring something or someone. Similarly, we defined expressive names for all the associations.

5.6.2 Improve Model Complexity

Model complexity quality pattern proposed the following recommendations to elevate the complexity and address its inherent factors in conceptual models. These recommendations are

adopted for our case-study model and thus most of them are applicable to class diagrams only with an exception of "Divide the model" recommendation that can be applied to other models as well. As mentioned above, the listed recommendations are not the only recommendations proposed by the complexity quality pattern. These are the recommendations resulting due to our selection of metrics from this quality pattern with respect to our case-study model.

5.6.2.1 Factorize associations (to remove redundant associations)

In any conceptual model, redundant concepts increase the complexity and waste resources. Similarly, redundant associations increase the structural complexity of the models and thus they must be identified and removed from the model. There are number of ways to identify redundant associations. The simplest one is to identify the association having same name. For example, in the case-study model we can see that two associations have the same name "Has License" and we can also notice that this set of associations can be reduced to one single association if we move this association to the parent class. In this case, we can see that both children of "Technical" class have this association thus if we move this association to the parent class (Technical) then both children will participate to the association due to inheritance whereas the redundant concept will be eliminated. We performed the same operation with another association named "Last Diploma" as it was also redundant.

5.6.2.2 High Cohesion GRASP design pattern (to increase cohesion)

As demonstrated in Chapter 3, quality patterns propose three types of recommendations including the recommendations to employ proposed design patterns for improving the model quality. However, employing design patterns for model improvement is a manual process. In response to complexity in our case-study model, the model complexity quality pattern proposed to employ high cohesion pattern to reduce model complexity. Thus in order to identify the model elements where this design pattern can be applied, we scanned the complete case-study model and found that "Personnel" class contains 8 methods that this class shouldn't be responsible for. Such as, it contains "CalculatePerfomedOvertime" and "CalculateNonApprovedOvertime" methods that should be implemented in "Overtime" class rather than "Personnel" class. Thus, by delegating the responsibilities to proper classes, we can reduce the complexity of the source class.

5.6.2.3 Polymorphism GRASP design pattern (to increase cohesion)

Similarly in order to apply the recommended polymorphism design pattern, we scanned the model to identify the elements where this design pattern can be applied. For example, we found that "Leave" class implements a method "OnNewFiscalYearUpdate" that updates the leaves on

every new fiscal year. However, some leaves can be cumulated (annually) whereas some cannot (lapse on yearend) such as casual leaves can't be cumulated. Thus, if we implement this method within the super class "Leave" then we will increase the complexity of this method by including multiple checking criteria for each type of leaves. However, it would be much feasible in this case to use GRASP's polymorphism pattern (as proposed through our approach) and implement this method within each type of leave to reduce the complexity.

5.6.2.4 Divide the model (to reduce semantic complexity)

We employed HR ontology (Annex-B) and identified that the original model contains elements to manage personnel and elements to generate pay. Thus, in order to reduce the complexity, we divided the initial model into two modules: Personnel and Pay. For example, the classes such as *Spouse, Children, Designation, Transfer, Attendance, Appointment* etc are clearly related to Personnel and thus are placed in Personnel module whereas the classes such as *Payscale, PayscaleStruct, PayLoan, PersonnelMonthlyPay, Advance* etc are related to pay generation and thus are placed in Pay module. Moreover, the classes such as *Overtime, Punishment, Awards, etc.* are also placed in Pay module as all of these classes affect the generation of pay. For example, if personnel works overtime then he/she will receive additional salary similarly if personnel receive a punishment (let say 20% deduction in salary) then he will receive 20 % less pay. By including related classes to the relevant module will cohesion and reduce the coupling among modules. If classes such as *Overtime, Punishment, Awards, etc.* were placed in Personnel module then every time a pay is generated, these classes were used by the Pay module and thus the dependency of Pay module on Personnel module would increase.

The two newly formulated modules are depicted as Figure - 27 and Figure - 28. All the metrics are recalculated for both the modules and the new values are listed as Table - 10. However, it must be noted here that if we could find a more comprehensive ontology then perhaps additional semantic groups could be identified.

The Following guidelines, as proposed through our approach, were employed for model division:

i. The model division can be done in two ways: Structural Division and Semantic Division

ii. The structural division is an easier but non-efficient method. Randomly select the model elements and divide them into multiple modules. But bad selection of elements can lead to low cohesion and high coupling among the resulting modules.

iii. The semantic division is a difficult but efficient method. Read the model carefully (or use some existing domain ontology) and classify the model elements with respect to some similarity or relationship. For example, classify the elements with respect to common functionality or interdependency. The elements with common set of goals or functionalities should be grouped together as a module. Such a division will increase the cohesion and reduce the coupling. Similarly, an existing ontology can be used to identify different semantic groups.

iv. Another possible type of division is to identify the complex parts of the model and to divide them into multiple modules to reduce the complexity.

5.6.2.5 Evaluate all cycles to remove redundant concepts

In conceptual modeling, existence of cycles signifies that information is duplicated. In class diagrams, sometimes cycles are inevitable whereas sometimes it's just a design error. So whenever there are cycles in the class diagram they should be revisited to check weather some redundant information exists and if yes then it can be eliminated. For example, in our case-study model we can identify a cycle between "Personnel", "Bank" and "Branch" classes. However we can notice that all branches are associated to banks, thus if a personnel is attached to a branch then we can identify the bank of that branch through the association between "Bank" and "Branch" classes and thus we don't require the association between the "Personnel" and "Bank" classes and so we deleted this association. Similarly we also deleted the association between the "PersonnelSpouse" class and "PersonnelChildren" class.

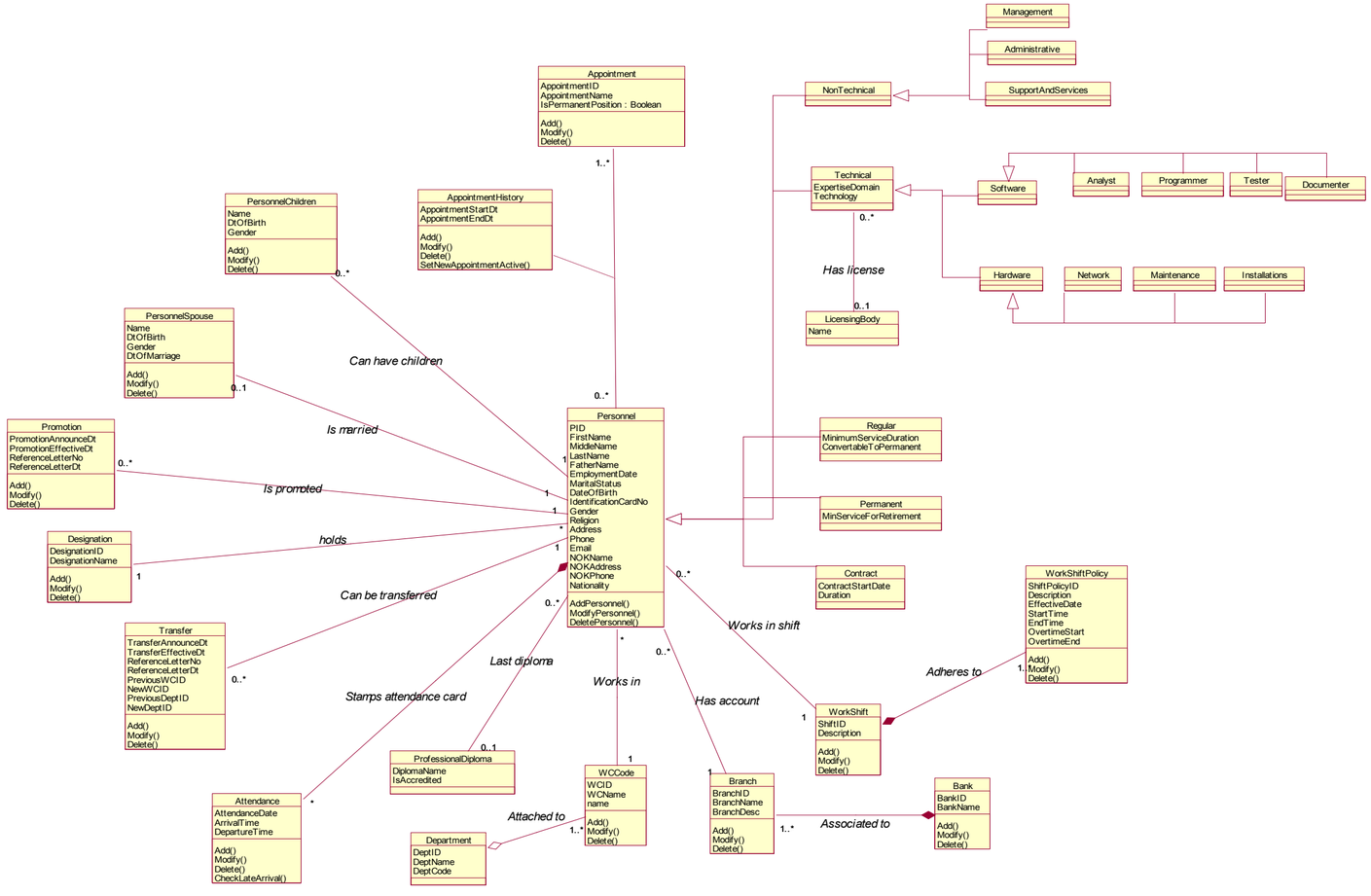


Figure - 27. Post Transformation Resulting Module for Personnel

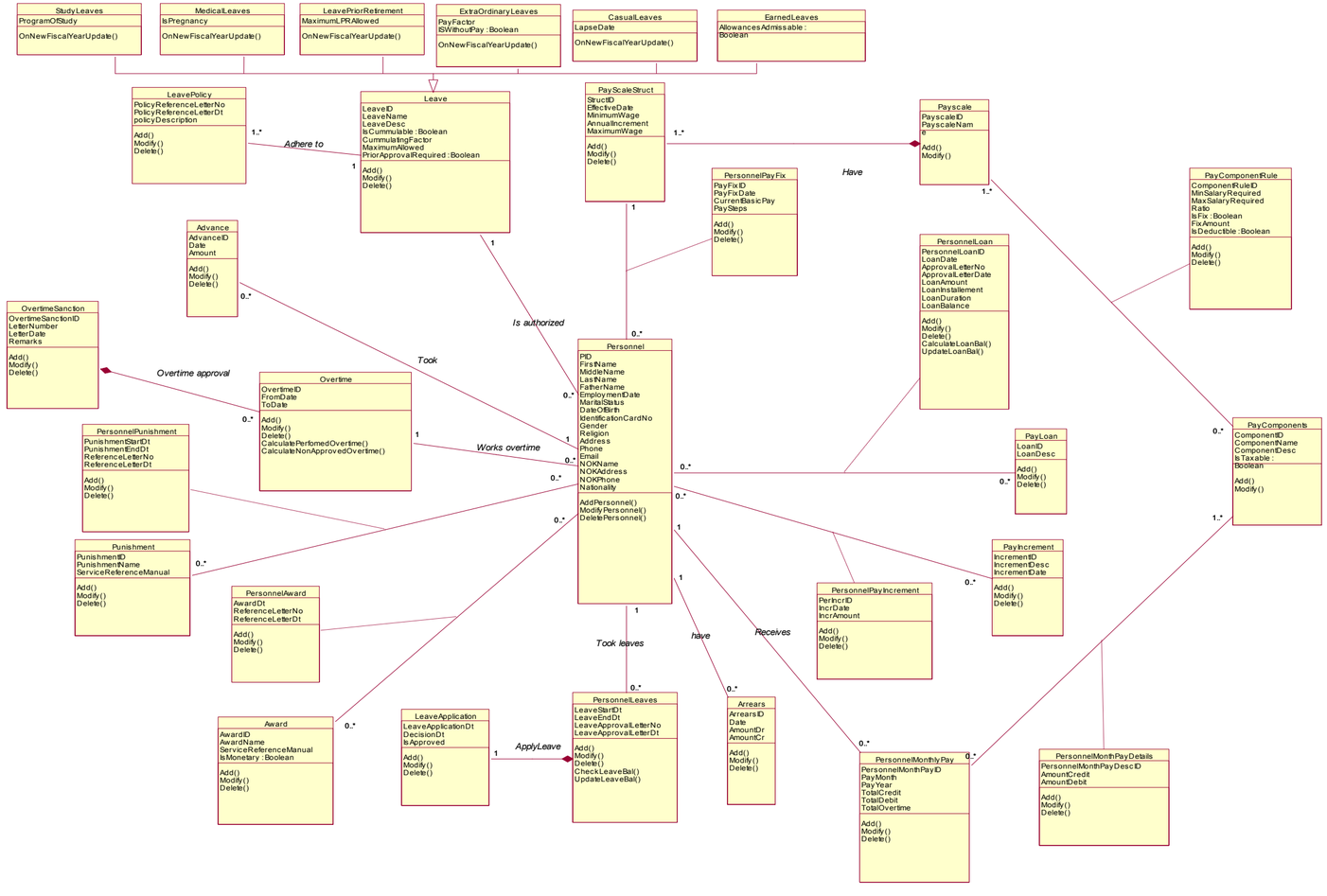


Figure - 28. Post Transformation Resulting Module for PayRe-evaluation of the Transformed Model

Once all the recommendations are applied to the original case-study model, the same set of metrics is recalculated to demonstrate the improvement due to our proposed quality evaluation and improvement process. The results are placed in Table - 10.

Table - 10. Post transformation metrics result

Quality Attribute	Metric	Original Model	Post transformation modules	
			Personnel Module	Pay Module
Completeness	Requirements Coverage Degree	0.7	1	1
	Degree of defined multiplicities	0.18	1	1
	Degree of named associations	0.5	1	1
Size	No. of Classes	46	33	23
	No. of Attributes	174	77	117
	No. of Methods	120	44	84
Structural Complexity	No. of Association	35	11	14
	No. of Association classes	8	1	7
	No. of Aggregation	1	1	0
	No. of Composition	6	3	3
	No. of Generalizations	14	17	6
	Maximum DIT	2	3	1
	No. of Cycles	7	0	1
	Degree of non-redundancy	0.93	1	1
Semantic complexity	Number of clusters	2	1	1

From Table - 10, we can see that the *requirements coverage degree* metric was "0.7" in the original model whereas it is "1" in the transformed models meaning that all the missing requirements are covered in the transformed models. Similarly, *degree of defined multiplicities* and *degree of named associations* metrics are equal to "1" as well signifying that all the multiplicities are identified and all the associations are named in the transformed models.

We can also compare that all the metrics (except *number of generalizations metric*) associated to the size and structural complexity quality attributes such as number of classes, number of attributes, number of associations, etc. have significantly low values compared to the original model implying that the transformed models are comparatively less complex as compared to the original model.

The value of the *Number of generalizations metric* is higher in the transformed model as the original model failed to divide the software personnel and hardware personnel into sub types. Similarly the original model classified the leaves into four types whereas the requirements states

that the leaves are of six types. Thus after incorporating these missing requirements, the *number of generalizations* increased in the transformed model.

5.7 Conclusion

In this chapter, we applied our proposed solution and processes on a real world model as a case study to evaluate their efficacy. We took a class diagram of a Human Resource (HR) system for evaluation and improvement with respect to a quality goal. We identified the relevant quality patterns and attributes with respect to the formulated goal. All the metrics were calculated; recommendations were generated and applied to the original model. The resulting transformed models were re-evaluated to check if the proposed recommendations actually improved the model or not. In the end, the initial results were compared with the post-transformation results. We identified that the transformed models have significantly better metrics results than the original models suggesting that the proposed approach has helped in improving the original model.

In the next chapter, we present our software prototype "CM-Quality" that implements our proposed solution and processes. We discuss the architecture of the prototype along with different interfaces available in *CM-Quality*.

Chapter 6
CM-Quality: Software Prototype Implementing the Proposed Approach

We designed and developed a prototype, ***"CM-Quality",*** which implements our quality approach. This implementation has two core objectives. It first helps in demonstrating the feasibility of the approach. The second objective is related to the validation of the approach as we made the prototype available to students, researchers, and practitioners to collect their feedbacks.

CM-Quality integrates an independent software tool, Qualis [Kersulec et al., 2009] to use the services related to metrics definition and calculation. CM-Quality has an import functionality based on XML allowing the evaluation of quality of IS specifications generated by existing commercial and open source CASE tools (Rational Rose, Objecteering, StarUML etc).

6.1 General Architecture

Figure - 29 illustrates the general architecture of the solution. CM-Quality is able to accept conceptual models designed using any modeling tool such as Rational Rose, Objecteering, etc. However, these models must be exported into OMG's XMI standard format. CM-Quality is capable of accepting models in XMI version 1.x and 2.0 formats. It is important to mention here that XMI contains all the model elements and their association information. However, XMI doesn't contain information about the graphical objects and their graphical position in the file. This leads to two issues:

i. We can't evaluate model based on graphical objects or their placement. For example, we can't calculate the *number of line crossings* metrics using models in XMI file as this information is not available in XMI.

ii. If XMI file is exported back to respective model file for a target modeling software such as Rational Rose, then the model will appear in a bad aesthetic form as modeling software will tend to place the objects randomly on the screen since no positioning information is contained in XMI.

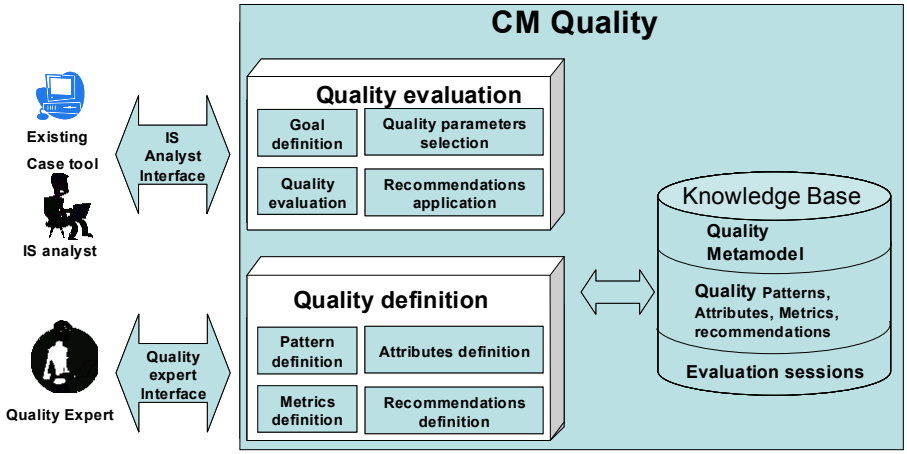


Figure - 29.General architecture of the solution

CM-Quality is conceived for two types of users Quality Expert and Analyst. Quality expert is a user having in depth knowledge about quality concepts. He is responsible for defining the quality concepts such as quality patterns, attributes, metrics, etc. and their relationships with each other in CM-Quality. In contrast the IS analyst is a normal user who is familiar with modeling notations and is responsible for designing different conceptual models. Analysts can only evaluate the models employing the quality concepts defined by quality expert.

CM-Quality contains a knowledgebase storing different quality concepts such as quality patterns, attributes, metrics, etc. defined by quality experts. Moreover, the knowledgebase also stores the evaluation sessions. CM-Quality's knowledgebase uses multiple XML file that collectively act as database repository.

CM-Quality applies the selected quality concepts stored in the knowledgebase on the target model for evaluation and furnish evaluation results along with recommendations for improvement as an output report.

6.1.1 Functional View for Quality Expert

CM-Quality is conceived for two types of user: Quality Experts and IS Analysts. Figure - 30 illustrates the systems behavior with respect to quality expert. It can be noticed that quality experts interact with CM-Quality with an aim to define the quality concepts in the following way:

i. To add, remove or modify quality patterns

ii. To add, remove or modify quality attributes

iii. To add, remove or modify metrics

iv. To add, remove or modify recommendations

v. To define or delete associations between quality patterns and quality attributes. This requires that both quality patterns and quality attributes are already defined.

vi. To define or delete associations between quality attributes and metrics. This requires that both quality attributes and metrics already exist.

vii. To define or delete associations between metrics and recommendations. This requires that both metrics and recommendations are already defined.

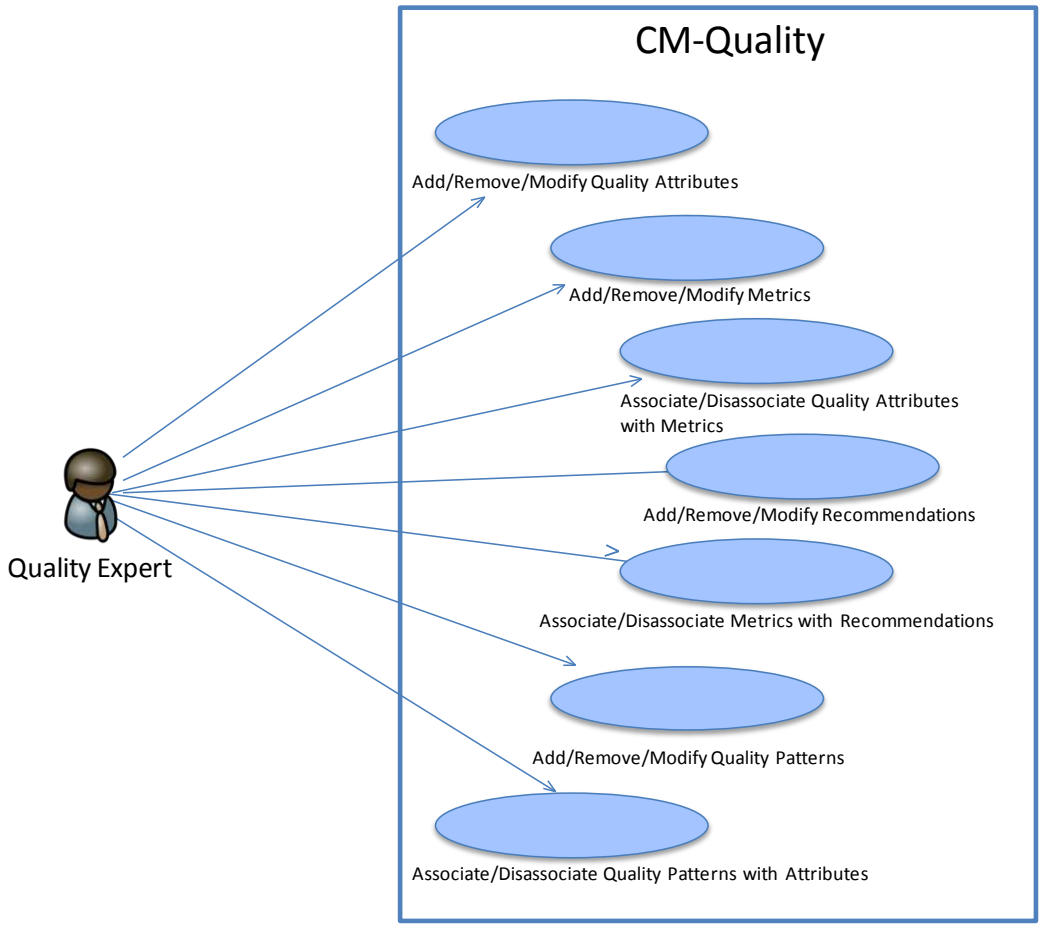


Figure - 30. Use Case Diagram: Define the Quality Concepts

6.1.2 Functional View for Analyst/User

Figure - 31 illustrates the use case diagram to evaluate quality. This use case describes the systems behavior with respect to IS Analyst. It can be noticed that analysts interact with CM-Quality to evaluate and improve their models. Their interactions include the following:

i. They use CM-Quality to select the target model for evaluation.

ii. They can browse existing quality goals to evaluate the model with respect to this goal thus bypassing the automatic detection and selection of relevant quality concepts.

iii. Formulate new quality goals in a structured way

iv. Select the relevant quality patterns for evaluation

v. Select the quality attributes

vi. Select the metrics for measurement

vii. They can execute the evaluation process on the selected model. This implies that the system evaluates the model by computing the selected metrics and then presents the evaluation results along with relevant recommendations for improvement.

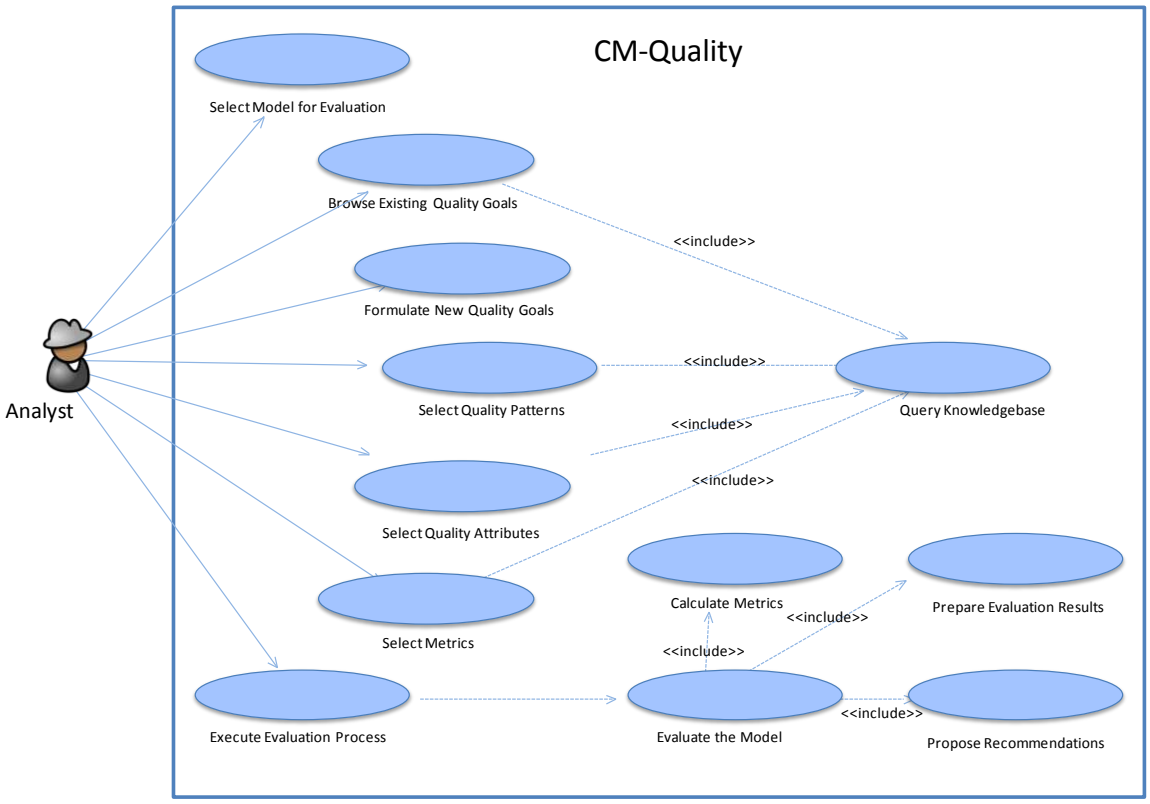


Figure - 31. Use Case Diagram: Evaluate the Quality

6.2 Detailed Architecture

CM-Quality is divided into two core modules for two types of users: quality experts and IS analysts. The quality expert is responsible for defining and managing quality concepts such as quality patterns, attributes, metrics, etc. through a quality driven methodology whereas the IS analyst applies these concepts for evaluating the conceptual models. The quality expert is also responsible for establishing the relationships among these quality concepts. For example, the quality expert identifies the quality attributes employed by each quality pattern. Similarly, he/she also associates the relevant metrics for measuring these quality attributes.

The quality expert can also evaluate the models but IS analysts can't define or manage the quality concepts due to their lack of knowledge. The two modules access a common knowledgebase Figure - 29.

6.2.1 The quality definition module

The *quality definition module* in CM-Quality is responsible for defining the "house-keeping" information such as quality concepts including quality patterns, attributes, metrics and

recommendations. This module is also responsible for establishing the relationships among different concepts. For example, the association between quality patterns and quality attributes is defined through this model. This module is available only to quality expert users as identification of erroneous quality concepts may lead to misleading evaluation results. This module incorporates four different utilities to define quality patterns, quality attributes, metrics and recommendations.

6.2.1.1 Pattern definition tool

Pattern definition tool implements the quality pattern identification process described in Section-4.3.1.2 to guide the quality expert in defining new quality patterns. The quality pattern identification is a difficult and time consuming task. However the scope of this tool doesn't incorporate the identification of quality patterns but merely their definition to CM-Quality. The quality experts are provided with editors helping the patterns definition according to the pattern definition structure defined in Chapter 3.

This tool is also the means for linking quality patterns with relevant and existing quality attributes for evaluation.

6.2.1.2 Attribute definition tool

The *attribute definition tool* includes a rich set of predefined quality attributes with their definition and reference to the literature. It also offers the possibility to add new attributes in a guided and structured way using the specialized interface in CM-Quality. This tool is also responsible for associating quality attributes with relevant and existing metrics for their measurement. It is important to mention here that quality attributes are generic for all types of conceptual models whereas most of the metrics are dependent on model types (such as class diagrams, etc.) and model elements (such as classes, attributes, etc.). Thus in order to measure quality attributes, all the relevant metrics for all model types must be associated with it else the attribute will be limited to certain model types for which metrics exist.

6.2.1.3 Metric definition tool

The *metric definition tool* is a complete and complex set of utilities providing both a language and a set of editors for metrics definition. This tool provides a GUI based approach for defining new metrics to measure every possible criterion that is based on the model elements of different models types. For example, this tool can be used to define a metric for calculating the number of classes in a class diagram. Similarly, the same tool is capable of defining complex metrics such as to calculate the cohesion in a model. This tool also provides the expert with a set of predefined quality metrics that could be browsed and modified.

6.2.1.4 Recommendation definition tool

R*ecommendation definition tool* allows the definition of recommendations in CM-Quality for model improvement. Similarly, this tool is also responsible for associating recommendations with metrics as these recommendations are proposed according to a given quality threshold of metrics. These recommendations correspond to best practices extracted from literature or proposed by quality experts.

6.2.2 The quality evaluation module

This module provides an IS analyst with a set of utilities for quality evaluation and improvement. It implements the quality driven process presented in Chapter 4. This module performs the following tasks through different utilities:

i. It helps the analysts in formulating their quality goal.

ii. It helps in identifying the relevant quality concepts (quality patterns and attributes) for model evaluation with respect to the formulated quality goal.

iii. It performs the evaluation by measuring different metrics associated to the selected quality concepts.

iv. It proposes the recommendations for model improvement.

6.2.2.1 Quality Parameters Selection Tool

The *quality parameters selection* tool initializes the quality evaluation session. This initialization includes the following:

i. The information about the modeling notation used (ER, UML, etc.).

ii. The specification to evaluate (class diagram, ER diagram, etc.).

iii. The selection of the target model in XMI standard.

iv. The validation of the selected XMI file with respect to OMG's specifications.

6.2.2.2 Goal Definition Tool

The *goal definition tool* enables the IS analysts to formulate their quality goal with least amount of effort following the standardized process illustrated in Chapter 4. This tool implements the goal template proposed by [Basili 93] to formulate a structured goal in order to enhance its understandability and to reduce the vagueness characterizing natural language.

6.2.2.3 Quality Evaluation Tool

The *quality evaluation tool* offers three main functionalities:

i. Identification of goal's domain through generated questions.

ii. Identification of relevant quality criteria.

iii. Quality evaluation.

Quality evaluation tool identifies the relevant quality concepts (quality patterns and attributes) and generates a list of questions to map the analysts' perception of formulated goal to the *Quality evaluation tool's* perception. This identification uses text matching techniques based on the goal expression and quality patterns components such as key words, context description, related patterns, etc.

Based on the responses to the questions, relevant quality patterns and attributes will be proposed to the analysts. *Quality evaluation tool* helps the analysts in selection of the appropriate quality patterns, quality attributes and metrics from the automatically proposed concepts for evaluation. After the selection, *Quality evaluation tool* evaluates the model by computing the selected metrics.

6.2.2.4 Quality Improvement Tool

Finally, based on the obtained quality values, the *quality improvement tool* proposes quality improvement advices in the form of recommendations. In the current version, this module does not automatically apply the proposed transformation rules associated to the recommendations.

6.2.3 The knowledgebase structure

Figure - 32 illustrates that *CM-Quality's* knowledgebase is composed of three abstraction levels. The highest level contains the quality meta-model implementation. The intermediate level is dedicated to quality concepts defined by the quality expert. It contains the quality attributes, metrics and recommendations created through CM-Quality. Finally, the lowest level stores the results of the evaluation sessions.

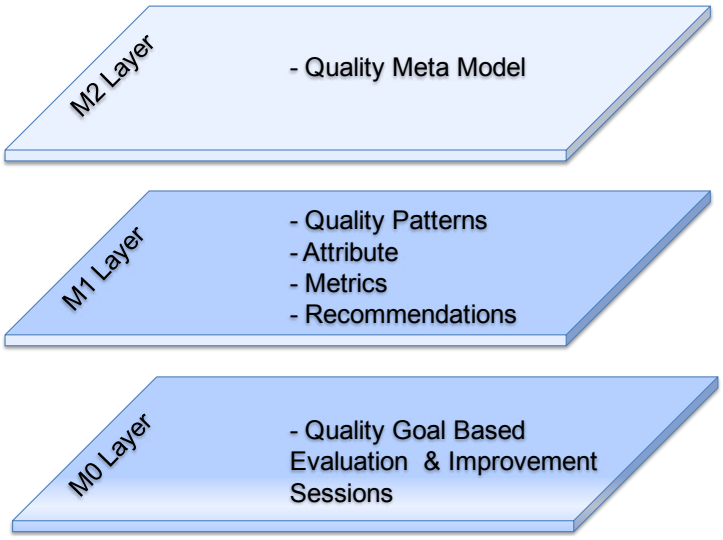


Figure - 32. Knowledgebase Structure

CM-Quality's knowledgebase is implemented using independent XML files. However, these files act as a database management system and reduce the deployment efforts due to their reduced dependencies.

6.2.4 Package Diagram

Functionalities in *CM-Quality* are divided into seven packages. The package diagram in Figure - 33 illustrates the different packages and interactions between the packages. Different functionalities of the prototype are grouped into different packages. For example, the *Quality Evaluator Package* encapsulates all the classes responsible for evaluating the conceptual model. Similarly, the *Quality Improver Package* encapsulates the classes responsible for model improvement.

As *CM-Quality* incorporates an existing prototype *Qualis* [Kersulec et al., 2009] for defining and calculating metrics, therefore this package diagram also includes the functionalities of this incorporated prototype. For example, the *Quality Evaluator Package* evaluates the CM by calculating different metrics. This metric calculation functionality was originally implemented in [Kersulec et al., 2009] and is part of our *Quality Evaluator Package* in addition to other functionalities. In the following sub-sections, we define the responsibilities of each package designed in CM-Quality.

6.2.4.1 CM Quality Core

CM Quality Core is the main package responsible for managing all other packages. It implements the main functions and employs all other packages to perform the desired operations. For example, this package calls the routines implemented in *Interface Manager Package* to design the different types of interfaces and to incorporate different types of validation on user input fields. Similarly, this package employs *XMI Parser Package* to extract the model information from the exported XMI files and uses this information to evaluate the model employing the functions implemented in *Quality Evaluator Package*. However, it is important to mention here that packages, other than *CM Quality Core Package*, can't access the functionalities of other packages directly. Every package is designed in such a way that they work as an independent entity and *CM Quality Core Package* manages all the access. In the above example, *CM Quality Core Package* employs *XMI Parser Package* to extract the model information and then send this information to *Quality Evaluator Package* for evaluation. Briefly speaking, this package functions as the central unit and delegates responsibilities to the concerned packages and controls the overall system.

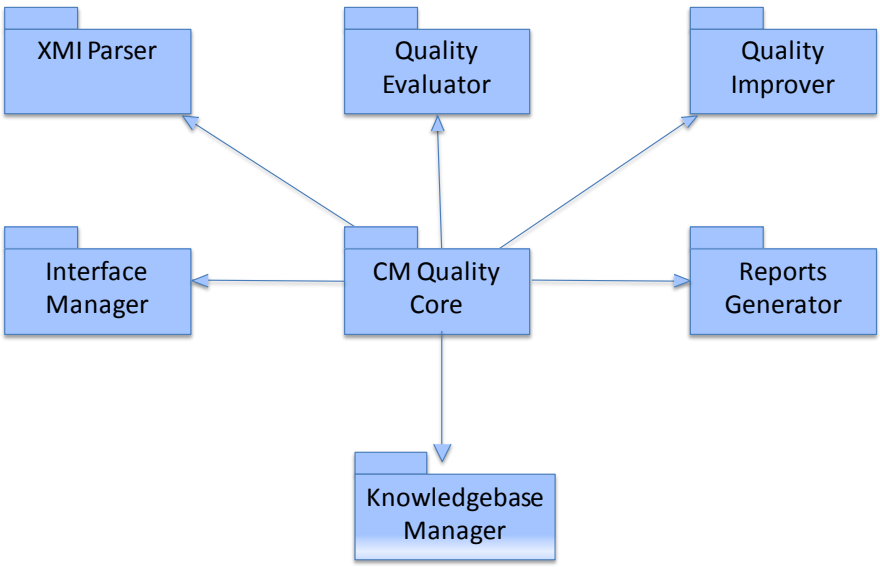


Figure - 33. CM-Quality Package Diagram

6.2.4.2 XMI Parser

As mentioned before, *CM-Quality* incorporates an existing prototype *Qualis* that was capable of defining and calculating metrics on models exported in XMI format. *XMI Parser Package*

offers these functionalities, implemented in *Qualis,* for parsing the XMI models in order to extract different information about the models. This information is used to calculate different metrics through the functionalities implemented in *Quality Evaluator Package* and to generate relevant improvement strategy employing the classes in the *Quality Improver Package*.

6.2.4.3 Interface Manager

Interface Manager Package encapsulates all the classes required to generate and manage different types of interface components for *CM-Quality*. For example, this package includes the classes to manage different tables in *CM-Quality* such as it manages how to bind data to different columns in a table or how table should be formatted, etc. This package also incorporates the different validation functions employed by *CM-Quality* for on-form verification of user inputs. For example, it ensures that the numeric values are not entered in the non-numeric fields.

6.2.4.4 Knowledgebase Manager

In *CM-Quality*, we have not used the traditional Database Management System (DBMS) for storing the knowledgebase contents due to deployment and licensing issues while portability. However, we have used multiple XML files to store the knowledgebase contents. Thus, manipulating knowledgebase contents from multiple XML files requires a sort of DBMS. *XML DB Manager Package* encapsulates all the functionalities that helps in manipulating the data stored in XML. This package also includes the functions to parse and execute different queries including complex ones with multiple joins.

6.2.4.5 Quality Evaluator

Quality Evaluator Package is of high importance in *CM-Quality* as this package encapsulates all the classes responsible to evaluate conceptual models. This package is responsible for formulating the quality goal, identification of relevant quality criteria (quality patterns, attributes and metrics) through sophisticated and efficient searching process (described later) and calculation of all the relevant metrics. It is important to mention here that metric calculation functionalities were originally implemented in *Qualis* but after integration they are included in this package.

6.2.4.6 Quality Improver

Quality Improver Package encapsulates all the functionalities responsible for generating relevant recommendations with respect to measured metrics results. These recommendations

include textual recommendations, transformations and proposed design patterns as described in Section-3.5.3.

6.2.4.7 Reports Generator

CM-Quality can be regarded as the only model evaluation software that provides proper printable reports, in the form of Portable Document Format (PDF), incorporating both quality evaluation results and improvement recommendations. *Reports Generator Package* encapsulates all the classes required to generate PDF files from XML result set. These classes include functions to design the report layout. *CM-Quality* employs Java API for XML Processing (JAXP) and Formatting Objects Processor (FOP) for generating the PDF reports. Thus, *Reports Generator Package* includes functions to generate reports using JAXP and FOP.

6.3 Quality Definition in CM-Quality

CM-Quality is a user-friendly tool aiming to implement the quality evaluation approach described in Chapter 3. As depicted in the meta-model (Figure - 7), quality patterns are formulated by using the existing quality attributes in the knowledgebase. Quality patterns serve as guidelines helping IS analysts (naïve or expert) to achieve a quality goal.

CM-Quality offers two interfaces; the first one, dedicated to quality experts aims to maintain and enrich the knowledgebase content. Whereas the second, dedicated to quality evaluation and improvement by IS analysts, attempts to match a quality goal with the quality patterns and/or quality attributes stored in the knowledgebase.

6.3.1 Quality pattern definition

As described in Chapter 3, defining a new quality pattern needs to answer the following three questions:

i. What is the context of the quality pattern or when can this pattern be used?

ii. What is the problem that this pattern can solve?

iii. How can this pattern solve the problem?

Once the quality expert answered the three questions, he/she can use the *Quality Pattern interface* (Figure - 34) to add a new quality pattern to the knowledgebase. The screen follows the process described in Section-4.2.1. Similarly, the same interface can be used to edit or delete the quality patterns from the knowledgebase. The Information defined through this interface is required to formulate the body of the quality pattern. As mentioned in the preceding chapter, a

quality pattern can be related to other predefined quality patterns. These related patterns help in identifying and elaborating the domain of the defined quality goal (details are discussed in the Section-6.4) and can be added using the button on the *Quality Pattern Screen* (Figure - 34).

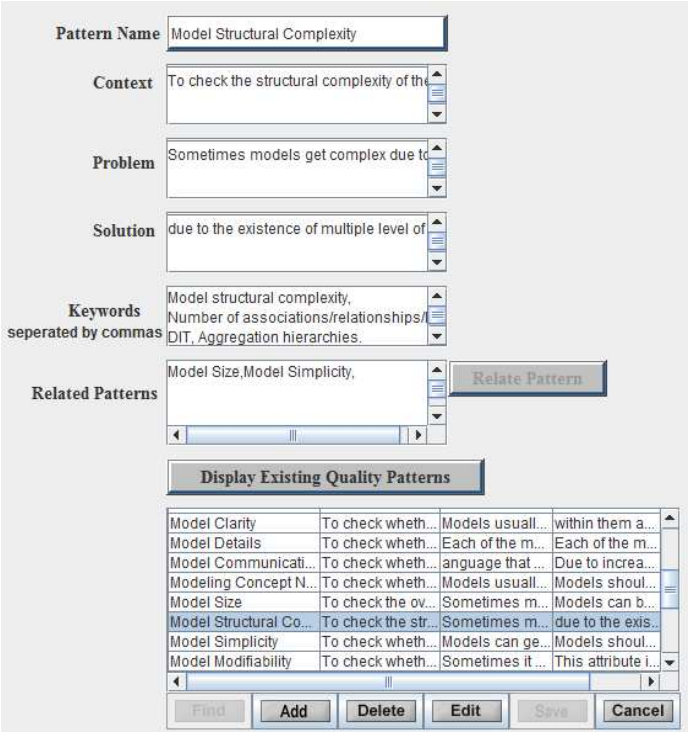


Figure - 34. CM-Quality Screen: Managing quality patterns

Once the quality pattern is added to the knowledgebase, corresponding or related quality attributes can be associated to it from the knowledgebase. The knowledgebase contains numerous quality attributes that are ready to use. Figure - 35 shows the association screen responsible for associating quality patterns with the existing quality attributes.

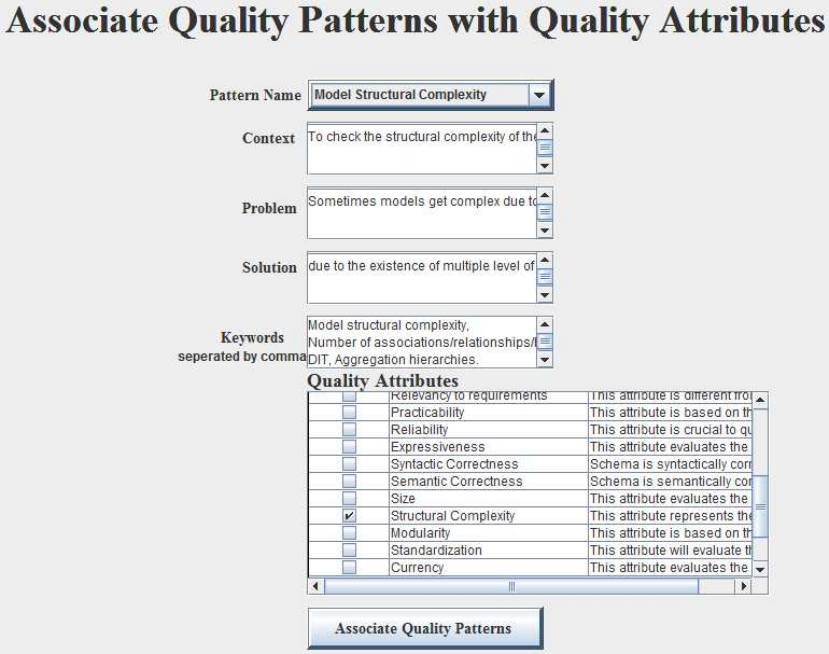


Figure - 35. CM-Quality Screen: Associate Quality Patterns with Quality Attributes

6.3.2 Quality attributes definition

Section-3.5.1 defines the concept of quality attributes in our approach and details how existing equivalent concepts such as dimensions, properties, characteristics, etc. are merged into the unified concept of quality attribute. Moreover, Section-4.2.2 describes the process for identifying new quality attributes. This process is implemented in the *Quality Attribute interface* (Figure - 36) of our software prototype. Users can add/edit/delete quality attributes from the knowledgebase using this interface. *Keywords* are identified for each quality attribute to help their identification during the evaluation process.

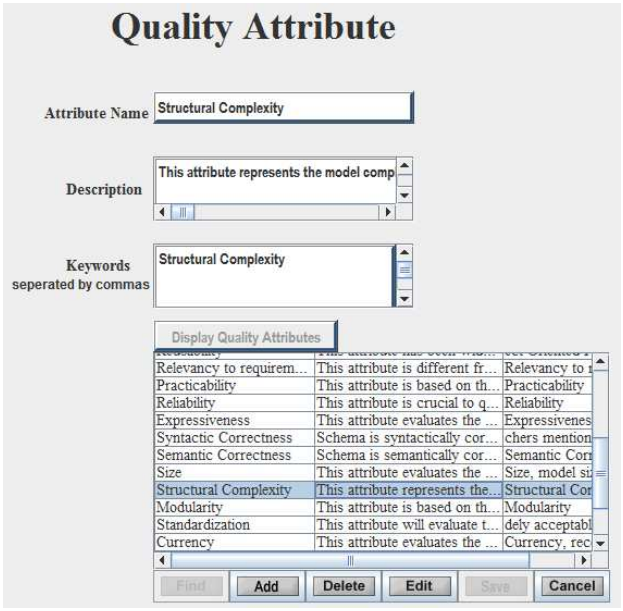


Figure - 36. CM-Quality Screen: Manage Quality Attributes

As mentioned before, quality attributes employ multiple metrics for their measurement. These metrics can be computed automatically or might require manual calculation. Thus, adding a new quality attribute requires its association with the appropriate quality metrics for its measurement. This association between quality attributes and metrics (both automatable and manual) can be defined using the separate screen as shown in Figure - 37.

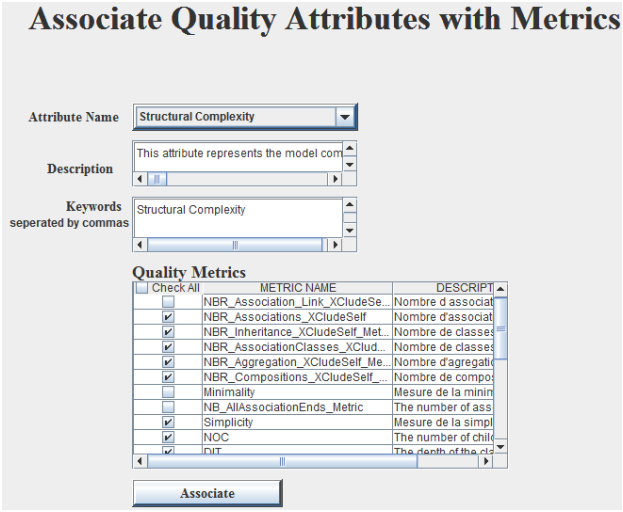


Figure - 37. CM-Quality Screen: Associating Quality Attributes with Metrics

6.3.3 Metric definition

Metrics are an important part of the evaluation process as they measure the aspects deemed important to users with respect to their vision of quality. In our approach, metrics are used to measure quality attributes. However, there are two types of metrics:

i. Metrics that can be calculated automatically such as calculating number of classes/attributes, etc.

ii. Metrics that are not automatable due to any reason such as number of line crossings, requirements coverage degree (see details in Chapter 5), etc.

In our approach, we employ both types of metrics and thus we incorporate them in our prototype. An important strength of our approach is the fact that we have developed in a previous work a prototype (*Qualis*) for metrics definition and evaluation [Kersulec et al., 2009]. *Qualis* implements a metrics definition language and so metrics don't need to be hard coded providing more flexibility in their definition. This also allows a simple enrichment of metrics. Our prototype integrates this metrics definition language to define automatable metrics. Here is an example of metric definition calculating the number of classes in a class diagram:

```
<metric name="NB_Classes_Metric" domain="model" >
<description>The number of classes belonging to a
model.</description>
<projection globalrelation="true" target="class"
condition="id!=''" />
</metric>
```

The above mentioned metric definition is performed using the *Metric Definition interface* (Figure - 38).

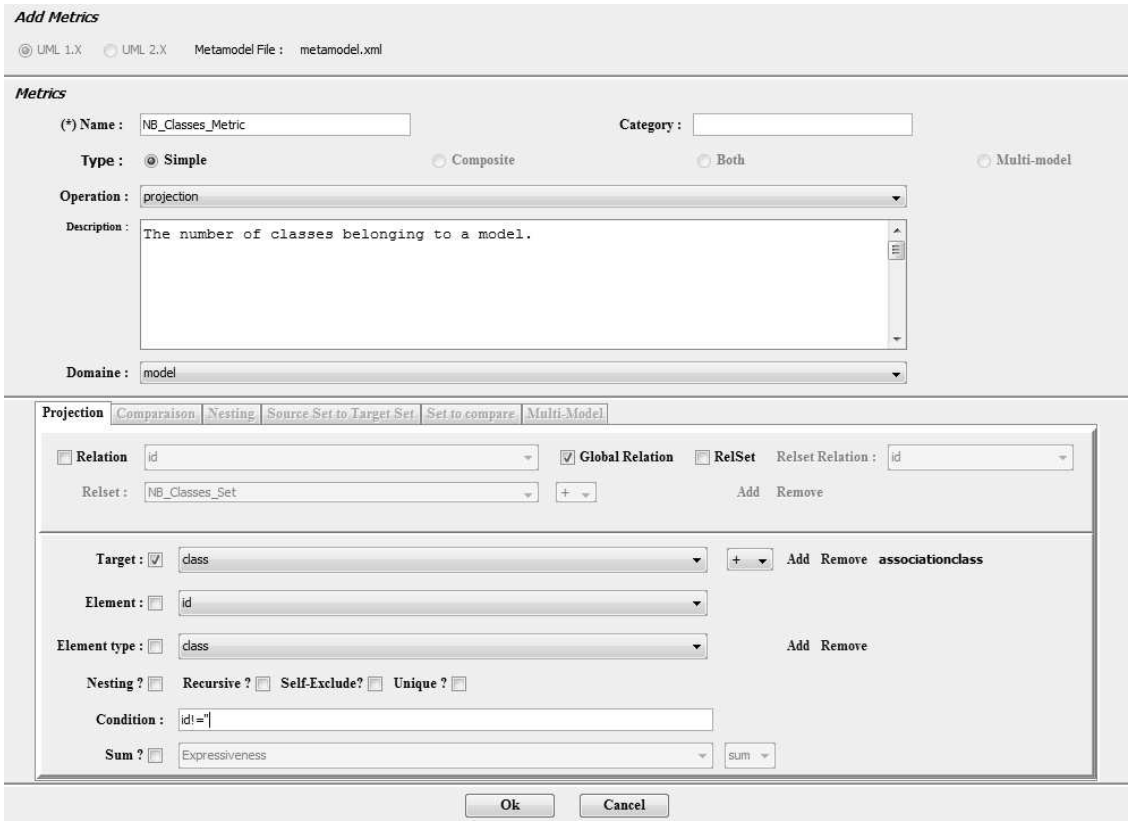


Figure - 38. CM-Quality Screen: Defining Automatable Metric

However, the above interface can't be utilized to create non-automatable metrics. Our approach employs several metrics that can't be computed automatically but are important for evaluation and subsequent improvement. We tested several quality evaluation utilities such as StarUML, Objecteering, UMLQuality, etc. but none of them provides any support for non-automatable metrics and thus they discard several important evaluation criteria that for the moment require manual computations. Our quality aware approach provides corrective actions for model improvement and thus we kept these non-automatable metrics in our knowledgebase so that relevant recommendations can be proposed to user for model improvement. Figure - 39 depicts the *Non-Automatable Metrics Definition Interface*. All the metrics defined using this interface are treated as equivalent to automatable metrics i.e. they can be associated to quality attributes, can be employed for any evaluation project and will propose relevant recommendations. The only difference between these metrics and automatable metrics is that they will not be computed by our prototype during the evaluation.

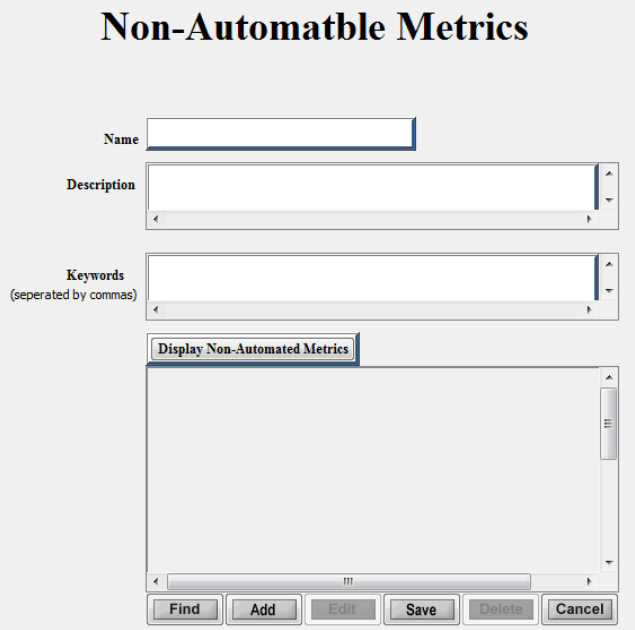


Figure - 39. CM-Quality Screen: Defining Non-Automatable Metric

6.3.4 Recommendation Definition

As mentioned in Chapter 3, one strength of our approach lies in the post evaluation feedbacks in the form of recommendations. These recommendations are part of the knowledgebase and are proposed to the user for improving their models. Figure - 40 depicts the *Recommendations Definition Interface*. This interface can be used to add/edit/delete recommendations from the knowledgebase. Moreover, our knowledgebase is capable of storing relevant supporting documents for the recommendations to help users in understanding the details about such recommendations. These supported documents are available to the user along with the recommendations for reference. For example, we can store existing human resource ontology (that was used in Chapter 5) as a reference for helping users in identifying different clusters from their complex models in order to divide them, as was demonstrated through our case study in Chapter 5.

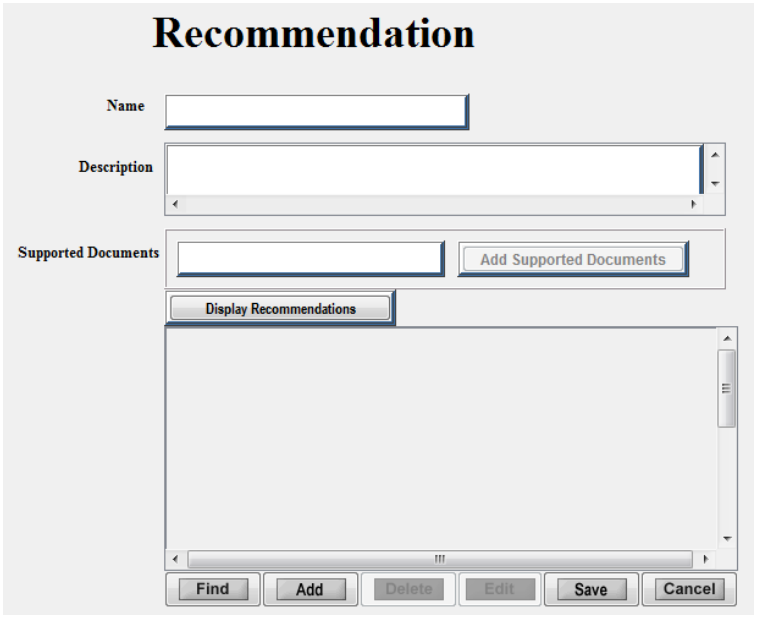


Figure - 40. CM-Quality Screen: Managing Recommendations

In our approach, recommendations are dependent on metric results i.e. they are proposed for improvement based on the measured values of the metrics. Thus, each recommendation must be associated to at least one metric and proper application criteria should be defined with respect to each metric so that they can be proposed effectively. This association between recommendations and metrics can be established using our prototype's interface as depicted in Figure - 41. In our approach, the relationship between metrics and recommendations is many-to-many.

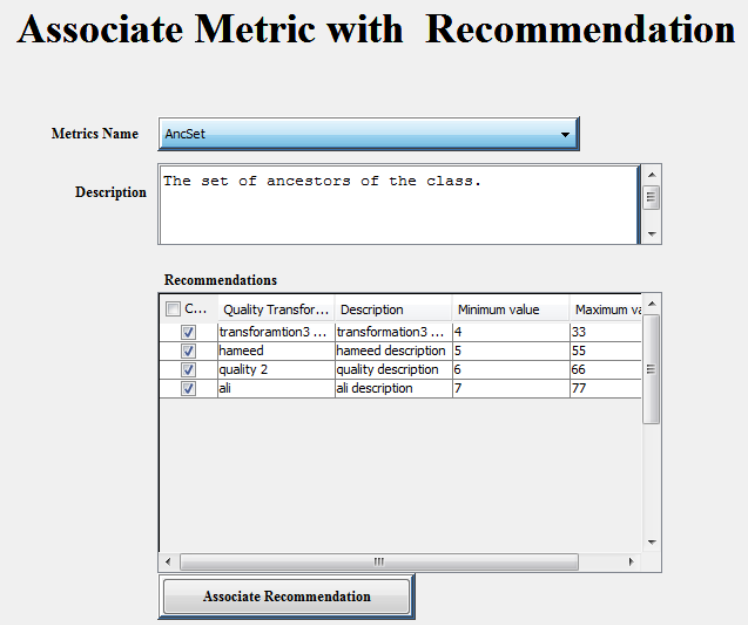


Figure - 41. CM-Quality Screen: Associating Recommendations with Metrics

6.4 Quality Evaluation in CM-Quality

The scenario presented in this section illustrates how the *CM-Quality* can be used to evaluate and improve the models. The quality definition module is conceived for quality experts only as it requires in depth knowledge about quality concepts. However as mentioned in Chapter 4, we provide two types of mechanisms to accommodate both basic analysts and quality experts for quality evaluation module. Quality experts can skip the goal formulation and directly start the evaluation process by selecting the quality patterns or quality attributes from the knowledgebase. However, it requires that they are aware of all the existing contents of knowledgebase and what each concept proposes.

The quality evaluation process starts by selecting the model to be evaluated. The model must first be exported to the XMI (XML Metadata Interchange) file format. XMI is the standard proposed by Object Management Group (OMG) for exchanging metadata information via XML. XMI has widely been used in the industry for enhancing the portability of conceptual models among different modeling tools. Our prototype is based on XMI and thus it can be used to evaluate models designed using any modeling tool capable of exporting its models into XMI. Thus, the user selects the model to be evaluated. Once the model is selected, the user is proposed the following four options:

i. Formulate new quality goal (for all type of users) i.e. start from the scratch.

ii. Use existing quality goal i.e. the quality goals that were previously used for evaluation (for all types of users).

iii. Select quality patterns directly (for quality experts only) i.e. the evaluation process starts by manually selecting the quality patterns thus skipping the goal formulation process and the process to map the formulated quality goals on to quality patterns.

iv. Select quality attributes directly (for quality experts only) i.e. start the process by manually selecting the desired quality attributes thus skipping the goal formulation process, the process to map the formulated quality goals on to quality patterns and the selection of quality patterns.

Since most users have limited knowledge about the different quality concepts therefore they are required to start the evaluation process by formulating the quality goal. Both the quality evaluation modes for quality experts are different with respect to their starting point only. The complete evaluation process encompasses all the steps from goal formulation to the generation of evaluation results with recommendations. In the next section we will describe the complete evaluation scenario that demonstrates the complete flow of the *CM-Quality* application starting from goal formulation to the generation of evaluation results. However, we will explicitly mention the starting point of each of the two modes of evaluation for quality experts.

This scenario doesn't include the housekeeping of knowledgebase i.e. it doesn't discuss about the insertion, modification or deletion of quality patterns, quality attributes, metrics, etc to the knowledgebase. It uses the existing contents of the knowledgebase for evaluation and propositions. However, *CM-Quality* contains numerous screens for manipulating the knowledgebase including the screens to manage quality patterns, quality attributes, metrics, etc. as shown above.

6.4.1 Goal Expression and Resolution

As described in Chapter 3, we have used the goal formulation templates proposed by [Basili 93] to help the user in formulating a structured goal with the least amount of effort. [Basili 93] divided the goal into four components:

i. Purpose of the goal i.e. object of analysis such as conceptual models, processes, etc.

ii. Intention of the goal. For example is it for evaluation, improvement, etc.

iii. Perspective or focus of the goal such as completeness, complexity, etc.

iv. Target point of view i.e. is this goal intended for analysts, users, etc.

We found that dividing the goal into these four components will help the users in formulating their quality goal more efficiently, effectively and with the least amount of effort. We have incorporated this template in our prototype. Figure - 42 depicts the interface responsible for goal formulation. The user can select as many sub goals as required. However a quality goal can have one and only one purpose and one point of view. The contents of the four combo-boxes are mentioned in Section-4.3.1.1. The text box in the interface provides a preview of the formulated quality goal in natural language to help the users in visualizing their formulated quality goals.

In this example (Figure - 42), the user is interested in evaluating the complexity and completeness of conceptual models (we will use this goal throughout this chapter as an example). Structured goals have enabled us to perform efficient searching as in this case we will search for relevant quality concepts corresponding to complexity and completeness only. The CM-Quality tool integrates a searching engine for identifying relevant quality concepts (quality patterns or attributes) with respect to the user defined quality goal. Searching process is discussed in the next section.

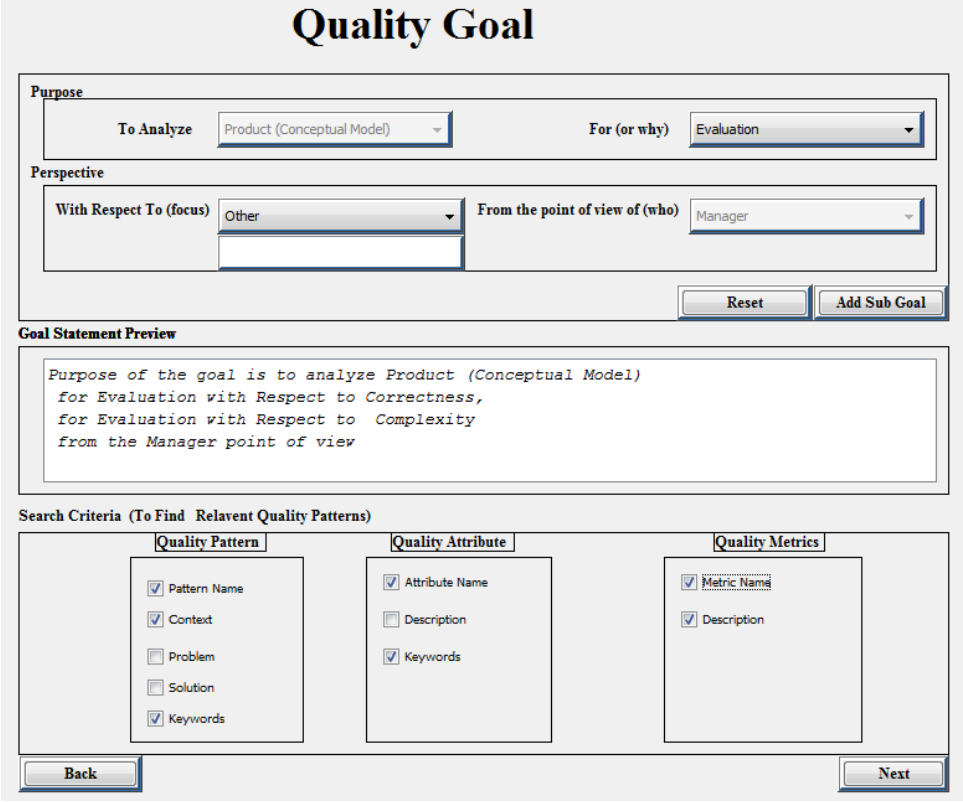


Figure - 42. CM-Quality Screen: Quality Goal Formulation Screen

6.4.2 Matching Formulated Goal to Quality Patterns

The incorporated search engine in *CM-Quality* uses information contained in quality patterns, quality attributes and their associated metrics to match a quality goal. This matching could take a lot of time. However, in order to accelerate the searching, the user has the option to select the target fields for searching. The user can choose the searchable fields from quality patterns, attributes and metrics.

In the previous section, we formulated a quality goal with intent to evaluate a conceptual model with respect to correctness and complexity. Once the quality goal is formulated and target searchable fields have been selected, the user launches the searching process. In our prototype, *CM-Quality*, the mapping of this goal onto relevant quality concepts involves four steps:

i. In the first step the user will answer the questions, demanded by *CM-Quality*'s search engine, to narrow the domain of the formulated goal, as was proposed by GQM (refer to Section-3.2.1 for more information about the generation of questions and GQM).

ii. Based on the responses of the questions, *CM-Quality* will propose a set of relevant quality patterns. In the second step, the user will validate the selection of the quality patterns. In this step the user can also manually select the quality patterns if it was not proposed by the prototype. However, this manual selection necessitates expertise in quality concepts.

iii. In the third step, the user will validate the selection of the quality attributes i.e. he/she will confirm the selection of quality attributes that should be used for evaluation. By default, all the quality attributes associated to all the validated quality patterns (from the second step) will be used for evaluation.

iv. In the last step, the user will choose the quality metrics that should be used for quantifying the quality attributes. By default, all the quality metrics that are associated with all the quality attributes validated in step-3 will be used for evaluation.

6.4.2.1 Step-1: Generating Questions to Identify the Domain of the Formulated Goal

As mentioned in Section-3.2, quality goals are translated into questions. These questions help users in narrowing the scope of goals yet specifying its domain and increasing the details about it. Questions also help in identifying the evaluation criteria with respect to the formulated goal. In *CM-Quality*, the search engine identifies the relevant quality concepts, with respect to the

formulated goal, and generates questions so as to map the search engine's perception of the goal with respect to users. For example, completeness can be related to requirements coverage whereas it can also be related to syntactic completeness (refer to Section-3.5.1 for details about these terms). In this case, *CM-Quality* will generate two questions asking the user if completeness is related to requirements coverage or semantic completeness.

CM-Quality incorporates a sophisticated search engine that helps the automatic identification of quality concepts that are in-line with the user defined quality goal. However, in order to facilitate the searching, the user has the option to select the target fields for searching. The user can launch searching on all the fields of quality patterns (such as name, context, problem, etc.), quality attributes (such as name, keywords, etc.) and quality metrics.

Upon selecting the target fields, the user will press the *Next* button on the goal formulation screen (Figure - 42) to launch the search process. The system will search perspective/focus of the goal, in our example completeness and complexity, in all the selected fields for possible matching.

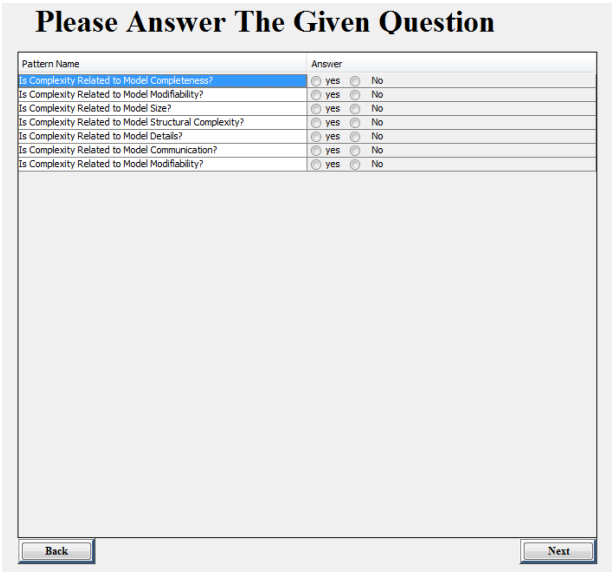


Figure - 43. Goal Creation Step-1: Generating questions to identify the domain of the formulated goal

Questions will be generated for all the resulting quality patterns matching the quality goal. However, these search results are constituted thanks to three different kinds of search:

i. If the quality goal matches the selected fields of the quality patterns, then a question will be generated for that quality pattern and added to the resulting table (Figure - 43). For example, one of the quality patterns in knowledgebase is named as "model complexity", thus the search will include questions about this quality pattern in the result.

ii. Similarly, the search will look for the goal terms in the selected fields of the quality attributes and if some matching quality attributes are found, then the system will look for all the quality patterns that are associated with this quality attribute and will generate and display the questions about the associated quality patterns in the result table. For example, knowledgebase contains a quality attribute that has complexity as a term in its name and similarly another quality attribute that has complexity as a term in its keywords. Thus the system will look for their associating quality patterns and will generate and display the questions about those quality patterns and not the quality attributes.

iii. Searching tool will also look for the matching terms in the selected fields of the quality metrics. And similarly to quality attributes, if some metrics exist that are in-line with the quality goal in question, the system will first look for the quality attributes that are responsible for these metrics and then will look for the quality patterns containing those quality attributes and include questions about those quality pattern in the resulting table (Figure - 43).

6.4.2.2 Step-2: Validation of Proposed Quality Patterns

Based on the user's response to the questions generated in Step-1, relevant quality patterns will be proposed. However, the user can change the selection based on his/her choice. Figure - 44 depicts the interface proposing the quality patterns relevant to the formulated quality goal and user's response to the questions.

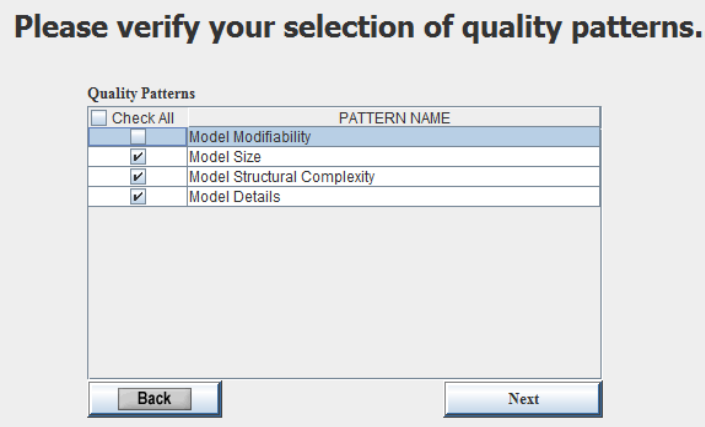


Figure - 44. Goal Creation Step-2: Validating the selection of proposed quality patterns

In addition to the proposed quality patterns, the user can also manually select the quality patterns that he/she thinks can be important for the quality goal and that were not identified by the search engine. Similarly, the user can also discard the quality patterns, resulted by the system, that he/she thinks are not relevant to the quality goal.

Once the user validates his/her selection of the quality patterns, he/she will press the *Next* button to go to the next step.

6.4.2.3 Step-3: Validation of the Selected Quality Attributes

The structure of a quality pattern contains a set of quality attributes i.e. quality patterns employ quality attribute(s) for evaluation. However, if a quality pattern is selected for evaluation then this doesn't require that all of its associating quality attributes will be employed for evaluation. The user can change the selection and decide the quality attributes to be used from each quality pattern for his/her goal specific evaluation project.

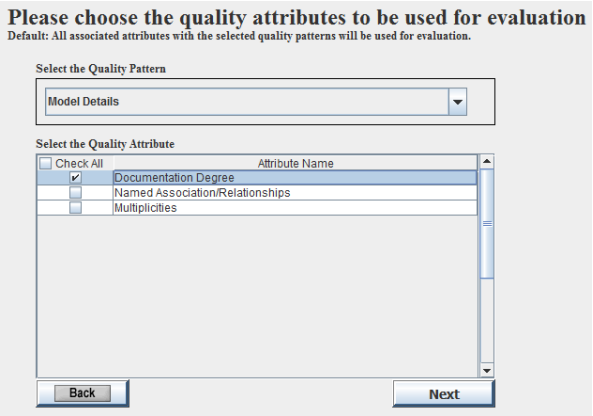


Figure - 45. Goal Creation Step-3: Validating the attributes selection for evaluation

In the third step, the user will see the screen shown in Figure - 45. The combo box on top of the screen contains all the quality patterns selected in step-2. Upon selection of quality pattern from the combo box, the table below will list all the quality attributes that are associated with the selected quality pattern. By default, all the quality attributes will be selected for evaluation. However, the user can change the selection and decide the quality attributes to be used from each quality pattern for his/her goal specific evaluation project. For example, Figure - 45 shows the "Model Details" quality pattern and the three quality attributes associated with this quality pattern. We can notice that only one quality attribute has been selected.

6.4.2.4 Step-4: Validation of the Selected Quality Metrics

Figure - 46 displays the last screen of the goal creation. The first combo box on the screen contains all the quality patterns selected in step-2 whereas the second combo box contains all the quality attributes selected in step-3. Upon selection of quality pattern from the combo box, the second combo box will list all the quality attributes that are associated with the selected quality patterns and were selected by the user in step-3. Once the user selects a quality attribute from the combo box, the table will list all the metrics that are associated with the selected quality attribute. By default, all the metrics will be used for evaluation. However, the user can choose the metrics on his/her discretion for his/her goal specific evaluation project. This list will also contain manual metrics but as mentioned above, manual metrics will not be calculated but will appear in the evaluation report along with recommendations.

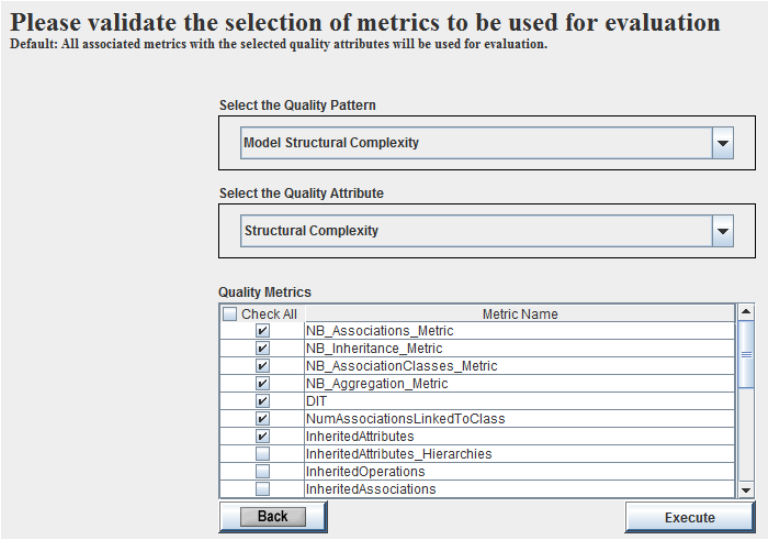


Figure - 46. Goal Creation Step-4: Validating the metrics selection for evaluation

For example, in Figure - 46, *"Model Structural Complexity"* is selected as the quality pattern and *"Structural Complexity"* is selected as the quality attribute. The table displays all the metrics associated with the selected quality attribute. Among all listed, only seven metrics are selected for evaluation.

6.4.3 Model Evaluation & Improvement

The model evaluation consists in assessing the quality of the target conceptual model by employing the selected quality criteria. The model evaluation is dependent on the calculation of the selected metrics as all other quality concepts are the abstractions for classification. The model evaluation process starts by calculating the metrics on the target model. Once the metrics are calculated, corresponding recommendations are proposed to the user for improvement. Our knowledgebase contains numerous recommendations depending on the metrics values. These recommendations can be textual recommendations, transformations or proposed design patterns (details about recommendations and their types can be consulted from Section-3.5.3)

CM-Quality is the only evaluation software that provides an independent evaluation report listing details about following:

i. User defined goal

ii. Employed quality patterns, attributes and metrics

iii. Detailed results of every metrics

iv. Detailed recommendations with metric for improving the model

The resultant report generated for the quality goal, used in this chapter as an example, is attached as Appendix-E.

6.5 Comparison of CM-Quality with Other Existing Softwares

In Chapter 2, we used the Table - 3 to compare existing evaluation tools. Now we will use the same criteria to position our prototype with respect to existing evaluation tools.

Table - 11. Comparing CM-Quality with existing evaluation software

Criteria	Objecteering	Rational Rose	Star UML	UML Quality	CM- Quality
Evaluate Static Diagrams	Yes	Yes	Yes	Yes	**Yes**
Evaluate Dynamic Diagrams	No	No	No	Yes	**Yes**
Granularity of evaluation criteria	Metrics	Metrics	Metrics	Metrics	**Quality Patterns, Attributes & Metrics**
Possibility to Add/edit evaluating criteria	No	No	No	Yes	**Yes**
Interface for adding/editing the evaluation criteria	No	No	No	No	**Yes**
Guidance process for selecting the requirement/project specific evaluation	No	No	No	No	**Yes**
Comparison of multiple models	No	No	No	No	**Yes**
Provision of evaluation report	Yes	No	No	Yes	**Yes**
Provision of post evaluation recommendations	No	No	No	Yes (limited with plug-in)	**Yes**

Following findings can be deduced from Table - 11:

i. Only UML-Quality and CM-Quality (our prototype) provide possibilities to manage the evaluation criteria but only CM-Quality provides a graphical user interface for managing these criteria. In UML-Quality, the absence of dedicated user interface makes it difficult to manage (add/edit/delete) the evaluation criteria.

ii. Only CM-Quality implements a guidance process for selecting the requirement specific evaluation criteria. CM-Quality also incorporates a sophisticated search engine for automatic detection and subsequent proposition of relevant quality concepts with respect to the formulated goal.

iii. CM-Quality is the only evaluation tool that supports the comparison of multiple models on the same evaluation criteria. Thus users can identify a better model among multiple version of the same model.

iv. CM-Quality is the only evaluation tool that generates an independent report in printable format (PDF) and includes both the evaluation results and the recommendations for improvement.

In view of the above findings, we can say that CM-Quality incorporates several shortcomings present in other existing evaluation applications. Moreover, CM-Quality is completely

customizable. It can be used for other types of conceptual models (from other domains) by formulating the relevant quality concepts for the target domain.

6.6 Conclusion

In this chapter, we presented our software prototype *"CM-Quality"* that implements our proposed solution and process. We started by illustrating the application architecture at multiple levels of granularities whereas in the last part we presented different interfaces available in CM-Quality for quality definition and quality evaluation operations. We took examples to demonstrate the flow of *CM-Quality* and described the searching process for automatic detection of relevant quality criteria with respect to a formulated quality goal. We also attached the generated evaluation report as Appendix-E. Following are the limitation of *CM-Quality:*

i. CM-Quality evaluates the complete model and proposes recommendations for the entire model thus if user is interested in evaluating only certain parts of the model then he can only do that by turning those parts into an independent model.

ii. Proposed transformations can't be applied automatically.

iii. CM-Quality can't be integrated to other modelers as an add-on. Thus it can work with other modelers through XMI only.

In the next chapter, we present the two validation experiments conducted for our approach. In the first experiment, we validated the selection of the quality attributes (from a thorough literature review) whereas in the second experiment, we validated the efficacy of our proposed quality approach including quality patterns.

Chapter 7
Validation

As mentioned in Chapter 3, our approach involves practitioners' viewpoint as its practical foundation. The main objective of our validation was twofold: one to study the evaluation strategy employed in practice and second to validate our approach at different stages. We involved experts both academics and practitioners using surveys, interviews, etc. To the best of our knowledge such a large scale experiment has never been performed with academics and practitioners as respondents. We conducted two experiments to validate our proposed approach at different stages. We have carefully selected the respondents for both the validation experiment such that all the respondents have prior knowledge about CM and some modeling experience.

We performed a thorough literature review and selected a set of quality attributes by federating the existing quality frameworks or literature (explained in Section- 3.5.1). Thus, a first experiment was performed to ensure that the resultant set of quality attributes (identified from the literature or defined as new concepts) represents most of the important aspects (if not entirely) in the evaluation of CM. This interim validation exercise (or experiment) was performed having experts from academics and practice as respondents. The main objectives behind this first validation were the following:

i. To collect respondents' feedback over the identified/selected set of quality attributes.
ii. To find the quality criteria that had been used in practice but are unknown to theory.
iii. To study the general practices and views of the respondents over the quality of CM.
iv. To study respondents knowledge about the existing evaluation methods and/or their employment of these methods for CM.
v. To collect respondents' views on the quality of CM.
vi. To study if CM is actually evaluated in practice for ensuring its quality.

The results of the above experiment helped us in validating the selection of our quality attributes and provided us with useful insights about the evaluation criteria considered important in practice.

We performed the second experiment to validate the efficacy of our complete approach including quality patterns. This experiment consisted of three steps and every respondent was required to complete all the three steps. We were interested in seeking the answers to the following questions through this experiment:

i. Are the respondents sensitive to CM quality?

ii. Can they improve bad or complex CM by themselves?

iii. Are the proposed quality patterns easy to understand?

iv. Are the quality patterns useful in evaluating the CM?

v. Is the transformed model, by applying quality patterns, really better than the original model?

The second experiment helped us in validating the strengths and benefits of employing our proposed approach and quality patterns in evaluating and improving the conceptual model. Both experiments are based on our proposed solutions to evaluate and improve the CMs. The results of both experiments represent qualitative data. For example, in the second experiment respondents were asked different questions after each step and they had to answer by yes/no. The questions were designed in such a way so as to serve as a feedback to our approach and can help us in ensuring the viability of our approach. Moreover, the collected data could be used to identify different trends rather than proving or disproving a hypothesis.

In order to answer these requirements, we found that it would be much more useful to emphasize on Exploratory Data Analysis (EDA) rather than traditional inferential statistics. Inferential statistics relies heavily on probability models that sometime provide deceptive notion of precision in not so ideal circumstances and most importantly the analysis is driven by preconceived ideas. On the other hand EDA provides a descriptive statistics to examine the data without preconceptions. It relies on graphical displays (different charts and graphs) to extract meaningful information from the data. Most importantly it doesn't seek more that what data can provide, as is the case with inferential statistics. EDA is an approach to analyze and understand data employing different graphical techniques or charts. [Hoaglin et al., 1983] argued that too much emphasis in statistics is placed on hypothesis testing and there is a dire need to understand data at first. EDA techniques and charts are extensively used in different ERP and customer relationship management (CRM) applications to identify different trends and predict different models from data.

In both experiments, we have used multiple charts and tables to analyze the respondents' responses to our questions. We were more interested in understanding our respondents feedback about our selected quality attributes and our approach then on testing some hypothesis. We were interested in detecting different trends among our respondents. Thus we divided the respondents' responses with respects to occupation and modeling experience to understand and identify different patterns of data. This view enabled us to analyze the data using multiple lenses such as comparing the responses from academics and practitioners.

In the next sections, we describe the two experiments.

7.1 Validating the Selected Quality Attributes

As discussed in preceding chapters, quality evaluation for CM requires a set of criteria along with a mechanism for their classification. In the domain of CM quality, researchers have proposed different criteria for evaluation but the main problem lies in their disparity and non-converging solutions. The proposed quality criteria or quality frameworks are independent of one another and thus it gets difficult to have a comprehensive and complete picture. Moreover, there doesn't exist any approach that can help in the identification of these evaluation criteria. The absence of consolidated and agreed quality criteria for CM has demotivated the acceptance and adoption of evaluation based strategies for CM. We conducted a survey, discussed later in this chapter, and found that analysts/modelers acknowledge the importance of implementing an evaluation strategy for CM but most of them don't know if any of such material existed in research. This gap between existing literature on CM evaluation and its usage in practice is due to the fact that neither a standardized set of criteria exists in the literature nor a consolidated quality approach has been proposed and diffused on a wide level.

In Section-3.5.1, we discussed the problems related to the existence of independent and autonomous quality frameworks and proposed to federate the existing literature to formulate a consolidated set of criteria for CM quality evaluation. In order to identify this consolidated set, different quality criteria from the previously existing quality frameworks or literature were extracted. Following guidelines were used for this activity:

i. Selection of various quality attributes from the literature such that each attribute must be generic and should remain valid for all types of conceptual models such as UML models, ER models, etc. Thus attributes specific to a particular notation (UML, ER etc,) can't be selected. However such attributes are merged into generic attributes that are closest with respect to semantics.

ii. All the existing dimensions, characteristics, properties, attributes, categories, etc. that can be directly quantified employing metrics can be selected as attributes. For example, completeness can be quantified using metrics such as requirements coverage degree, semantic completeness, etc. therefore it can be selected as an attribute. However, the dimensions (such as syntactic quality, semantic quality, pragmatic quality, etc.) proposed by [Krogstie et al., 1995], [Lindland et al., 1994], etc. are not at the same level of abstraction and thus can't be considered as attributes. Moreover, these dimensions are just a way of classifying different criteria.

iii. Identification and classification of relevant metrics into respective quality attributes for measurements. For example, metrics such as number of classes, number of attributes, etc. are used for measuring complexity quality attribute.

iv. As mentioned before, the same quality concept has been defined differently by different researchers. For example, [Nelson et al., 2005] identified nine different definitions for "completeness". Thus as per our approach, completeness is equivalent to a quality attribute and thus we combine all the definitions of completeness within a single quality attribute named as "completeness" and formulated different metrics to cater the dissimilar requirements of the existing nine definitions.

v. [Purao et al., 2003] identified identical names for some semantically different metrics and different names for semantically same concepts. In our approach, we merged all the semantically similar concepts as one quality attribute. Similarly for semantically different concepts having identical names, we merged them into the relevant concepts.

vi. Identification or enrichment of different quality attributes to incorporate different epistemological foundations/questions for CM. As mentioned in Section-3.1.3, we tried to seek the answer to epistemological question such as "Why do we make CM?" We identified all the reasons that led to the employment of CM for designing the system and enriched the definition of completeness and understandability quality attributes to include these reasons. For example, we included the semantic and syntactic aspects to the completeness quality attributes by formulating or identifying relevant metrics. Similarly, we included all the aspects related to enhancing the understandability of the CM and its correct interpretation into the understandability quality attribute.

The above mentioned activity resulted in the selection/identification of a set of quality attributes that were generic and represent different aspects of the conceptual models such as complexity, maintainability, etc. Moreover, the advantage of this activity was the elimination of

redundant concepts in addition to unification of different frameworks, identification of grey areas and provision of a more comprehensive and flexible set of quality criteria for conceptual models. We identified twenty one quality attributes that incorporate a wide range of quality criteria already existing in the literature. These attributes can be consulted from Table - 15.

The above mentioned federation activity is incomplete without incorporating the insights from the practice and can be questionable without exercising a proper validation. For example, in order to be sure that the resultant set of quality attributes represents the most important aspects (if not entirely) in the evaluation of CM, an interim validation exercise was planned and performed having experts, both academics and practitioners as the respondents. Therefore, a web-based survey, built on the above mentioned selected quality attributes, was formulated. This validation exercise tried to collect the responders' views on the holistic quality of the conceptual models in addition to their feedback over the identified/selected set of quality attributes.

Following purposes were envisaged from survey:

i. To observe if practitioners also regard quality evaluation as an important aspect in CM and, if they do then, to study their knowledge about the existing evaluation methods and/or their employment of these methods for CM.

ii. To study if actually CM is evaluated in practice for quality as the software.

iii. To serve as a validation exercise in providing feedback from experts both academics and practitioners over the efficacy of the selected quality attributes.

iv. To study the general practices and views of the professionals over the quality of conceptual models. This includes the identification of attributes or other criteria that had been used in practice but are unknown to theory.

As mentioned above, a web-based survey was formulated to conduct this study. To the best of our knowledge, such a large scale experiment has never been performed with academics and practitioners as respondents. This was a closed survey and was accessible through a special link, provided to the invited participants only to avoid unintended participants. We have carefully selected the respondents for this validation experiment. This was a comprehensive survey containing 42 general questions and our selected quality attributes specific questions. However, all the questions were directly related to the quality of conceptual models. These questions include the two feedback questions where the participants were required to mention:

i. Attributes that in their view are crucial to the quality of conceptual models (they can identify up to seven attributes).

ii. How do they compare two conceptual models representing the same reality or modeling the same problem? They were required to identify and mention up to seven attributes/properties that they think they will employ in choosing the best model with respect to their perception of quality.

The survey consists of the following four sections to target the different types of information:

i. General Information about the respondents.

ii. Respondents' knowledge about CM.

iii. Respondents' knowledge about CM quality and their feedback over the selected quality attributes.

iv. Respondents' general practices about conceptual modeling quality.

The survey provides the respondents with the dictionary and an instant help about the definitions and details of all the terms and concepts used in the survey including the definitions of all the selected quality attributes.

7.1.1 Sample

In total 179 professionals (including IS managers, IS developers, researchers, etc.) were contacted to complete the survey. These respondents were carefully selected in a way that they should have prior knowledge and experience about CM. For example, we selected the authors of those research articles that were based on quality evaluation aspects of CM. These researchers include some well known researchers in the field of CM quality such as Daniel Moody, Geert Poels, Islay Davies, Andrew Burton-Jones, etc. Similarly, this survey was sent to analysts/project managers/developers of a big software development firm where I had worked in the past for about four years. However among the 179 contacted respondents, 57 completed the survey that resulted in the response rate of 31.8%. Among the received 57 responses, three were discarded due to errors in the provided data or incomplete information about the important parts of the survey.

Table - 12 provides the basic information about the respondents. It can be seen that our respondents come with a wide range of experience encompassing between one and twenty six years of experience with a mean of 6.4 years. Similarly, the respondents have an average modeling experience of 4.25 years including respondents between one year and fifteen years of modeling experience.

Table - 12. Experiment 1: General information about the respondents

Total Respondents	54
Male	49
Female	5
Average Age	30.3 years
Min Age	27.5 years
Max Age	50 years
Average Experience	6.4 years
Min Experience	1 years
Max Experience	26 years
Average Modeling Experience	4.25 years
Min Modeling Experience	Less than or equal to 1 year
Max Modeling Experience	Between 10 & 20 years

Respondents were required to select their modeling experience from six classes (listed below). These classes don't have an equal interval as we wanted to have a more precise detail about our respondents with the least possible classes. We knew in advance that more than 90% of our respondents will have a modeling experience of less than 10 years (as the survey was sent to selected respondents only). Thus we formulated the classes in such a way to get more precise information about these 90% respondents. This classification has also helped us in calculating a more precise weighted arithmetic mean about our respondents since we took the mean of each class and multiplied it with its frequency. For example, we have ten respondents that belong to class "Between 1 & 3 years" thus we took the mean of this class i.e. 2 and multiply it with 10 and used it to calculate the mean listed in Table - 12 or later in this chapter. Such short interval classes enabled us to get a more precise estimate about majority of our respondents and have also helped in reducing the number of classes. The different classes are:

i. Less than or equal to 1 year
ii. Between 1 & 3 years
iii. Between 3 & 5 years
iv. Between 5 & 10 years
v. Between 10 & 20 years
vi. More than 20 years

Figure - 47 depicts the division of respondents with respect to their modeling experience. It can be seen that the majority of our respondents belongs to a class having a modeling experience

between three and five years. Similarly, we can also compute that 55% of our respondents have a modeling experience between three and twenty years compared to 26% having an experience of one year or less. Similarly, 24% of our respondents have a modeling experience of more than 5 years. The pie chart (Figure - 47) represents how our selected set of respondents is rich in diverse experience.

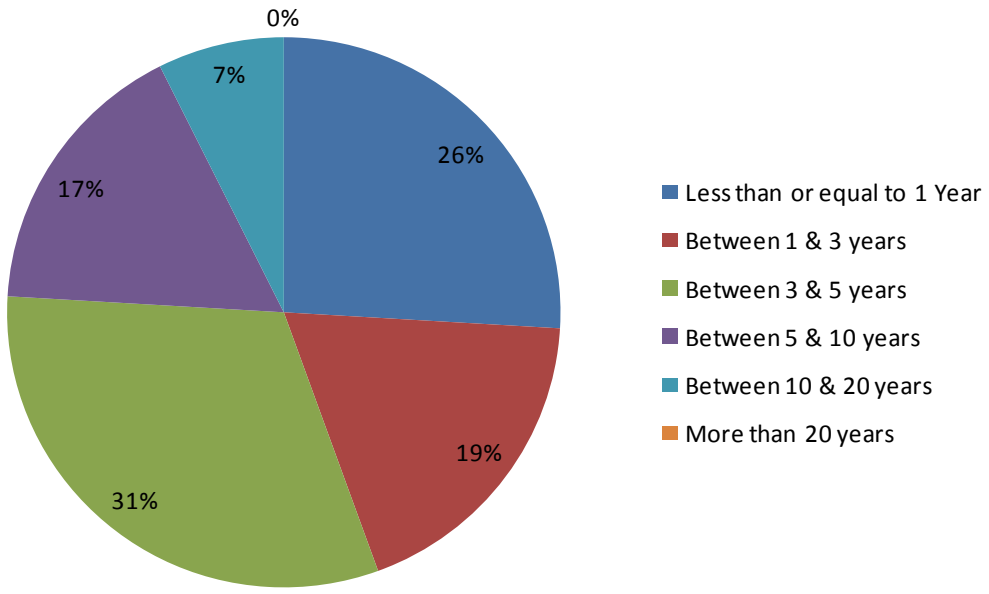


Figure - 47. Experiment 1: Classification of respondents with respect to modeling experience

Respondents were required to select their occupation from a list of fifteen pre-defined occupations. However all of our respondents belong to either of the following five occupations: analysts, IS project manager, lecturer/professor, researcher, software developer. Table - 13 summarizes the distribution of respondents with respect to their occupation. It also provides min, max and average information about age, experience, modeling experiences for each of the five occupation categories for richer understanding about our respondents. Minimum and maximum modeling experiences are the average of the class boundaries. For example, maximum modeling experience of 7.5 year means that the respondent belongs to "between 5 and 10 years" class similarly, min modeling experience of 1 year means that the respondent belong to "Less than or equal to 1 year" class.

Table - 13. Experiment 1: Classification of respondents with respect to occupation

Occupation	Analysts	IS Project Manager	Lecturer/ Professor	Researcher	Software Developer
Number of Respondents	7	12	7	9	19
Average Age	31.4	30.42	33.2	30.3	28.9
Min Age	27.5	27.5	27.5	27.5	27.5
Max Age	50	40	50	40	40
Average Experience	9.7	7.9	8.7	3.6	4.8
Min Experience	4	4	2	1	1
Max Experience	26	15	26	7.5	15
Average Modeling Experience	6.8	4.1	8.8	2.1	2.7
Min Modeling Experience	2	1	1	1	1
Max Modeling Experience	15	7.5	15	4	7.5

We were also interested in understanding the different quality evaluation practices for CM employed by various organizations with respect to their sizes. Thus, the respondents were required to select the size of their organization from a list of six groups. These groups range from small organizations having less than 50 employees to as big as having more than 1000 employees. The distribution of respondents with respect to their organizational strength is shown in Table - 14.

Table - 14. Experiment 1: Respondents with respect to organization size

Company Size:	Count
Less than 50 employees	15
Between 50 & 100 employees	7
Between 101 & 200 employees	8
Between 201 & 500 employees	11
Between 501 & 1000 employees	2
More than 1000 employees	9
Not answered	2
TOTAL	54

It can be observed from Figure - 48 that 20% of our respondents belong to large organizations having more than 500 employees including 16% respondents that belong to organizations having more than 1000 employees. Similarly, 4% of the respondents didn't provide this information.

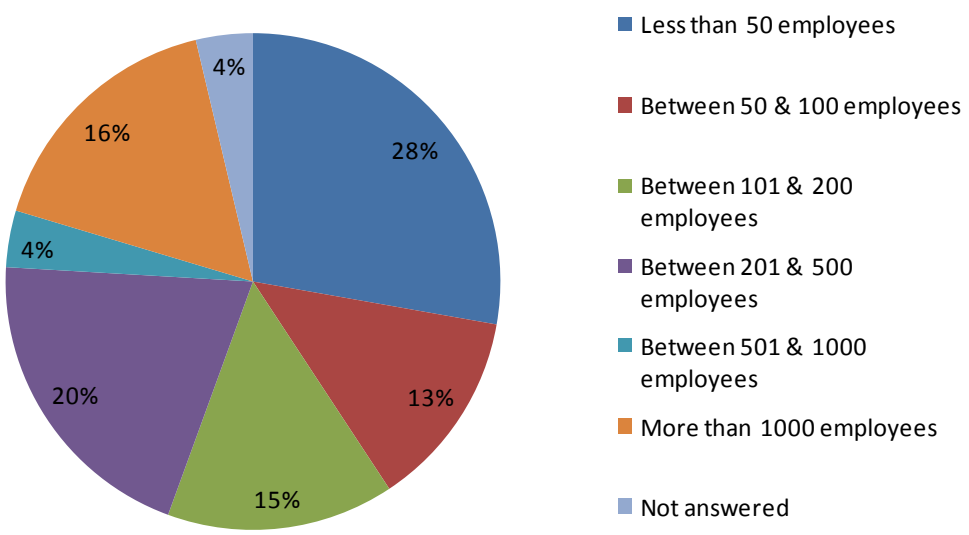


Figure - 48. Experiment 1: Respondents with respect to organization size

7.1.2 Data Analysis

The collected data shows that all of our respondents knew about CMs and 83% of these respondents use CM at the time of the survey. We also enquired from the respondents about their knowledge on the existence of any standards for evaluating the quality of conceptual models. The respondents were required to answer the questions in yes/no. If they knew about some standard then they were required to provide the name of that standard. We asked this information to extend our horizon on the existence of any evaluation standard for CM that is in the market or used in the practice but is unknown to us. To our surprise nine respondents (16%) claimed that they knew a standard and six provided the name of the standards. The provided names include: IEEE standard (without any reference), object modeling technique (OMT), UML, object management group (OMG). However none of these are standards for CM quality evaluation.

In the next section of the survey, we asked the respondents if they consider the imposition of quality approach on the conceptual models to directly influence the quality of the final product. 85% of the respondents replied in affirmation. However, it is interesting to note that 90% of the respondents have never used any method or framework to evaluate the quality of conceptual models (two of the respondents didn't answer this question so we didn't include them in calculating the percentage). Among the five respondents who employ any quality evaluation method for CM, two respondents can be regarded as quality experts as they have published at least one article in the field of CM quality evaluation. This shows that despite the appreciation of

importance of implementing a quality approach, professionals do not employ any methods to improve the quality. Such a behavior has resulted due to the gap between research and practice. To date there does not exist any quality framework that is standardized, simple and comprehensive enough to accommodate the requirements of the practitioners.

In the next part of the survey, we intended to collect the respondents' feedback over the efficacy of the selected quality attributes. All the attributes were put in one table and respondents were required to mark all the attributes into either *'not related to quality', 'I am not sure', 'directly related to quality'* or *'indirectly related to quality'* using radio buttons. However there was not a real difference between the answers of the last two options as respondents have to rely on their cognition to categories the attributes into what is directly related to quality and what is not. Thus, we found it more interesting to merge these two options as one so that we can have a clear distinction between the attributes that are related to and not related to quality. Moreover, we were not interested in classifying the attributes into being directly related or not but to validate if the selected attributes is related to quality or not. The responses are summarized in the Table - 15 and attributes are sorted with respect to *"Related to Quality".* All the values are in percentages of the responses and are rounded off to the nearest tenth digit. Table - 15 should be read as, for example, 88.9 % of the respondents think that 'Documentation' quality attribute is related to quality against 0% that think it is not related to quality. Similarly, 11.1% of the respondents declare their inability to categorize 'Documentation' quality attribute in any of four classes.

Table - 15. Experiment 1: Respondents' feedback on the selected quality attributes

Attributes	NOT Related to Quality	Related to Quality	Not answered	I am not sure
Documentation	0	88.9	0	11.1
Naming Convention	7.4	87	3.7	1.9
Minimality	3.7	87	1.9	7.4
Understandability	7.4	87	3.7	1.9
Relevancy	3.7	83.3	3.7	9.3
Extendibility	3.7	83.3	3.7	9.3
Semantic Correctness	1.9	81.5	3.7	13
Reliability	11.1	79.6	3.7	5.6
Usage of standard notations	3.7	79.6	3.7	13
Clarity	22.2	75.9	0	1.9
Completeness	7.4	75.9	3.7	13
Structural complexity	11.1	75.9	1.9	11.1
Expressiveness	0	74.1	3.7	22.2
Syntactic Correctness	13	74.1	3.7	9.3
Currency	3.7	74.1	3.7	18.5
Modularity	5.6	72.2	1.9	20.4
Size	16.7	70.4	3.7	9.3
Modifiability	11.1	70.4	1.9	16.7
User Vocabulary	11.1	64.8	3.7	20.4
Reusability	16.7	64.8	3.7	14.8
Implementability	22.2	63	3.7	11.1

It is clear from the Table - 15 and the bar chart (Figure - 49) above that there exist only three attributes in our selected set of quality attributes for which less than 70% of the respondents think that they are related to quality. Similarly, there are only two attributes (Clarity and Implementability) for which 22.2% of the respondents think that they are not related to quality. Thus, we can say that the selected set of quality attributes are well identified and represents the attributes that are also considered important by other populations.

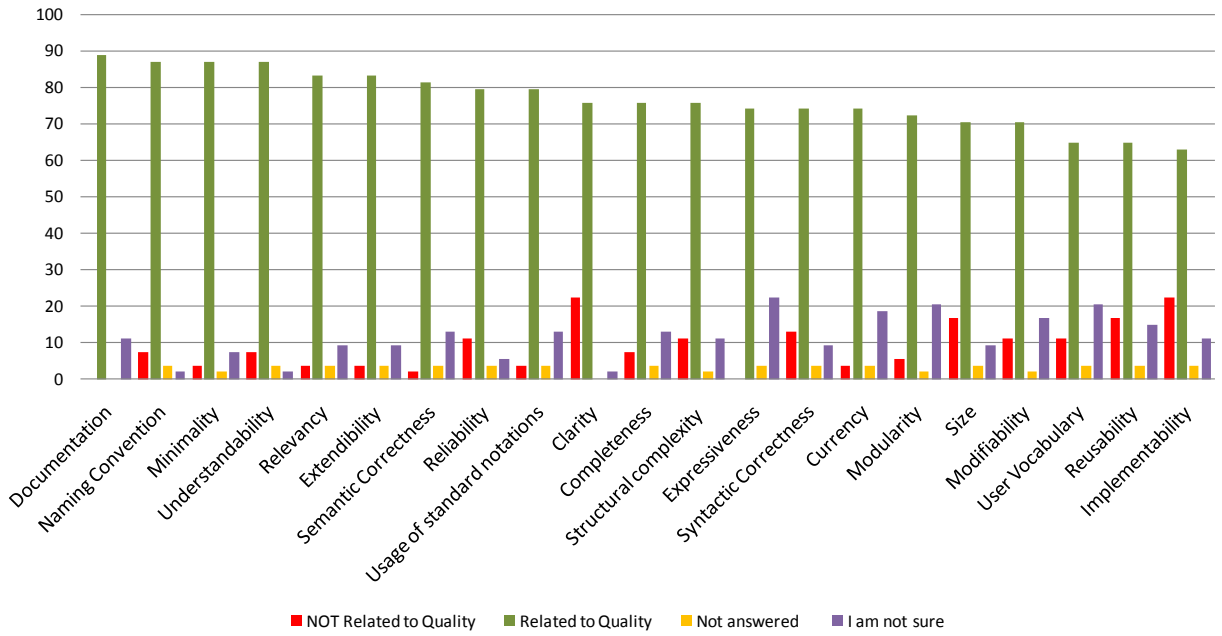


Figure - 49. Experiment 1: Bar chart depicting respondents' feedback on the selected quality attributes

In the last part of our survey, we tried to study the general practices and views of the professionals over the quality of conceptual models. We asked the respondents to list attributes that in their view are crucial to the quality of conceptual models. Similarly, we also asked them to identify attributes/properties that they might employ in choosing the best CM among multiple CM representing the same reality or modeling the same problem. This activity helped us in identifying a new quality attribute and also helped in extending the domain of the existing quality attributes. For example, a lot of our respondents listed the aspects related to practicability of the model to be relevant to quality. They consider that if models are not practicable due to implementation difficulties (such as unprocurable technology, scarce resources, etc.), design difficulties or time constraints then it is not good. Thus we selected practicability into our set of quality attributes. Practicability is different from the already existing implementability quality attribute as implementability is related only to the efforts needed for implementing a model meaning that the model is feasible and implementable. Whereas practicability is related to the factors that signify that the model is not feasible and implementable.

In the next section, we describe the experiment that was used to validate our proposed quality approach.

7.2 Validating the Proposed Quality Approach

In Chapter 3 we proposed quality patterns to capitalize existing knowledge and past experiences so that they can be reused in future. However, the viability of our proposed quality patterns can only be assessed/validated through an experiment. Thus, we used the class diagrams presented in Chapter 5 to formulate an experiment. This experiment consists of the following three steps:

i. In the first step, respondents were given the original class diagram in Chapter 5 and the set of requirements (Appendix-D) that was followed to make this class diagram. Respondents were required to analyze this CM (class diagram) to identify the problems in the model from the provided list. Later they were asked about their proposed solution to remove the identified problems. In this step, respondents were not provided with any information about any quality attributes or metrics. Thus, they had to use their cognition and/or previous knowledge/experience to identify the problems and solutions.

ii. In the second step, respondents were provided with a documentation that explains two quality patterns: model complexity quality pattern and model completeness quality pattern (described in Section-3.5.4 and Section-5.3.1.1). This documentation includes the problems targeted by these quality patterns and the proposed solution to answer these problems. The respondents were also provided the list of the calculated metrics so that relevant recommendations can be adapted by the respondents to improve the model. In the end respondents were required to answer the set of questions. Respondents were not required to actually do all the modifications in the model but to understand the provided quality patterns and apply them.

iii. In the third step, respondents were explained the problems that can be identified in the original model employing the two quality patterns given in the second step. Similarly, the solution to these problems was also explained to them that were proposed through these quality patterns. In addition, respondents were provided with the transformed models that resulted after applying all the recommendations, proposed through the quality patterns, on the original model provided in step1 (these models can be consulted from Chapter 5). Respondents were required to evaluate the transformed models and answer the questions.

In short this experiment consisted of three steps in which respondents were required to do the following:

i. Improve the quality of a model using their existing knowledge or cognition. With this exercise, we tried to study the cognitive efforts put in by respondents and the criteria employed by them to evaluate and improve the CM using their existing knowledge. Moreover, this step served as an interesting source of knowledge for identifying and enriching our proposed quality patterns.

ii. Improve the quality of a model using our proposed quality pattern concept. This step helped in validating the quality patterns' understandability and ease of use.

iii. Evaluate the results of quality improvement obtained by applying quality patterns on the given CM. This step helped in validating the efficiency of using quality patterns.

7.2.1 Sample

This experiment was given to evening M.Sc. students (in printed and/or electronic form) who have prior knowledge and experience about CM. Most of these students are currently employed in an organization. Moreover, this experiment was also sent to some professors and researchers from academics along with some analysts, project managers, developers, etc. from practice.

Twenty five respondents submitted all the three steps of the experiment. The low response rate was due to the length of the experiment. The experiment took approximately one hour (as communicated by some of our respondents). This experiment was sent to experienced respondents and most of them were employed. Therefore responding to such a lengthy experiment by a majority was a bit difficult. However, these 25 respondents came with different profiles and vast experiences. This sample size can be considered as sufficient to validate our approach due to the following reasons:

i. This was a very detailed and comprehensive experiment that demanded the respondents to actually understand the provided quality patterns and our approach, then apply these quality patterns on a complex model (provided) and finally respond to our questions. Thus the experiment didn't consist of questions that can be answered just by having an overview of the approach. The respondents can't answer to our questions without actually understanding all the provided material. We analyzed the collected data carefully to identify non-serious responses. We found that all the respondents completely read the provided material, understood our approach and carefully responded to our questions.

ii. All the respondents took part in the experiment voluntarily. They were told in advance that this experiment will take less than one hour. They were not offered any reward or gift

for taking part in this detailed experiment. So all the respondents submitted their responses purely on their will and interest in the experiment.

iii. All of our respondents knew about CM especially class diagrams (as the provided models were class diagrams) and most of them have prior experience in modeling.

iv. The responses to asked questions are converging and not dispersed. There is a clear convergence of respondents towards every question. For example 88% of our respondents think that quality patterns were easy to understand whereas only 12% consider they were not easy to understand. It would have been difficult to rely on this sample size if the responses of our respondents were very balanced for example, 55% would have responded in affirmation whereas the 45% in negation.

Respondents were required to provide information about their age and modeling experience. They have to select the modeling experience from the following six classes: Less than or equal to 1 year, between 1 & 3 years, between 3 & 5 years, between 5 & 10 years, between 10 & 20 years and more than 20 years. The details about selecting these classes for modeling experience and the method of calculating average modeling experience is the same as in the first experiment.

Table - 16 provides the basic information about the respondents. It can be seen that the respondents have an average modeling experience of 3.1 years.

Table - 16 . Experiment 2: General information about the respondents

Total Respondents	25
Average Age	31.1 years
Min Age	22.5 years
Max Age	50 years
Average Modeling Experience	3.1 years
Min Modeling Experience	Less than or equal to 1 year
Max Modeling Experience	Between 5 & 10 years

Figure - 50 illustrates the division of respondents with respect to their modeling experience. It can be seen that the majority of our respondents belong to a class having a modeling experience between three and five years. Similarly, we can also compute that 44% of our respondents have a modeling experience between three and twenty years including 12% having a modeling experience between 5 and 10 years. Moreover, we don't have any respondent having a modeling experience of more than 10 years.

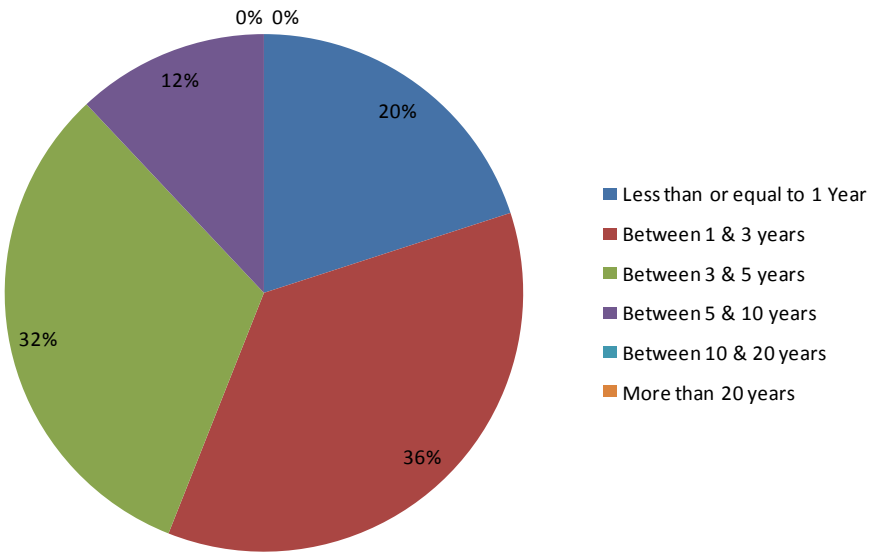


Figure - 50. Experiment 2: Respondents' division with respect to modeling experience

Respondents were required to provide information about their occupation so that different profiles of responses can be identified from the results or results can be interpreted based on occupation. Most of our respondents belong to either of the following five occupations: analysts, IS project managers, lecturers/professors, researchers, software developers with an exception of three who were respectively a technician, an IT-auditor and a chief technical officer (CTO) and are placed under "others". Table - 17 illustrates the division of respondents with respect to their occupation.

Table - 17 . Experiment 2: Classification of respondents with respect to occupation

Occupation	Student	Lecturer/ Professor	Researcher	Software Developer	Project Manager	Analyst	Other
Number of Respondents	9	1	2	4	5	1	3
Average Age	25.3	32.5	30	30	37.5	50	33.3
Min Age	22.5	32.5	27.5	27.5	32.5	50	27.5
Max Age	27.5	32.5	32.5	32.5	50	50	40
Average Modeling Experience	2.2	2	3	4.4	3.7	1	4.2
Min Modeling Experience	1	2	2	2	1	1	1
Max Modeling Experience	4	2	4	7.5	7.5	1	7.5

Pie chart in Figure - 51 displays the division of respondents with respect to their occupation. It can be seen that 12% of our respondents are academics (professors and researchers) compared to 52% from practice (including respondents classified under "other" as all the three are practitioners). However, 36% of our respondents were post graduate students. Minimum and maximum modeling experience are the average of the class boundaries. For example, maximum modeling experience of 7.5 year means that the respondent belongs to "between 5 and 10 years" class similarly, min modeling experience of 1 year means that the respondents belongs to "Less than or equal to 1 year" class.

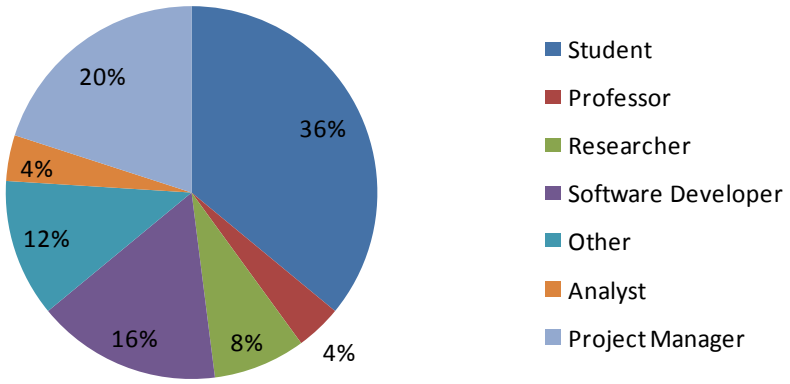


Figure - 51. Experiment 2: Respondents' division with respect to occupation

7.2.2 Data analysis:

This experiment consists of three steps. Respondents were provided with a different material for each step. They were required to follow the sequence of the steps and not to consult the documents of the next steps in advance. Neither can they modify their responses of the previous steps after consulting the documents of the next step. Each of the three steps were dependent on each other as we intended to compare the three different results sets to evaluate the efficacy of our proposed approach. For example, if the respondents read the documentation provided in the second step then they will know about the different quality attributes, metrics, recommendations for evaluating and improving the model. Thus their responses to the first step may be biased by this knowledge as we intend to test the respondent's cognition, past knowledge and past experience to identify the problems in the model without having any knowledge about our proposed approach or quality patterns.

In the next sub-sections we will analyze the results of each step.

7.2.2.1 Step-1:

Respondents were given a complex class diagram and an extract of requirements in the first step. This is the same class diagram (original model) that was used in Chapter 5 to test our proposed evaluation and improvement approach. Respondents were required to identify different problems or errors in the provided model. In this step, respondents were not provided with any information about any quality attribute or metrics. Thus, they have to use their cognition and/or previous knowledge/experience to identify the problems and solutions. There was no time limit so the respondents could take as much time as they want to understand the model and identify the problems. In the end, they were required to respond to the following two sets of information:

i. To select the problems in the provided model from the list

ii. To select the actions that they think should be used to modify the model to remove the identified problems

Table - 18 summarizes the respondents' responses to the provided list of problems. It can be seen that 10/25 (10 out of 25) respondents consider that numerous line crossings are a problem in the provided model. Similarly, 19/25 respondents think that the model contains numerous classes, attributes, etc. that increase the complexity of the model. However, it is interesting to note that all the respondents (25/25) consider the missing cardinalities, un-named associations, etc. (syntactic completeness) to be a problem in the model.

Table - 18. Experiment 2: Identified problems in the original model by the respondents

Understandability	Numerous line crossings	10/25
	Used language in the model	4/25
Complex	Number of classes, attributes, methods, etc. in the model	19/25
	Number of associations, aggregations, generalizations, etc. in the model	14/25
	Usage of standard notations	1/25
Incomplete	Missing requirements	10/25
	Syntactic completeness (missing cardinalities, un-named associations, etc.)	25/25
Remaining errors	Syntactic errors	10/25
	Semantic errors	13/25

Similarly, Table - 19 sums up the respondents' selection of actions to solve the problems identified in Table - 18. For example, twenty two respondents think that they would have improved the model by completing all the syntactic requirements. However, it is interesting to note that only 4 out of 25 respondents consider that factorizing associations can be of any help in

improving the model. The lower selection of this solution can be due to the incapability of the respondent to understand the concept of factorization of associations. Moreover, the most popular employed solution is to complete the syntactic requirements such as identifying the cardinalities and naming the associations.

Table - 19. Experiment 2: Respondents' identified solution to the problems in the original model

Our proposed solution	Selected as solution
Redraw the Diagram	6
Delete the classes arbitrarily	7
Merge the classes	13
Divide the model arbitrarily	6
Divide the model wrt some semantics	15
Factorize the associations	4
Complete all the requirements	10
Complete all the syntactic requirements	22
Remove all the syntactic errors	12
Remove all the semantic errors	14

For each of the above mentioned solution selected by the respondents, they were asked to provide details about their suggested actions or transformations that they might have employed as a solution. For example, as mentioned in Table - 19, thirteen respondents think that they would have improved the model by merging the classes. Thus each of these thirteen respondents was required to provide the details about the classes they think might be merged or how they would have merged the classes. But as mentioned in Table - 20, only 5 respondents completed the respected section for this solution and, among these 5 respondents, only 4 actually identified the classes that can be merged or suggested a way to merge the classes whereas one respondent just proposed to "merge the classes". Among all the received suggestions, two were discarded as they were not related to any of the solution mentioned in Table - 19.

Table - 20. Experiment 2: Respondents' suggested corrective actions in response to selected solution

Our proposed solution	Selected as solution	Responded to details	Actually Suggested details about transformation
Redraw the Diagram	6	0	0
Delete the classes arbitrarily	7	4	1
Merge the classes	13	5	4
Divide the model arbitrarily	6	0	0
Divide the model wrt some semantics	15	12	4
Factorize the associations	4	2	1
Complete all the requirements	10	6	2
Complete all the syntactic requirements	22	10	3
Remove all the syntactic errors	12	2	1
Remove all the semantic errors	14	0	0

7.2.2.2 Step-2

In the second step respondents were provided with details about model complexity and model completeness quality patterns (described in Section-3.5.4 and Section-5.3.1.1). These details include the problems targeted by these quality patterns and the proposed solution to solve these problems. Moreover, all the metrics that are used by these quality patterns for evaluation were calculated for the original model (provided in the first step) and were provided to the respondents. These metrics results helped the respondents in choosing the relevant recommendations from the provided quality patterns to improve the model. Respondents were not required to actually do all the modifications but to understand the evaluation and improvement process described in these two patterns so that they can realize the advantage/disadvantage of employing quality patterns for evaluating and improving the model. In the end respondents were required to answer the following seven questions (we have numbered the questions and these numbers will be used in the charts to represent these questions):

- Q1: Were the quality patterns easy to understand?
- Q2: Were the quality patterns easy to use?
- Q3: Did they help in identifying the problems?
- Q4: Did they identify the problems that you didn't identify before?

- Q5: Was the proposed solution good?
- Q6: Did they help in improving the initial model?
- Q7: Will you use the quality patterns in future?

Figure - 52 illustrates the respondents' answers to the above mentioned questions. It can be seen that 88% of the respondents think that quality patterns were easy to understand, 92% think that quality patterns helped in identifying the problems, 72% believed that quality patterns detected the problems that they couldn't detect in the step-1. Moreover, 88% of the respondents regard the proposed solution by quality patterns to be good and that it helped in improving the initial model. Similarly, 92% of the respondents want to use quality patterns in the future to evaluate and improve their models.

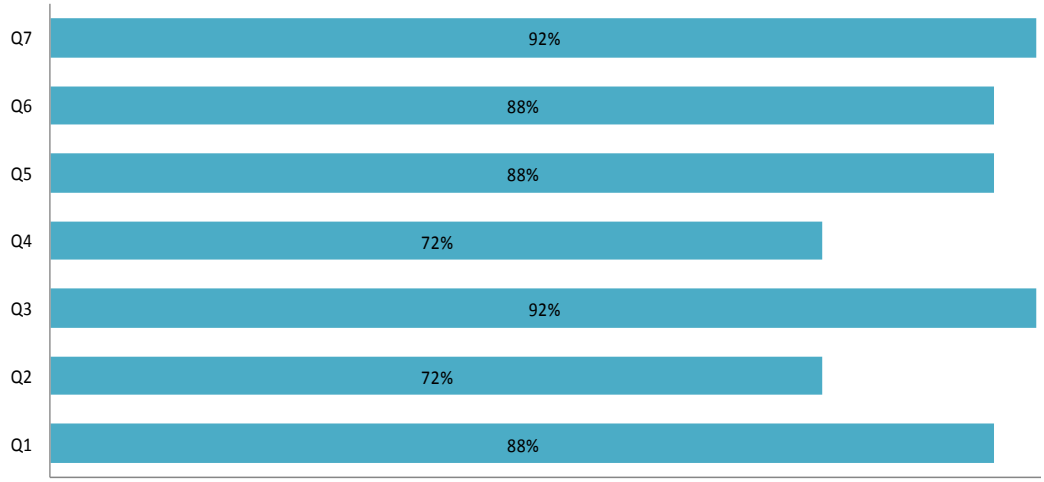


Figure - 52. Experiment 2: Respondents' feedback to questions asked in step-2

Table - 21 and Figure - 53 decompose the responses illustrated in Figure - 52 with respect to respondents' occupation. This decomposition will enable us in identifying the different profiles of responses. For example from Figure - 52, we learned that 92% of the respondents think that quality patterns helped in identifying the problems whereas from Figure - 53 we can see that this 92% is composed of 28% weightage from students and 64% from all others. However, it is interesting to note from Table - 21 that this 28% weightage actually represents 77% (7 out of 9) of the students. Similarly, the 64% weightage of all others represent 100% of the responses from all

other respondents. This can also be interpreted as that other than 23% students all other respondents considered that quality patterns actually helped in identifying the problems.

Table - 21. Experiment 2: Responses to questions asked in step-2 with respect to respondents' occupation

	Student	Professor	Researcher	Software Developer	Analyst	Project Manager	Other	Total
Q1	9/9	1/1	2/2	3/4	1/1	5/5	1/3	22/25
Q2	8/9	0/1	2/2	3/4	0/1	3/5	2/3	18/25
Q3	7/9	1/1	2/2	4/4	1/1	5/5	3/3	23/25
Q4	5/9	0/1	2/2	4/4	0/1	4/5	3/3	18/25
Q5	7/9	1/1	2/2	4/4	0/1	5/5	3/3	22/25
Q6	7/9	1/1	2/2	4/4	0/1	5/5	3/3	22/25
Q7	8/9	1/1	2/2	4/4	1/1	5/5	2/3	23/25
Total	9	1/1	2	4	1	5	3	

Let us take another example. Figure - 52 illustrates that 88% of the respondents regard the proposed solution by quality patterns to be good. Now if we look at chart on Figure - 53, we can notice that this 88% affirmation response is composed of 28% weightage from students, 0% weightage from analysts and 60% from all others. However, if we refer to detailed statistics in Table - 21 then we notice that this 28% weightage actually represent 77% (7 out of 9) of the students. Similarly, the 0% weightage from analysts represents 0% (0 out 1) positive response from analysts.

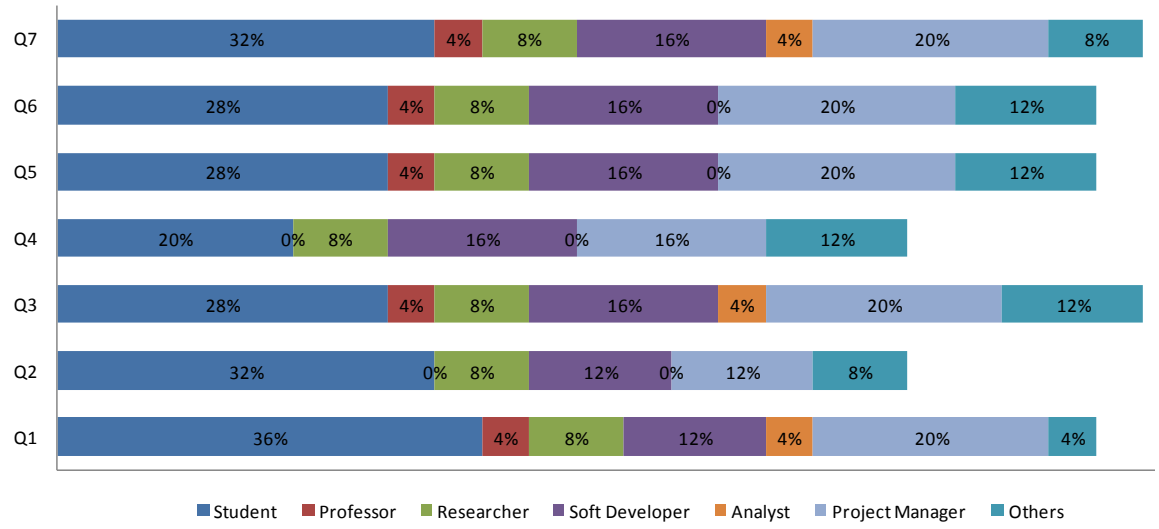


Figure - 53. Experiment 2: Respondents' feedback to questions asked in step-2 with respect to occupation

We decomposed the responses illustrated in Figure - 52 with respect to respondents' modeling experience into Figure - 54 and Table - 22 . This view will help us in analyzing the responses with respect to modeling experience. It is evident that if more experienced respondents think that our quality patterns don't help in identifying the problem then the weightage of their response should be of more importance to less experienced respondents. Let us analyze the responses for Q6 that enquires the respondents if the quality patterns helped in improving the initial model. From Figure - 52, we can see that 88% of the respondents think that quality patterns helped in improving the initial model. Whereas from Figure - 54, we can see that this 88% is composed of 32% weightage from respondents having modeling experience between 3 and 5 years whereas 12% have a modeling experience between 5 and 10 years and the remaining 44% includes the respondents having one to two years of modeling experience. However, it is interesting to note from Table - 22 that the 44% weightage from experienced respondents (with modeling experience between 3 and 10 years) actually represent 100% of respondents in these two classes ("between 3 and 5 years" and "between 5 and 10 years). Thus 12% reduction in the response of Q6 is due to the less experienced respondents (belonging to two lower experienced classes). From these views it can be thought that perhaps the proposed solution through quality patterns is better understood by more experienced respondents than less experienced due to their limited experience.

Table - 22. Experiment 2: Response to questions asked in step-2 with respect to modeling experience

	Less than or equal to 1 year	Between 1 & 3 years	Between 3 & 5 years	Between 5 & 10 years	Total
Q1	5/5	9/9	6/8	2/3	22/25
Q2	3/5	6/9	6/8	3/3	18/25
Q3	4/5	8/9	8/8	3/3	23/25
Q4	2/5	7/9	7/8	2/3	18/25
Q5	4/5	7/9	8/8	3/3	22/25
Q6	4/5	7/9	8/8	3/3	22/25
Q7	5/5	8/9	7/8	3/3	23/25
Total	5	9	8	3	

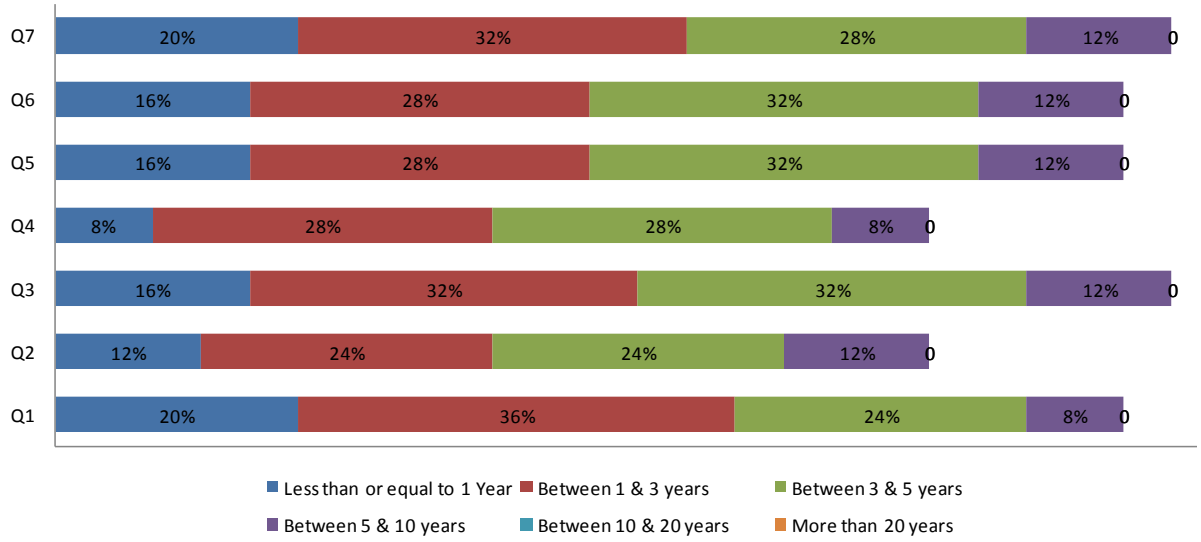


Figure - 54. Experiment 2: Respondents' feedback to questions asked in step-2 grouped by modeling experience

7.2.2.3 Step3

In the third step respondents were explained the problems that were identified in the original model employing the two quality patterns given in the second step. Similarly, the solution to these problems was also explained that were proposed through these quality patterns. In addition, respondents were given the transformed models that resulted after applying all the recommendations, proposed through the quality patterns, on the original model provided in step1

(these transformed models can be consulted from Chapter 5). In this step, respondents were required to evaluate the transformed models and answer the following three questions in addition to identifying the remaining problems or errors in the transformed model. Respondents were required to select the problems or errors from the same list as was provided in step-1 for original model. The three questions are:

- Q1: Are the new models easier to understand as compared to the initial model?
- Q2: Do the transformed models contain any errors?
- Q3: Have they solved the problems you identified in the first step?

Figure - 55 illustrates the respondents' responses to the above mentioned questions. It can be noticed that 96% of the respondents think that the transformed models are easier to understand as compared to the initial model. Similarly, 24% of the respondents think that the transformed models contain some errors whereas 84% of the responses suggest that the transformed models solved all the problems identified in the first step.

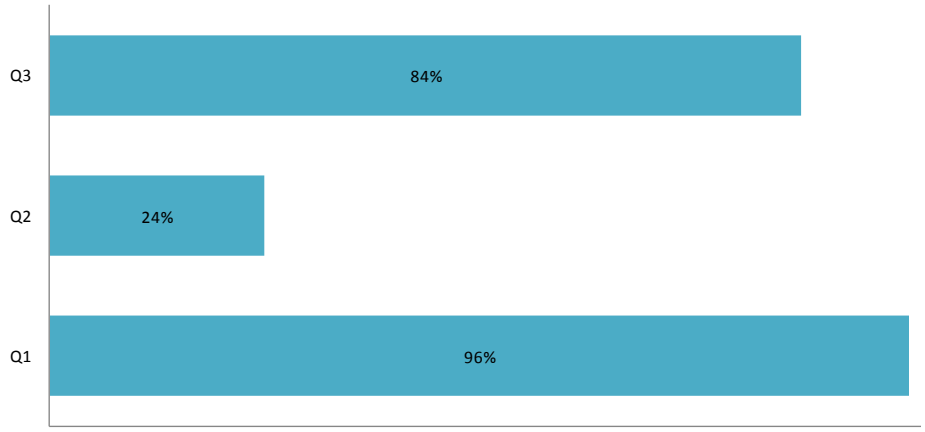


Figure - 55. Experiment 2: Respondents' feedback to questions asked in step-3

Table - 23 and Figure - 56 compare the number of errors identified by respondents in the original model and in the transformed model. It can be seen that the number of errors in the transformed model is reduced significantly implying that the quality patterns have actually helped

in improving the CM. For example, 10 respondents identified the missing requirements in the original model whereas 5 respondents identified the missing requirements in the transformed model. However it must be stated here that we have rechecked the transformed model with respect to the provided requirements (step-1) and found that the model represents all the requirements. Thus we are not sure about the requirements that are identified as missing by the 5 respondents.

Table - 23. Comparison between problems indetified in original and transformed model

		Original Model	**Transformed Model**
Understandability	Line crossings	10	2
	Used language	4	4
Complex	Numerous classes, attributes, etc.	19	8
	Numerous associations, generalizations, etc.	14	6
Incomplete	Usage of standard notations	1	1
	Missing requirements	10	5
	Syntactic incompleteness	25	5
Remaining errors	Syntactic errors	10	5
	Semantic errors	13	5

Similarly it is important to mention here that when the respondents identified the problems and errors in the original model (step-1), they have to rely on their cognition and past knowledge whereas when they identified the problems in the transformed model (step-3), they have sufficient knowledge about different quality attributes, metrics and recommendations. Thus it is for sure that they are more trained to identify errors now than in the first step. Thus this factor must be kept in mind while comparing the results of step-1 and step-3.

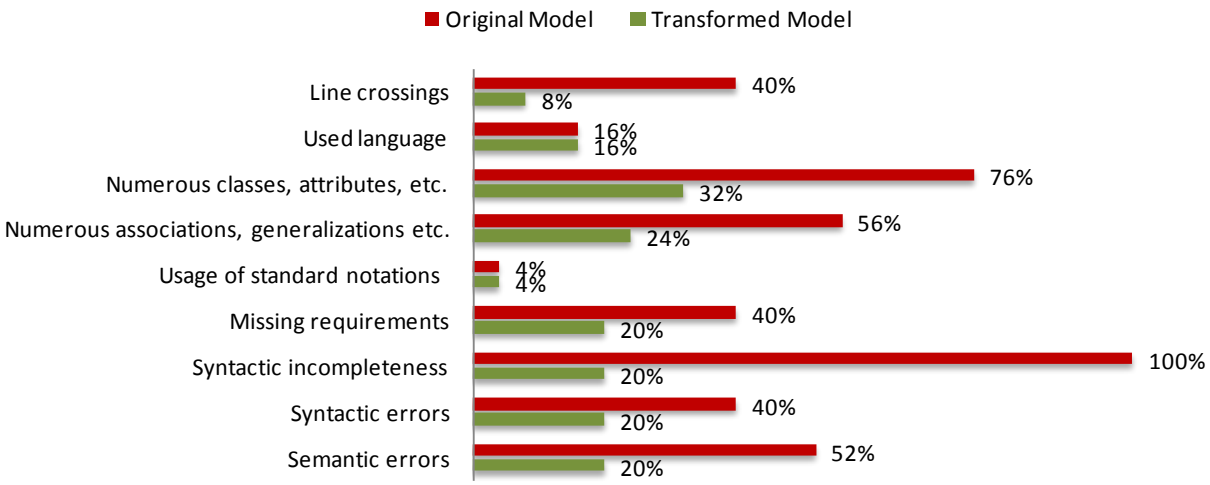


Figure - 56. Comparision of identified problems in original model and transformed model

7.3 Conclusion

In this chapter, we presented the two experiments that were conducted to validate our approach at different stages. We start by discussing our approach to federate the existing literature and to formulate a consolidated set of criteria for CM quality evaluation. We describe the first experiment and analyzed the results to validate the selection of the quality attributes federated thorough literature review. For both experiments, we employed Exploratory Data Analysis (EDA) [Hoaglin et al., 1983] approach for analyzing the data using multiple tables and charts.

In the next section, we discussed our second experiment that was conducted to validate the efficacy of our complete approach including quality patterns. This experiment consisted of three steps and respondents had to complete all the three steps and respond to our questions asked after each step. We analyzed the respondents' responses using multiple charts and tables. We also analyzed the different responses with respect to respondents' occupation and modeling experience classes. These different lenses helped us in identifying different trends and groups of responses and have also helped us in understanding the responses in a better way.

However following are the limitations of our experiments:

i. Most of the quality criteria provided by respondents as a feedback in first experiment consisted of those quality attributes that were already in the survey.

ii. The sample size of the second experiment is twenty five which is sufficient for our requirements but the results could be reinforced by a wider experiment.

iii. In step-1 of the second experiment, we intended to identify new solutions to the selected problems from the respondents but most of the respondents just provided the names of solution that were mentioned in the questions.

iv. Some of the problems identified, by respondents, in the transformed model don't exist in the model. For example, 8% respondents consider that the transformed model has line crossings whereas it doesn't have any line crossings.

v. The experiment was performed using two quality patterns only. So other quality patterns can be tested to identify different trends or responses.

vi. The quality patterns were applied only on one class diagram and thus they must be tested on multiple models to compare the results.

In the next chapter, we conclude the thesis and provide some perspectives and future extensions of the work.

Chapter 8
Conclusion

It has now been widely agreed that the quality of the end-system depends on the quality of the conceptual models (CM). Therefore, a good analysis and design method should ensure that CMs must adhere to some quality criteria, as they are the communicating mediator between the users and the development team. Hence if the conceptual models are scanned for defects and the defects be corrected then it is likely to reduce the number of change requests for the end system. Moreover, these errors and deficiencies in the CMs will not be propagated along the development process.

Research on CM quality evaluation is rather young and without any known standards. Due to the absence of any standards or guidelines for CM, different researchers have proposed different quality criteria or frameworks to evaluate CM quality. However, most of these frameworks are independent of one another [Moody 05] and emphasize on their identified characteristics as relevant to quality. This leads to the existence of disparate and autonomous quality frameworks proposing non-converging solutions and resulting in the existence of multiple definitions for the same concept and different names for semantically same concepts. Moreover, all existing criteria proposed by researchers have been classified by themselves into their self identified dimensions, attributes, characteristics, properties, etc. that are not even at the same level of abstraction as their other counterparts. Thus, the reader gets confused by the existence of different classification vocabularies such as dimensions, characteristics, properties, attributes, concepts, etc. and what differentiates each one of them.

We found that there is a lack of methodologies putting together the evaluation of CMs through a guidance process. Often the readers are left with a proposed set of evaluation criteria that can be used for evaluation. Thus if someone is interested in evaluating the CMs then he/she must have in depth knowledge about each and every available quality criterion so that the best set of evaluation criteria can be selected for the problem. Moreover, most of the existing quality frameworks help in identifying the problems rather than helping in removing those problems. Another major hurdle in evaluating the quality of conceptual models is the lack of tools automating the evaluation process and proposing corrective actions for improvements.

8.1 Contributions

Our solution targets the problems related to conceptual modeling quality in a comprehensive way. In order to formulate a complete solution, we designed multiple artifacts for different aspects of CM quality. These artifacts include the formulation of comprehensive quality criteria (quality attributes, metrics, etc.) by federating the existing quality frameworks and identifying the quality criteria for gray areas, formulation of quality patterns to encapsulate past-experiences and good practices, designing of the guided evaluation and improvement process for conceptual modeling quality and finally the development of a software prototype implementing our proposed quality aware approach and guided evaluation-cum-improvement process.

Most of the existing quality frameworks on CM are independent of one another and propose their vision of CM quality. This has resulted in the existence of disparate and autonomous quality frameworks proposing non-converging solutions. In reply, we synthesized (existing concepts proposed by researchers) and added the new concepts to formulate a comprehensive quality approach for conceptual models that also resulted in federating the existing quality frameworks. This activity enabled us in identifying a set of quality attributes that were generic (applicable to different types of conceptual model) and represent different aspects of the conceptual models such as complexity, maintainability, etc. Moreover, we were also able to eliminate the redundant concepts and issues related to the existence of multiple definitions for the same concept and different names for semantically identical concepts. After the formulation of this set of comprehensive quality criteria, we conducted a validation experiment on professionals to collect their feedback over the identified/selected set of quality criteria.

Even after the formulation of the above mentioned comprehensive quality criteria, we identified that the process for selecting the relevant quality criteria (including quality attributes and metrics) with respect to a particular requirement remains trickier for a non-expert user. Thus we proposed to adopt the concept of design patterns to store past-experiences and good practices and formulated a set of quality patterns. These quality patterns encapsulate valuable knowledge in the form of established and better solutions to resolve quality problems in CM. We identified different recurring problems in CM and proposed the best set of quality criteria for their evaluation and improvement and encapsulated this information in the form of quality patterns. Thus, we hope that efforts will not be duplicated in finding a good solution for the recurring problems for which a quality pattern exists.

In order to help the analysts (or anyone) in evaluation the quality of their CM, we designed a guided quality driven process encompassing methods and techniques to evaluate and improve the

conceptual models with respect to a specific user requirement or goal. Our process guides the user in formulating the desired quality goal, helps him/her in identifying the relevant quality patterns or quality attributes with respect to the quality goal and finally the process helps in evaluating the quality of the model and propose relevant recommendations for improvement.

We developed a software prototype "CM-Quality" implementing our proposed quality approach and guidance process for evaluating and improving CMs. Our prototype automates all the above mentioned steps of our approach and implements a workflow enabling its users to evaluate and improve CMs efficiently and effectively. CM-Quality maintains a knowledgebase storing different quality concepts such as quality patterns, quality attributes, metrics, recommendations, etc. It helps the users in formulating their quality goals in a structured manner. It then helps the users in identifying the relevant quality criteria with respect to their formulated quality goal by automatically searching the contents of the knowledgebase. After the selection of the quality concepts (quality patterns and quality attributes), CM-Quality evaluates the model by automatically calculating the different metrics associated to the selected quality concepts. It then proposed the post-evaluation feedback in the form of recommendations for model improvement.

8.2 Future Work – Perspectives

Our thesis opens multiple directions for future research. This future work could be extensions to the actual work or new perspectives that are new work.

The first research direction aiming at extending our work includes the enrichment of quality criteria such as identifying new quality patterns, new quality attributes and new metrics. For example, we have included numerous metrics for class diagrams in our knowledgebase. Therefore different metrics can be formulated for other types of conceptual models such as use case diagrams, sequence diagrams, etc. Similarly, some new and more effective metrics could be formulated to replace the existing metrics.

The second research direction, for improving the actual work, includes the extension of our prototype in the following ways:

i. To integrate an ontology of quality concepts (if exists) to help the identification of relevant quality concepts efficiently.

ii. To include the automatic application of proposed transformations. In our approach transformation are a kind of recommendations. The current version of our prototype provides details about the relevant transformations whereas the application of these transformations is a manual process. However, if transformations can be applied

automatically then perhaps a good model can be extracted from a crude one in a short span of time.

iii. In the current state, CM-Quality evaluates the complete model and proposes recommendations for the entire model. For example, it can propose recommendations related to model's complexity if the entire model is complex or it can recommend employing the polymorphism pattern to manage the complexity but it can't identify the exact portion of model where this recommendation or pattern must be applied. It will be a milestone achievement if an extension in this direction can be made. This will help the user in identifying the exact problem areas of the model so that they can be targeted to improve the overall model.

iv. To integrate CM-Quality to existing modelers as an add-on so that quality evaluation is available on the same time as modeling. At the current stage, users have to first design the model and then do the evaluation whereas if quality evaluation is available at runtime or during the designing of the models, then it will be frequently used by users to evaluate and improve their models.

The third research direction could be to formulate an ontology of quality concepts for CM. As of today there doesn't exist any such ontology. With the advent of such ontology, the identification of relevant quality criteria or quality concepts will be much easier. This ontology will also help to consolidate the existing quality frameworks at one place and can be used to identify relationships among these concepts.

The fourth research direction can be to provide the analysts with a means to improve the CM with respect to desired value of a quality attribute. For example, if the user wants that his/her model should have complexity=0 then the model should be evaluated and recommendations should be proposed in a way that the value of complexity attribute becomes 0 if all the recommendations are applied. Now consider an example when a user wants to have complexity=0% and maintainability=90%, thus the recommendations should be proposed in a way that when the model is transformed, the new model will have exact values for complexity and maintainability.

Appendix A
Quality Attributes

Following are the details about quality attributes.

1. Clarity

This attribute is based on the graphical arrangement of the elements within a model. It evaluates the model quality by referring to the number of elements (such as classes, use cases, attributes, etc.) present in the model and the number of line crossings they have. This attribute is based on the hypothesis that the greater the number of elements present in a model the less clearer it gets and thus poses difficulty in reading the model. Similarly if there are more line-crossings in a model (such as ER diagram or class diagram) then it might be difficult to track the links and thus it might gets difficult to understand the concept.

2. Completeness

This attribute is based on the coverage of user requirements. It will try to evaluate the quality by comparing the conformance between concepts depicted in the conceptual model and the ones expressed by the users through the requirements. Furthermore, this attribute can be used to compare completeness among several schemas modeling the same reality. A schema is considered complete if it covers all the modeling elements present in other schemas representing the same reality.

3. Currency

This attribute evaluates the quality based on the currency of the model. With currency we means to check whether the model represent the actual implemented version of the model. For example, a database administrator has added a new attribute in the table without updating the database model then this model does not represent the actual underlying structure.

4. Documentation

It is based on the assumption that well documented models will be easily readable and understandable. If documentation is provided for every modeling element (such as classes, attributes, etc.) then it will help the reader in understanding the model quickly and easily.

5. Extendibility

Software extension is an important and recurring activity as new requirements continue to emerge within the organization. Therefore, if conceptual models are designed in such a way that they can be extended to accommodate the new requirements then it will ease the software extension process. This attribute is based on the ease with which a model can be extended to include new concepts or functionality. However, we hypothesize that if conceptual models have high degree of modularity then they can accommodate new concepts easily and thus have highly extendible.

6. Expressiveness

This attribute evaluates the expressiveness of a model. A model is expressive if it represents users' requirements in natural way and is understandable without additional explanation. It evaluates whether the employed concepts are expressive enough to capture the main aspects of the reality. E.g. Inheritance link is more expressive then association. So the more the expressive concepts are used, the more the schema will be expressive.

7. Modifiability

This dimension is based on the attributes that evaluates the ease with which a model can be maintained. This dimension is based on the hypothesis that the quality of the model can be represented by its degree of maintainability. Several researchers have showed that complexity in models affect its maintainability or modifiability. Similarly, the ability to understand a model contributes towards its maintainability. However, understandability can be ameliorated by the use of standard notations or guidelines.

8. Minimality

This attribute is based on the notion of the redundant elements and is directly or indirectly related to other attributes. It is based on the hypothesis that the model gets more and more

complex if it contains redundant concepts. Similarly, it is equally based on the notion of reusability. If the concepts are reused in the model then it will decrease the size and structural complexity of the model and thus will contribute towards decreasing its complexity.

9. Modularity

This attribute is based on the object-oriented practices and hypothesize that high modularity leads to ease in maintainability. However, this attribute extends its domain and evaluates the modularity by verifying the cohesion and coupling of the modules. Cohesion can be defined as a measure to calculate the grouping of the common responsibilities or functionalities within one module. It is deemed to have high cohesion in the module to have the common responsibilities grouped in the same class. Similarly, coupling can be defined as the dependency of the module to rely on other existing modules. Coupling is deemed to be as low as possible to have less reliance on other modules and thus to have ease in maintainability.

10. Naming Convention

It is based on the assumption that the clear and consistent naming will result in the high readability of a model. For example if a model uses "FN" to denote a First Name of an Employee then it will require more effort to decode the abbreviated variable than if it would have used "FirstName" as the variable. Moreover, this attribute will try to evaluate the different aspects related to naming such as it will try to check whether the associations are named or not in a class diagram.

11. Practicability

This attribute is based on the notion of feasibility of the model. It verifies whether the model employs the concepts or elements that are realistic and can be materialized. For example, there can be some models that require unprocurable sophisticated technology for implementation.

12. Relevancy to requirements

This attribute is different from "Completeness" in a way that it is employed for finding the relevancy between the concepts present in the model and the ones required by the users. It will

help in removing the irrelevant concepts present in the model thus will implicitly affect the complexity and functionality dimensions.

13. Reliability

This attribute is crucial to quality in a way that if the model is not reliable then it can jeopardize all the later stages of the system development. This is a composite attribute and depends on almost all of the above-mentioned functionality attributes. In simple words, we can say that a model is reliable if it covers all the requirements of the users, does not cover any irrelevant concepts i.e. it is minimal and is practicable.

14. Reusability

This attribute has been widely recognized and appreciated in the Object Oriented Paradigm. Reusability is considered a major opportunity for improving quality and productivity of systems development. This attribute evaluates the quality of the model in twofold: First, it checks whether the model employs the previously developed models (e.g. use of existing modules) and secondly it helps in evaluating the chances of this model to be reused in the future (e.g. is it very specific or generic?). Some studies suggest that reusability is feasible only if planned at the design stage because of loss of generalizability at subsequent stages.

15. Semantic Correctness

Schema is semantically correct if the concepts are used according to their definition. This attribute takes into account the semantic quality dimension defined in [Lindland et al., 1994]. We hypothesize that if we have formalized knowledge about the problem domain then we can evaluate this attribute by measuring differences between the model and the knowledge domain. Semantic correctness can also be measured by comparing the model with available and validated models representing the same reality. This attribute can use collaboration patterns to improve the evaluation process.

16. Size

This attribute evaluates the overall complexity of the model with respect to the number of instances of different elements present in the model. It is based on the hypothesis that the more

there are structural elements in the model the more it gets complex. These elements can include entities, classes, use cases, actors, attributes, methods, etc. This attribute does not take into account elements such as associations, generalization relationships, dependencies, etc. as they relate to the structural complexity of the model.

17. Structural Complexity

This attribute represents the model complexity due to the existence of different relational elements within the model. These elements can include associations, aggregations, generalizations, dependencies, transitions, relationships, etc. This attribute will contain several metrics that will measure the different aspects of the structural complexity of the model.

18. Syntactic Correctness

Schema is syntactically correct if the concepts are properly defined in the schema. This attribute takes into account the syntactic quality dimension defined in [Lindland et al., 1994]. Though [Purao et al., 2003] mentions about the maturity of the controls over the syntactic quality issues in conceptual models, this attribute will make sure that every concept is defined as per the valid syntactic rules of the employed grammar.

19. Understandability

This attribute is based on the hypothesis that the ease in model understanding leads to ease in its maintenance. This attribute will try to evaluate the ease with which the model can be understood. However, understandability is dependent on other attributes such as those in Readability and Complexity dimension. The authors in [Genero et al., 2004] have shown that complexity in models leads to low understandability and thus affect the maintainability of the model.

20. Usage of Standard Notations

This attribute evaluate the model on its usage of standard language or notations. Here by ‘standard language or notations’ we mean the use of widely acceptable notations to represent the models such as the use of Unified Modeling Language or Entity Relationship notations. Here we

hypothesize that the use of standard notation for the formulation of models will lead to higher understandability and analyzability and thus will contribute in the easy in maintenance.

21. User Vocabulary

It is based on the assumption that the readability of a model will enhance if the reader can make easy correspondence between the modeling elements contained in the conceptual schema and the requirements in the textual description. Such as using ‘Employee’ label to represent employees of the company rather than using ‘Emp’ label.

Appendix B
Quality Patterns

Following are the identified quality patterns.

1. Model Completeness Quality Pattern

Pattern Name: Model Completeness

Context:

i. To check if the model is complete with respect to syntactic and semantics. This pattern should be employed to validate and improve the model for its completeness.

Problem:

i. Incomplete conceptual models (CM) pose threat to the later stages of development as they will result in an end system that doesn't provide all the functionalities it was conceived for. So the CM should be evaluated for any missing user requirements.

ii. Similarly, if CM is not syntactically complete then it can hamper the understandability of the model. Syntactic completeness relates to the notation used (e.g. verifying that multiplicities are defined for associations or associations have a valid name in a class diagram)

iii. Calculate the following metrics (metrics 2 and 3 are applicable to class diagram only) to check if this pattern is relevant for the current problems of the model:

   d. Requirements Coverage Degree [Cherfi et al., 2003]: This metric is based on the notion of completeness of user requirements. It has been widely accepted that if the requirements errors are detected earlier in the designing phase then the cost of their correction gets much lower. This metric calculates the ratio between the concepts covered by the modeling elements in the conceptual schema and the ones expressed by the users through the requirements.

Let:

X = Number of requirements covered by modeling elements;

Y = Total number of requirements;

Then:

$$\text{Requirements Coverage Degree} = \frac{X}{Y}$$

Range:

Requirements Coverage Degree = 1, if all the requirements expressed by user are covered in the conceptual model.

Requirements Coverage Degree = 0, if none of the requirements expressed by user are covered in the conceptual model.

e. Degree of defined multiplicities: This metric calculates the ratio between the total numbers of defined multiplicities within a model to the total number of associations in a model.

Let:

X = Number of defined (or existing) multiplicities or cardinalities;

Y = Number of association links;

Z = Number of composition and aggregation links;

Then:

$$\text{Degree of Defined Multiplicities} = \frac{X}{2 * Y + Z}$$

Range:

Degree of Defined Multiplicities=1, if both ends of the association links, compositions links and aggregation links are defined.

Degree of Defined Multiplicities=0, if no multiplicities are defined in the model.

f. Degree of named associations: If proper naming is assigned to every relationship or association then it enhances the understandability of the model. This metric calculates the ratio between the number of named associations and the total associations.

Let:

W = Number of named relationships or associations;

X = Number of association links;

Y = Number of association classes;

Z = Number of composition and aggregation links;

Then:

$$\text{Degree of Named Associations} = \frac{W}{X - Y + Z}$$

Range:

Degree of Named Associations = 1, if all the association links, compositions links and aggregation links are defined except those association links that have association classes.

Degree of Named Associations = 0, if no associations are named in the model.

Solution:

i. CM should incorporate all the requirements demanded by users.

ii. CM should contain all the syntactic elements required by the target modeling notation.

iii. Following transformations can be used for improvement:

a. Incorporate missing requirements

b. Define missing multiplicities

c. Define missing associations labels

Keywords: completeness; syntactic completeness; semantic completeness; requirements coverage;

Related patterns:

2. Model Complexity Quality Pattern

Pattern Name: Model Complexity

Context:

v. To check the overall complexity of the model with respect to the number of instances of different elements (number of classes/entities/attributes etc) present in the model. This pattern is suitable for models containing numerous elements.

Problem:

i. Sometimes models contain several classes/entities/uses-cases etc. This can hamper the understandability of the model. Miller ("The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information", 1956) have proved that adults can hold 7 ± 2 objects in their working memory.

ii. Similarly, the existence of numerous elements can induce complexity.

iii. This induced complexity can hamper the maintainability as complex models are difficult to maintain.

iv. Calculate the following metrics (following metrics are applicable to class diagram only) to check if this pattern is relevant for the current problems of the model:

k. Number of Classes: Total number of classes in a model.

l. Number of Attributes: Total number of attributes in model.

m. Number of Methods: Total number of methods or functions in the model.

n. Number of cycles: Total number of cycles within a model.

o. Degree of non-redundancy [Cherfi et al., 2002b]: This metric calculates the ratio between the non-redundant concepts and the total concepts present in the model.

p. Number of Associations: Total number of associations in a model.

q. Number of Aggregations: It calculates the number of aggregation relationships within a class diagram.

r. Number of Compositions: It calculates the number of composition relationships within a class diagram.

s. Number of Generalizations: It calculates the total number of generalization relationships in a model.

t. Depth Inheritance Tree: It calculates the longest path from the class to the root of the hierarchy in a generalization hierarchy.

Let:

Xi belongs to class, association, inheritance link, association class, aggregation link, composition link;

NB(Xi) = Number of elements of type Xi;

NBR(Xi) = Number of redundant elements of type Xi in the model;

Then:

$$\frac{\sum_{i}\left(NB(Xi)-NBR(Xi)\right)}{\sum_{i}NB(Xi)}$$

Range:

Degree of Non-Redundancy = 1, if the model doesn't contain any redundant concept.

Degree of Non-Redundancy = 0, if the model contains all the concepts that are redundant.

Solution:

i. Models can be made simpler if they are divided into small independent modules each with limited number of concepts and functionalities.

ii. Following transformations can be employed for improvement:

a. Remove redundant elements

b. Factorize associations to remove redundant associations

c. Divide the model

d. Merge classes

e. Divide a class

iii. Following design pattern can be employed to improve the quality of the model:

c. GRASP high cohesion pattern

d. GRASP polymorphism pattern

Keywords: complexity; maintainability; modify; understandability; size; number of classes/entities etc.; number of concepts; number of attributes;

Related patterns:

i. Model Evolution (Complex model are difficult to maintain)

ii. Model Readability (models containing numerous elements can be difficult to read)

3. Model Correctness Quality Pattern

Pattern Name: Model Correctness

Context:

ii. To check if the model is syntactically correct i.e. every concept in the model is defined as per the valid syntactic rules of the employed grammar and semantically correct i.e. the concepts are used as per their definition in the target domain. This pattern can be used to evaluate and improve the model for its correctness.

Problem:

v. Syntactically incorrect CM doesn't model the concepts correctly with respect to the employed grammar and are thus difficult to understand by different users.

vi. Semantically incorrect conceptual models (CM) can jeopardize the development of the end system as if the requirements are not correctly depicted in the CM then the system will not perform the functions in the same way as it should be.

vii. Similarly, if the requirements are wrongly modeled then the developed system will be unacceptable to the user (e.g. if client follows American accounting principles then he/she will not accept the systems based on British accounting principles).

viii. Calculate the following metrics to check if the model is incorrect or contains errors:

   d. Degree of syntactic correctness: This metric is based on the syntactic correctness of the CM. This metric calculates the ratio between the syntactic errors and the total errors identified in the CM.

Let:

X = Number of existing syntactic errors;

Y = Total number of errors identified in the model;

Then:

$$\text{Degree of Syntactic Correctness} = \frac{X}{Y}$$

Range:

Degree of Syntactic Correctness=1, if CM contains only syntactic errors.

Degree of Syntactic Correctness=0, if CM doesn't contain any syntactic errors.

e. Degree of semantic correctness: This metric calculates the ratio between the number of semantic errors and the total number of errors identified in the model.

Let:

X = Number of existing semantic errors;

Y = Total number of errors identified in the model;

Then:

$$\text{Degree of Semantic Correctness} = \frac{X}{Y}$$

Range:

Degree of Semantic Correctness=1, if CM contains only semantic errors.

Degree of Semantic Correctness=0, if CM doesn't contain any semantic errors.

f. Degree of relevant requirements: This metric is based on the notion of relevancy between the concepts present in the model and the ones required by the users. Irrelevant concepts in the model affect the complexity and functionality. This metric calculates the ratio

between the number of irrelevant requirements modeled in the CM and the total number of the requirements communicated by the user.

Let:

X = Number of irrelevant requirements identified from the model;

Y = Total number of requirements communicated by the user;

Then:

$$\text{Degree of Relevant Requirements} = \frac{X}{Y}$$

Range:

Degree of Relevant Requirements=1, if CM modeled all the irrelevant requirements.

Degree of Relevant Requirements=0, if CM contains all the relevant requirements.

Solution:

i. Remove all the syntactic errors from the CM.

ii. Remove all the semantic errors from the CM i.e. all the concepts modeled in the CM should be defined with respect to the target domain.

iii. Remove all the irrelevant concepts from the model.

iv. Add all the missing relevant concepts.

Keywords: correctness; syntactic correctness; semantic correctness; relevant requirements; irrelevant requirements;

Related patterns:

4. Model Evolution Quality Pattern

Pattern Name: Model Evolution

Context:

i. To check whether the model is easy to modify or extend for future or changing requirements. This pattern can be used to validate and improve the model with respect to modifiability and extension.

Problem:

i. Modification or extension is a continuous and important activity for any software project. They account the most in any maintenance contract. However, sometimes it gets difficult to incorporate the required changes into models due to the complexity of the models. Different researchers have empirically shown that complexity in models hampers their modifiability or extension.

ii. Similarly, if the models are not modular or the defined modules have high values of coupling then the modification to one module can pose problems to other modules and might require extensive modifications.

iii. Following metrics can be calculated to check if this pattern is relevant for the current problems of the model:

   a. Cohesion: Cohesion can be defined as a measure to calculate the grouping of the common responsibilities or functionalities within one module. It is deemed to have high cohesion in the module to have the common responsibilities grouped in the same class. This metric is defined in [Cherfi et al., 2003a].

Let:

X(i) = Number of links within a module i;

Y(i) = Number of couples of modeling elements that can be constructed from module i;

Z = Number of modules in a model;

Then:

$$\text{Cohesion} = \frac{\sum_{i=1}^{Z} X(i)/Y(i)}{Z}$$

Range:

Cohesion =1, if all modules have the same number of links as the number of couples.

b. Coupling: Coupling can be defined as the dependency of the module to rely on other existing modules. Coupling is deemed to be as low as possible to have less reliance on other modules and thus to have ease in maintainability. This metric calculates the number of other concepts to which a concept is coupled. Low value for this metric signifies that the model is modular and promotes encapsulation. This metric is defined in [Cherfi et al., 2003a].

Let:

X = Number of links relating different modules;

Then:

Coupling = X

Range:

Coupling = 0, if all the modules are independent of one another.

Coupling > 0, if at least two modules are dependent on each other.

c. Calculate the following metrics for complexity (following metrics are applicable to class diagram only and these metrics are defined in *Model Complexity Quality Pattern*): number of classes, number of attributes, number of methods, number of cycles, degree of non-redundancy, number of associations, number of aggregations, number of compositions, number of generalizations, depth inheritance tree.

Solution:

i. Models should be divided into smaller modules with limited number of modeling elements to reduce complexity as structural complexity in models leads to low modifiability and thus directly affects the maintainability of the model.

ii. Modules should be identified in such a way that all the related functionalities and responsibilities are grouped into the same module to increase the cohesion.

iii. Modules must be independent of each other and must be loosely coupled with other modules.

iv. Following transformations can be employed for reducing the model complexity:

   a. Remove redundant elements

   b. Factorize associations to remove redundant associations

   c. Divide the model

   d. Merge classes

   e. Divide a class

v. Following design pattern can be employed to improve the quality of the model:

   a. GRASP high cohesion pattern

   b. GRASP polymorphism pattern

Keywords: maintainability; modifiability; extendibility; modularity;

Related patterns:

i. Model Complexity

5. Model Feasibility Quality Pattern

Pattern Name: Model Feasibility

Context:

i. To validate if the model is the feasible and practical to implement.

ii. To validate if the model employs the concepts or elements that are realistic and can be materialized. This pattern should be employed to validate and improve the feasibility and practicability of the model.

Problem:

i. CM can employ the concepts or elements that are not realistic and can be difficult to materialize. For example, there can be some models that require unprocurable sophisticated technology for implementation such as asking for an automatic feed from a manual system.

ii. In the current age, technology is changing rapidly hence systems tends to upgrade to new platforms or supports new technologies. For example, previously softwares were designed to work on computers whereas with the advent of smart phones, most of the software vendors tend to provide their software for mobile devices. Thus if CM are specific to some target technology then they can't be used to develop systems for other technologies and the efforts will be duplicated. However, if the CM be made as generic as possible then they can be implementation using any technology.

iii. Similarly, models might incorporate irrelevant requirements or semantically different but relevant requirements. If the requirements are wrongly modeled then the developed system will be unacceptable to the user. Thus all the functionalities should conform to users' requirements.

iv. Calculate the following metrics to check if this pattern is relevant for the current problems of the model:

   a. Degree of conformance to target technology: This metric verifies if the concepts depicted in the model can be implemented in the target language. It calculates the ratio between the number of concepts that can be implemented in the target language and the total number of concepts in the model.

Let:

X = Number of concepts that can be implemented in the target language;

Y = Total number of concepts in a model;

Then:

$$\text{Degree of conformance to target technology} = \frac{X}{Y}$$

Range:

Degree of conformance to target technology=1, if all the concepts can be implemented in the target technology.

Degree of conformance to target technology=0, if none of the concepts can be implemented in the target technology.

b. Degree of tool dependant functionality: This metric is based on the notion of generic models. If models are generic then they can be implemented in any target technology whereas if the models are specific to some target technology then they might not remain valid for other technologies. This metric calculates the ratio between the concepts that are specific to some target technology to the total number of concepts.

Let:

X = Number of concepts that are specific to some target technology;

Y = Total number of concepts in a model;

Then:

$$\text{Degree of tool dependant functionality} = \frac{X}{Y}$$

Range:

Degree of tool dependant technology=1, if all the concepts are specific to some target technology.

Degree of tool dependant technology=0, if none of the concept is specific to some target technology.

c. Calculate the degree of relevant requirements metrics. This metrics is defined in *Model Correctness Quality Pattern.*

Solution:

i. CM must try to be as generic as possible. Thus, if possible, replace all the tool specific (or language specific) concepts by the generic concepts.

ii. As mentioned above, it is beneficial to have generic CM. However, if model contains some language specific concepts then ensure that those concepts are implementable in the desired target language. If not then replace all those concepts with the desired target language specific concepts.

iii. Remove all the irrelevant concepts from the model.

iv. Model must incorporate the relevant requirements in their true sense and there must not be any difference between the concepts present in the model and the ones expressed in user requirements.

v. Add all the missing relevant concepts.

Appendix B:
Quality Patterns

Keywords: practicability; feasibility; relevancy to requirements; irrelevant requirements; tool dependency; conformance with target technology;

Related patterns:

6. Model Readability Quality Pattern

Pattern Name: Model Readability

Context:

i. To check if the model is easy to read i.e. the model must not demand additional efforts to read. These efforts can be due to any reasons such as bad graphical arrangements, aesthetics, language barrier etc. For example, if the model contains numerous line crossings then it demands additional efforts to identify the linking objects (such as classes in a class diagram). This pattern can be used to evaluate and improve the model for its readability.

Problem:

i. Models can have poor arrangement of graphical objects within them and thus increases the number of line crossings and hampers the clarity of the model. Similarly, a model can contain several concepts and object within them (lack of modularity) and can also use inappropriate font size thus making it difficult to read.

ii. Similarly, due to increasing outsourcing or offshore procurement projects, it has been observed that the technical documents or CM are written in the language chosen by the vendor. This language might not be acceptable to the end-user. For example, technical document or models written in English language might not be acceptable to French speaking end user. The situation gets worse if the user is unfamiliar with the character-set of the model language such as Chinese character-set for English speaking user. Such language barriers require additional efforts for readability.

iii. Calculate the following metrics to check if the model is difficult to read:

   a. Graphical Objects per Model: This metrics calculates the total number of graphical objects per model (such as classes, entities, associations etc.). It has been argued by the researchers that structural complexity increases when the number of model elements increases. Thus the greater the number of graphical objects in a model, the greater the efforts required to read and understand it.

   b. Degree of line crossings: This metric is based on the graphical arrangement of the elements within a model. If model elements are not well arranged or if model contains

numerous elements then the number of line crossings may increase and it gets difficult to read the model. This metric calculates the ratio between the number of line crossings and the total number of links (such as associations, relationships, etc.).

Let:

X = Number of line crossings in a model;

Y = Total number of links such as relationships, associations, etc. within a model;

Then:

$$\text{Degree of Line Crossings} = \frac{X}{Y}$$

Range:

Degree of Line crossings = 0, if CM doesn't contain any line crossing.

Degree of Line crossings > 0, if CM contains at least one line crossing.

c. Degree of legible font size: This metrics is used to evaluate the font size of different texts on the model. It calculates the ratio between the number of text objects that are below the optimum font size (i.e. difficult to read) to the total number of text objects.

Let:

X = Number of text objects below the optimum font size;

Y = Total number of text objects in the model;

Then:

$$\text{Degree of Legible Font Size} = \frac{X}{Y}$$

Range:

Degree of Legible Font Size=1, if all the text objects are below the optimum font size i.e. all text objects are difficult to read.

Degree of Legible Font Size=0, if all the text objects are equal and above the optimum font size i.e. all text objects are easy to read.

d. Language vocabulary rate: This metrics is based on the assumption that the readability of a model will enhance if the model is written in a language known to user. For example, if CM is written in Chinese language then it is difficult to read by the user who doesn't know Chinese character-set. This metric calculates the ratio between the number of text items that are in an unfamiliar language and the total number of text items in the model

Let:

X = Number of text items in an unfamiliar language;

Y = Total number of text items in the model;

Then:

$$\text{Language Vocabulary Rate} = \frac{X}{Y}$$

Range:

Language Vocabulary Rate=1, if all the text items are in an unfamiliar language.

Language Vocabulary Rate=0, if all the text items are in a familiar language.

Solution:

i. Models should be divided into small modules with limited number of concepts and objects per model to improve the clarity. Following transformations can be employed for improvement:

   f. Divide the model

   g. Merge classes

   h. Remove redundant elements

   i. Factorize associations to remove redundant associations

ii. Graphical objects in the model must be arranged in a way to reduce the number of line crossings. This can be done in the following way:

   a. Place the objects (such as classes) with the most links (such as associations in class diagram) in the center of the model and all the associating objects (other classes) surrounding them.

   b. Try bending the lines (instead of straight lines) to reduce the line crossings.

   c. If intersection is unavoidable then use bridge symbol (⌒) to maintain the distinction between the two lines.

iii. All the text objects should employ proper font size to increase the legibility of the model.

iv. CMs should use the language acceptable to user.

Keywords: clarity; legibility; line crossings; font size; graphical objects per model;

Related patterns:

7. Model Reception Quality Pattern

Pattern Name: Model Reception

Context:

i. This pattern can be used to evaluate and improve the CM with respect to its reception by the user.

ii. To check whether the model uses terms and language that are end-user friendly.

Problem:

i. If CM uses texts/labels in an unknown language or character-set, with respect to the user, then the benefits of CM might not be attained.

ii. If models use difficult terms or labels then they might not be perceived correctly by the user.

iii. Similarly, if a lot of technical vocabulary is used in the models then the non-technical users might fail to perceive the model's objective correctly.

   a. Calculate the following metrics to check if the model can be perceived correctly by the end user: user vocabulary rate, technical vocabulary rate, language vocabulary rate, etc. These metrics are explained in the "Model Understandability Quality Pattern".

Solution:

i. Utilize basic and simple terms as much as possible.

ii. Replace the terms unknown to user by the known terms.

iii. Replace the technical terms/labels from the model to the common/non-technical terms/labels.

iv. CMs should use the language acceptable to user.

Keywords: model perception; reception; user vocabulary; used language; technical vocabulary; target language;

Related patterns:

i. Model understandability

ii. Model readability

8. Model Reliability Quality Pattern

Pattern Name: Model Reliability

Context:

i. To validate if the model can be relied for later stages of development.

ii. To validate if the model is up-to-date with respect to the implemented model or other developed models.

Problem:

i. Software failures are generally caused by errors that could result from decisions during analysis. Every concepts depicted in the model must be verifiable through some requirement document. If the concepts can't be verified then either they are irrelevant or misunderstood.

ii. Versioning issues are very common in ISD and it has been witnessed that upcoming modifications are directly incorporated into the system without updating the model thus users are left with two different versions of same model.

iii. Similarly, during the alpha or beta testing, new or changing requirements are directly implemented into the systems without updating the CMs thus jeopardizing the future maintenance operations.

iv. Following metrics can be calculated to check if this pattern is relevant for the current problems of the model:

   a. Verifiability: This metric verifies if the concepts depicted in the model can be relied for future development. This metric calculates the ratio between the number of concepts that can be verified from the user requirements and the total number of concepts.

Let:

X = Number of concepts that can be verified from the user requirements;

Y = Total number of concepts in a model;

Then:

$$\text{Verifiability} = \frac{X}{Y}$$

Range:

Verifiability=1, if all the concepts are verifiable through user requirements.

Verifiability=0, if none of the concept is verifiable through user requirements.

b. Versioning Control: This metric ensures that the CM is up-to-date with respect to the implementation model. It calculates the ratio between the implemented concepts that are not modeled in the CM and the total number of concepts.

Let:

X = Number of implemented concepts not present in the model;

Y = Total number of implemented concepts;

Then:

$$\text{Versioning Control} = \frac{X}{Y}$$

Range:

Versioning Control=1, if none of the implemented concepts are present in the CM i.e. CM is totally different from the implemented model.

Versioning Control=0, if all the implemented concepts are present in the CM.

c. Recency: This metric ensures that the CM is up-to-date with respect to the upcoming new/modified requirements (through change order requests). It calculates the ratio between the concepts that can be extracted from the new/changing requirements (through change order request or other documents) and are implemented to the system but are absent from the CM and the total number of concepts extracted from these new/changing requirements.

Let:

X = Number of implemented concepts, from new / changing requirements, that are absent from the CM;

Y = Total number of concepts extracted from the new / changing requirements;

Then:

$$\text{Recency} = \frac{X}{Y}$$

Range:

Recency=1, if none of the concepts from the new/changing requirements are also modeled in the CM i.e. CM is out-of-date after the modifications.

Recency=0, if All the concepts from the new/changing requirements are also modeled in the CM i.e. CM is up-of-date.

Solution:

i. Recheck if the concepts present in CM and missing from the requirements documents are not irrelevant or misunderstood. If they are irrelevant then they should be removed from the model whereas if they are misunderstood then they should be implemented correctly.

ii. All the concepts that are implemented during the modifications must also be updated in the CM.

iii. All the concepts from the new/changing requirements must also be implemented in the CM.

Keywords: reliability; currency; recency; verifiability; versioning control;

Related patterns:

9. Model Reusability Quality Pattern

Pattern Name: Model Reusability

Context:

i. The context of this quality pattern is twofold. First it verifies if the model employs the previously developed models (e.g. use of existing modules) and secondly it checks if this model can be reused in future (for example to check if this model is specific or generic).

Problem:

i. Reusability is considered a major opportunity for improving quality and productivity of systems development. Studies suggest that reusability is feasible only if planned at the design stage because of loss of generalizability at subsequent stages. Thus, it is important to verify the reusability of the models.

ii. Evaluating and improving reusability in model is important since it enhances the system's functional reliability because the reused component/module has been tested multiple times therefore errors and deficiencies would have been rectified during its maturity cycle.

iii. Similarly, some models are designed in a way that they get very specific and cannot be reused in future thus can waste future resources.

iv. Moreover, if the models are not modular or the modules are not properly identified then the reusability of the model will be compromised.

v. Following metrics can be calculated to check if this pattern is relevant for the above mentioned problems:

   a. Reusability Degree: This metric calculates the ratio between the number of reused concepts and the total concepts present in the model.

Let:

X = Number of reused concepts;

Y = Total number of concepts in a model;

Then:

$$\text{Reusability Degree} = \frac{X}{Y}$$

Range:

Reusability Degree =1, if all the concepts in a model are reused from exiting modules.

Reusability Degree =0, if none of the concepts in a model are reused from exiting modules.

b. Overall model reuse. This metric is adopted from [Basili et al., 1990]. It calculates the aggregated reuse of the whole model by summing the reuse of every individual concept in the model. This metric uses the following formula for calculation:

Let:

X = Any concept present in the model;

Reuse(X) = Count of all the ancestors of the concept "X" and the concepts inherited by concept "X"

I = Number of all the distinct concepts in the model

Then:

$$\text{Reuse (Model)} = \sum_{I} \text{Reuse } (X_I)$$

Range:

Overall Model Reuse = ∞, if all the concepts have multiple ancestors and numerous inherited concepts.

Overall Model Reuse = 0, if none of the concept has any ancestor or any children.

c. Calculate the cohesion and coupling metrics for modularity. These metrics are defined in *Model Evolution Quality Pattern.*

Solution:

i. Search the model to identify the concepts for which equivalent concepts exists in the repository for reusability.

ii. Decompose the model into multiple independent modules to facilitate the reusability.

iii. Modules should be identified in such a way that all the related functionalities and responsibilities are grouped into the same module to increase the cohesion.

iv. Modules must be independent of each other and must be loosely coupled with other modules.

v. Following design pattern can be employed to improve the modularity of the model that will enhance the reusability of the model:

   a. GRASP high cohesion pattern

   b. GRASP polymorphism pattern

Keywords: reusability; reusability degree; model reuse; modularity;

Related patterns:

ii. Model Evolution

10. Model Semantic Completeness Quality Pattern

Pattern Name: Model Semantic Completeness

Context:

i. To check if the model incorporates all the requirements demanded by the user and the domain of the model. This pattern should be employed to validate and improve the model for its semantic completeness.

Problem:

i. Incomplete CM poses threat to the later stages of development as they will result in an end system that doesn't provide all the functionalities it was conceived for. So the CM should be evaluated for any missing user requirements.

ii. Similarly, CM should also take into account the specific requirements of the modeled domain otherwise the developed system will not work properly. Most of the time user requirements don't incorporate the domain specific requirements. For example, user requirements can state that the future system should be based on American accounting principles but it will not state the details about the Accounting principles. This supplementary information is critical to the success of the system and must be taken care in the CM.

iii. Calculate the *requirements coverage degree* metric to check if this pattern is relevant for the current problems of the model. This metric is described in *Model Completeness Quality pattern*.

Solution:

i. CM should incorporate all the requirements demanded by users.

ii. CM should contain all the domain specific required.

iii. Following transformations can be used for improvement:

   a. Incorporate missing requirements

   b. Incorporate the missing domain specific requirements

Keywords: semantic completeness; completeness; requirements coverage;

Related patterns:

i. Model completeness

ii. Model syntactic completeness

11. Model Semantic Correctness Quality Pattern

Pattern Name: Model Semantic Correctness

Context:

i. To check if the model is semantically correct i.e. the concepts are used as per their definition in the target domain. This pattern can be used to evaluate and improve the model with respect to semantic correctness.

Problem:

i. Semantically incorrect conceptual models (CM) can jeopardize the development of the end system as if the requirements are not correctly depicted in the CM then the system will not perform the functions in the same way as it should be.

ii. Similarly, if the requirements are wrongly modeled then the developed system will be unacceptable to the user (e.g. if client follows American accounting principles then he/she will not accept the systems based on British accounting principles).

iii. Metrics such as *degree of semantic correctness*, *degree of relevant requirements* etc. can be calculated to check if the model is semantically incorrect or contains semantic errors:

Solution:

i. Remove all the semantic errors from the CM.

ii. All the modeled concepts should adhere to their definition in the target domain.

iii. Remove all the irrelevant concepts from the model.

iv. Add all the missing relevant concepts.

Keywords: correctness; semantic correctness; relevant requirements; irrelevant requirements;

Related patterns:

i. Model Correctness

ii. Model Syntactic correctness

12. Model Size Quality Pattern

Pattern Name: Model Size

Context:

i. To check the complexity of the model with respect to the number of instances of numerous classes/entities/attributes etc present in the model. This pattern is suitable for models containing several classes/entities/attributes etc. However, this pattern does not take into account elements such as associations, generalization relationships, dependencies etc. as they relate to the structural complexity of the model.

Problem:

i. Large CM contains several classes/entities/uses-cases etc. that hampers the understandability and induce complexity.

ii. This induced complexity can hamper the maintainability as complex models are difficult to maintain.

iii. Calculate the following metrics to check if this pattern is relevant for the current problems of the model: number of classes, number of entities, number of use-cases, number of attributes, number of methods, etc. Some of these metrics are described in Model Complexity Quality pattern.

Solution:

i. Models can be made simpler if they are divided into small independent modules each with limited number of classes/entities/attributes/methods etc.

ii. Following transformations can be employed for improvement:

   a. Remove redundant elements

   b. Divide the model

   c. Merge classes/entities

Keywords: size; complexity; maintainability; understandability; number of classes/entities etc.; number of concepts; number of attributes;

Related patterns:

i. Model structural complexity

ii. Model complexity

iii. Model evolution

13. Model Structural Complexity Quality Pattern

Pattern Name: Model Structural Complexity

Context:

i. To check the structural complexity of the model with respect to the number of associations/relationships/depth inheritance tree etc. present in the model. This pattern is suitable for models containing numerous associations/ relationships/ generalizations/ compositions/aggregations etc. However, this pattern does not take into account elements such as classes, attributes, methods etc. as they relate to the size of the model.

Problem:

i. CM gets complex due to the existence of numerous different relational elements within the model. These elements can include associations, aggregations, generalizations, dependencies, transitions, relationships etc. that hampers the understandability and induce complexity.

ii. Similarly, complexity also can be increased due to the existence of multiple level of inheritance.

iii. Calculate the following metrics to check if this pattern is relevant for the current problems of the model: number of relationships, number of associations, number of aggregations, number of compositions, number of generalizations, depth inheritance tree, etc. Some of these metrics are described in Model Complexity Quality pattern.

Solution:

i. Models can be made simpler if they are divided into small independent modules each with limited number of concepts and functionalities.

ii. Following transformations can be employed for improvement:

   a. Remove redundant elements

   b. Factorize associations to remove redundant associations

c. Divide the model

d. Merge classes

iii. GRASP high cohesion pattern can be employed to improve the quality of the model.

Keywords: structural complexity; maintainability; modify; understandability; number of associations/relationships etc.; depth inheritance tree;

Related patterns:

i. Model size

ii. Model complexity

iii. Model evolution

14. Model Syntactic Completeness Quality Pattern

Pattern Name: Model Syntactic Completeness

Context:

i. To check if the model is syntactically complete i.e. to check if associations have proper labels, multiplicities or cardinalities are defined, data types are defined for attributes, etc.

Problem:

i. If CM is not syntactically complete then it can hamper the understandability of the model.

ii. Syntactic completeness relates to the notation used (e.g. verifying that multiplicities are defined for associations or associations have a valid name in a class diagram etc.)

iii. If the information such as attribute data type, function return type, parameters etc. are missing from the model then the chances of errors can enhance during the implementation.

iv. Calculate the following metrics to check if this pattern is relevant for the current problems of the model: degree of defined multiplicities, degree of named associations, percentage of defined attribute types, etc. Some of these metrics are described in *Model Completeness Quality pattern*.

Solution:

i. CM should contain all the syntactic elements proposed by the target modeling notation.

ii. Following transformations can be used for improvement:

   a. Define missing multiplicities

   b. Define missing associations labels

   c. Declare the data types of all the attributes

   d. Define all the parameter of the functions

   e. Declare the return type of all the functions

Keywords: syntactic completeness; completeness; named associations; defined cardinalities;

Related patterns:

i. Model semantic completeness

ii. Model completeness

15. Model Syntactic Correctness Quality Pattern

Pattern Name: Model Syntactic Correctness

Context:

i. This pattern can be used to check if the model is syntactically correct i.e. every concept in the model is defined as per the valid syntactic rules of the employed grammar.

Problem:

i. Syntactically incorrect CM doesn't model the concepts correctly with respect to the employed grammar or notations.

ii. Syntactically incorrect models are thus confusing and difficult to understand by different users.

iii. Metrics such as degree of syntactic correctness and degree of single notation can be calculated to check if this pattern can be used for the problem in hand. These metrics are described in Model Completeness Quality pattern and Model Understandability Quality Pattern respectively.

Solution:

i. Remove all the syntactic errors from the CM.

ii. If model employs more than one notation then model should be redesigned employing a single notation.

Keywords: correctness; syntactic correctness;

Related patterns:

i. Model correctness

ii. Model semantic correctness

16. Model Understandability Quality Pattern

Pattern Name: Model Understandability

Context:

i. To check whether model is easy to understand.

ii. To verify that the model employs widely accepted and standard notations such as UML, ER models etc to increase understandability.

iii. To verify that the model employs concepts that is more expressive in defining the relationships between different concepts. Such as using inheritance relationships where applicable instead of associations.

iv. To check whether the model employ terms and language that are easy to understand by the end-user.

v. To check whether the model elements are documented to help better understanding.

vi. To check whether the model uses consistent naming throughout the model.

Problem:

i. If models are not understandable then they are difficult to maintain or modify.

ii. If CM employs notations that are not standardized or common, it affects its understandability. Similarly, a model can contain different notations such as using UML and ER notations in one model that is syntactically wrong.

iii. Models frequently use concepts that are easy to manage but are less expressive. Such as using multiple associations to denote an inheritance relationship. However, if expressive concepts are used then they simplify their understanding.

iv. Understandability of a model is enhanced if the reader can make easy correspondence between the modeling elements contained in the conceptual schema and the requirements in the textual description. Similarly, if a lot of technical vocabulary is used in the models then it might be difficult for others to understand the model without additional efforts.

v. Each of the model elements (or concepts) should be documented to provide additional information to its user for enhancing their understandability. Whereas, several model elements are left with no documentation thus causing difficulties in their understanding.

vi. Consist naming plays a vital role in enhancing the understanding of a model. Naming convention has long been used in programming for easy navigation and simplistic understanding of code. Whereas models sometimes fail to follow any naming convention and might include multiple spellings to denote a single concept. For example, a model can use 'EMPLOYEE' label at one class to denote the employee, whereas it uses 'EMPL' label to denote employee for an association thus confusing the reader.

vii. Similarly, due to increasing outsourcing or offshore procurement projects, it has been observed that the technical documents or CM are written in the language chosen by the vendor. This language might not be acceptable to the end-user. For example, technical document or models written in English language might not be acceptable to French speaking end user. The situation gets worse if the user is unfamiliar with the character-set of the model language such as Chinese character-set for English speaking user. Such language barriers require additional efforts for readability.

viii. Calculate the following metrics to check if the model is easy to understand:

a. Degree of single notation: A model must restrict to one and only notation. Using multiple notations within a single model creates confusion leading to difficulty in understanding and is a semantic error. This metric calculates the ratio between the numbers of model elements conforming to one notation (such as how many model elements conform to class diagram notations in a class diagram) to al the model elements.

Let:

X = Number of model elements conforming to a single target notation;

Y = Total number of model elements;

Then:

$$\text{Degree of Single Notation} = \frac{X}{Y}$$

Range:

Degree of single notation = 1, if model restricts to only one modeling notation.

Degree of single notation < 1, if model employs more than one modeling notation.

b. Expressiveness. This metric is described in [Cherfi et al., 2002b]. It measures whether the used concepts are expressive enough to capture the main aspects of the reality. For example, Inheritance link is more expressive then association. So the more the expressive concepts are used, the more the schema will be expressive and easy to understand. Similarly we can also calculate the expressiveness of the schema as a whole. A schema is said to be expressive when it represents users' requirements in natural way and can be easily understood without additional explanation. This metric assigns the weights of every concept and then takes the ratio between the calculated total value of the schema and the union of all the schemas describing the same reality.

c. User Vocabulary Rate: It is based on the assumption that the understandability of a model will be enhanced if the reader can make easy correspondence between the modeling elements contained in the conceptual schema and the requirements in the textual description. This metric calculates the ratio between the number of user specific labels (those labels/terms that are also present in requirements documents) to the total number of labels.

Let:

X = Number of user specific labels in the model;

Y = Total number of labels in the model

Then:

$$\text{User Vocabulary Rate} = \frac{X}{Y}$$

Range:

User Vocabulary Rate = 1, if all the employed labels including the associations names are also found in the requirements documents so user can make easy correspondence.

User Vocabulary Rate = 0, if all the employed labels are new to user and is not present in the requirements documents.

d. Technical vocabulary rate: It is based on the assumption that the understandability of a model will be enhanced if the reader can make easy correspondence between the

modeling elements contained in the conceptual schema and the requirements in the textual description.

Let:

X = Number of technical labels in the model;

Y = Total number of labels in the model

Then:

$$\text{Technical Vocabulary Rate} = \frac{X}{Y}$$

Range:

Technical Vocabulary Rate = 1, if all the employed labels including the associations names are technical terms instead of common language terms.

Technical Vocabulary Rate = 0, if all the employed labels are common language terms instead of technical terms.

e. Documentation Degree: It is based on the assumption that well defined schemas have comments associated with each of the modeling elements (classes, attributes etc.).

Let:

X = Number of documented modeling elements in the model;

Y = Total number of modeling elements in the model

Then:

$$\text{Documentation Degree} = \frac{X}{Y}$$

Range:

Documentation Degree = 1, if all the modeling elements have documentation or comments attached to it.

Documentation Degree = 0, if none of the modeling elements have documentation or comments attached to it.

f. Degree of conformed names: If all modeling elements conform to a proper naming convention then it enhances the understandability of the model. Users can easily identify the type and other information about that modeling element just by looking at

its name. This metric calculates the ratio between the numbers of the conformed names in a model to the total number of names within a model.

Let:

X = Number of conformed names in a model;

Y = Total number of names in the model;

Then:

$$\text{Degree of Conformed Names} = \frac{X}{Y}$$

Range:

Degree of conformed names = 1, if all the names conform to a single naming convention.

Degree of conformed names = 0, if none of the name conform to a single naming convention.

g. Language vocabulary rate: familiarity with the model's language and character-set enhances its understandability. This metrics is explained in the *"Model Readability Quality Pattern"*.

Solution:

i. CM must employ a widely accepted and standard notation for ease in understandability such as UML or ER. Thus if CM is designed using some non standard notations then it should be redesigned employing an appropriate standard notation.

ii. Model must employs one and only one notation that must be acceptable to user. Thus, if model employs more than one notation then model should be redesigned employing a single notation.

iii. Identify all the portions and relationships where a less expressive concept has been employed and that can be substituted by more expressive concepts. This will help in communicating the user requirements in a more natural way and with less concepts.

iv. Replace the terms unknown to user by the known terms. Use the same terms as in the requirement document to enhance the end-user understandability.

v. Utilize basic and simple terms as much as possible.

vi. Replace the technical terms/labels from the model to the common/non-technical terms/labels.

vii. Provide additional documentation and comments for every model elements.

viii. Models should use clear and consistent naming to enhance the understandability of a model. For example, programmers frequently use small "m" before naming any method and uses small "v" before naming any variable. Similarly, models should use same spelling to denote one concept throughout the model.

ix. CMs should use the language acceptable to user.

Keywords: standard notations; expressiveness; schema expressiveness; concept expressiveness; user vocabulary; used language; technical vocabulary; target language; naming convention; conformed names; multiple spellings.

Related patterns:

i. Model complexity

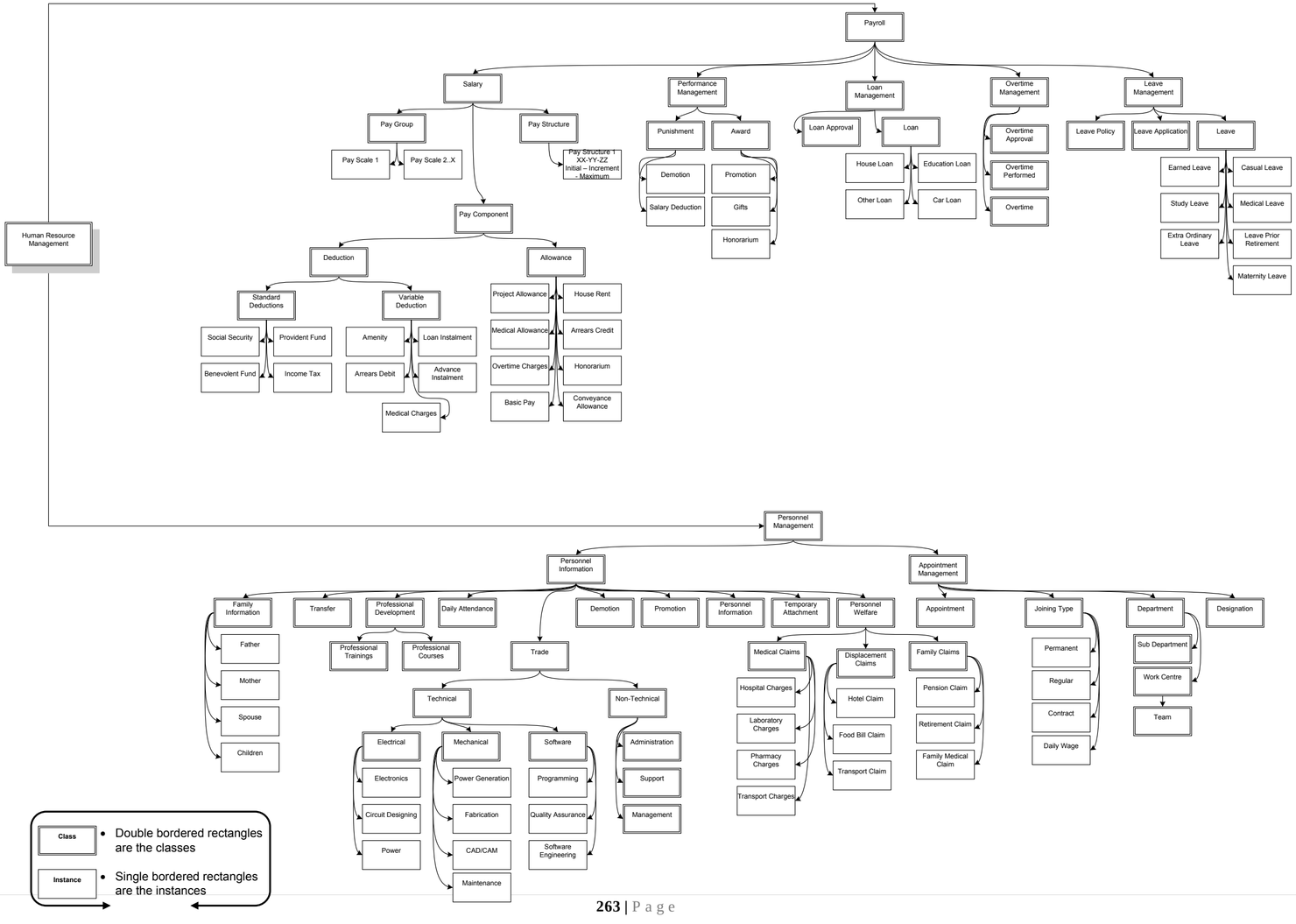
ii. Model readability

iii. Model reception

Appendix C
Human Resource Ontology

Appendix C:

Human Resource Ontology



Appendix D
User Requirements for Case Study

The Following requirements, as specified by the user, will be employed to calculate the requirement coverage degree metric. These are only parts of the requirements:

i. Each personnel (employees are referred to as personnel) has a unique identification number.

ii. Information such as name, address, employment date, marital status, etc. should be included into the system.

iii. Personnel could be either a regular employee or a permanent employee or on contract basis.

iv. Personnel should belong to either of the two categories: technical or non technical

   a. Technical personnel could be either related to software or hardware trade.

      - Software personnel must belong to either of the following specializations: analyst, programmer, tester or documenter.
      - Hardware personnel must be either of the following: Network support, hardware maintenance, installations.

   b. Similarly, non technical personnel must be either of the following: Management, administrative, support and services.

v. Every personnel is authorized with a limited amount of leaves.

vi. Leaves are of the following six types: Earned leaves, casual leaves, study leaves extra ordinary leaves, leave prior retirement and medical leaves.

Appendix E

CM-Quality Evaluation Report

CM-Quality Evaluation Report

Formulated Goal:

Purpose of the goal is to analyze Product (Conceptual Model)
For Evaluation with Respect to Correctness,
For Evaluation with Respect to Complexity
From the Manager point of view

Results:

Pattern Name:
Model Complexity Quality Pattern

Attribute Name
Size

Metric Name: Number of Classes

Model Element	Values
Complete Conceptual Model	46

Recommendation: Divide the model (to reduce semantic complexity)

Application Criteria (Metric Value):

Description: Model division can be done in two ways: Structural Division and Semantic Division

i. Structural division is an easier but non-efficient method. Randomly select the model elements and divide them into multiple modules. But bad selection of elements can leads to low cohesion and high coupling among the resulting modules.
ii. Semantic division is a difficult but efficient method. Read the model carefully (or use some existing domain ontology) and classify the model elements with respect to some similarity or relationship. For example, classify the elements with respect to common

functionality or interdependency. The elements with common set of goals or functionalities should be grouped together as a module. Such division will increase the cohesion and reduces the coupling. Similarly, existing ontology can be used to identify different semantic groups.

iii. Another possible type of division is to identify the complex parts of the model and divide them into multiple modules to reduce the complexity.

Related References: Asunción Gómez-Pérez, Jaime Ramírez and Boris Villazón-Terrazas: An Ontology for Modelling Human Resources Management based on standards. KES (1) 2007: 534-541.

Recommendation: Merge Classes

Application Criteria (Metric Value):

Description: Concepts with similar functionalities can be merged as one or can be removed to reduce redundant concepts.

i. Sort all the relevant and related attributes/functions among different classes.
ii. Package related attributes and functions within same class to increase cohesion.

Related References: NIL

Recommendation: High Cohesion GRASP design pattern (to increase cohesion)

Application Criteria (Metric Value):

Description: We propose to employ high cohesion GRASP pattern to reduce model complexity by reducing the complexity of the source class as in-cohesive classes are inefficient, large and complex. Thus perform the following tasks:

i. Assign class the responsibilities related to other responsibilities of the class.
ii. Find if the class contains methods that this class shouldn't be responsible for and delegate the responsibility of this method to the suitable class.

Related References: http://en.wikipedia.org/wiki/GRASP_(object-oriented_design)

Recommendation: Polymorphism GRASP design pattern

Application Criteria (Metric Value):

Description: Use High Polymorphism Pattern to reduce the complexity and increase the cohesion of the class. Following steps can be performed:

iv. When related behaviors vary by class type then the responsibilities should be assigned polymorphically to the specialization classes. Polymorphism Pattern increases the cohesion.
v. Identify all the hierarchies in the model.

vi. Within each hierarchy, identify if a parent class implements a method that could have different implementation for its children. If yes, then this method should be assigned to all the specialized classes to reduce the complexity of the class.

vii. For example, different shapes can use overrided polymorphic Draw() function to draw their shape by themselves instead of one complex generic function to draw all types of shapes.

Related References: http://en.wikipedia.org/wiki/GRASP_(object-oriented_design)

Metric Name: Number of Attributes

Model Element	Values
Complete Conceptual Model	174

Recommendations: Divide a class

Application Criteria (Metric Value):

Description: If there are numerous attributes within a single class then perform the following steps:

i. Identify the attributes or functions that are irrelevant within the scope of the class (to increase cohesion).

ii. Try adding these attributes/functions to the existing relevant class.

iii. If no class exists that is relevant for these attributes/functions, then add these attributes and functions in a new class and define the associations.

iv. If all the attributes/functions are relevant to the class then classify them into obligatory and optional and then split the class into two classes: one containing all the obligatory attributes/functions and the other containing all the optional attributes/functions.

Related References: NIL

Metric Name: Number of Methods

Model Element	Values
Complete Conceptual Model	120

Recommendations: Divide a class

Application Criteria (Metric Value):

Description: If there are numerous attributes within a single class then perform the following steps:

i. Identify the attributes or functions that are irrelevant within the scope of the class (to increase cohesion).
ii. Try adding these attributes/functions to the existing relevant class.
iii. If no class exists that is relevant for these attributes/functions, then add these attributes and functions in a new class and define the associations.
iv. If all the attributes/functions are relevant to the class then classify them into obligatory and optional and then split the class into two classes: one containing all the obligatory attributes/functions and the other containing all the optional attributes/functions.

Related References: NIL

Attribute Name

Structural complexity

Metric Name: Degree of non-redundancy

Model Element	Values
Complete Conceptual Model	0.927

Recommendation: Remove redundant elements

Application Criteria (Metric Value):

Description: Following steps can be performed:

i. Check the model to identify redundant elements such as classes, associations etc that have the same name or are semantically equivalent.
ii. Remove the redundant elements in a way that no information is lost.
iii. For example: if a model contains two classes named as professor and lecturer such that they are not the child of the same parent (implying that they don't specialize the distinction between the professor and lecturer) then they both represent the same concepts and thus we have a redundant concept. However, if both the concepts have different attributes and methods then verify if the attributes and methods are semantically same if not then both of these concepts are non-redundant.
iv. In the first class diagram (Figure-1), lecturer and professor inherit from teacher so they might have some distinct properties. Whereas in the second class diagram (Figure-1)

both the classes looks similar and thus can be redundant

Related References: NIL

Recommendation: Evaluate all cycles to remove redundant concepts

Application Criteria (Metric Value):

Description: Existence of cycles signifies that information is duplicated. In class diagrams sometimes cycles are inevitable whereas sometimes it's just the design error. So whenever there are cycles in the class diagram they should be revisited to check if some redundant information exists and if yes then they can be eliminated.

Related References: NIL

Recommendation: Factorize associations (to remove redundant associations)

Application Criteria (Metric Value):

Description: In any conceptual model, redundant concepts increase the complexity and wastes resources. Similarly, redundant associations increase the structural complexity of the models and thus they must be identified and removed from the model. There are number of ways to identify redundant associations with simplest being to identify the association having same name. Thus, all the redundant association must be removed.

Related References: NIL

Metric Name: Number of Associations

Model Element	Values
Complete Conceptual Model	35

Recommendation: Factorize associations (to remove redundant associations)

Application Criteria (Metric Value):

Description: In any conceptual model, redundant concepts increase the complexity and wastes resources. Similarly, redundant associations increase the structural complexity of the models and thus they must be identified and removed from the model. There are number of ways to identify redundant associations with simplest being to identify the association having same name. Thus, all the redundant association must be removed.

Related References: NIL

Metric Name: Number of Aggregations

Model Element	Values
Complete Conceptual Model	1

Recommendation: NIL

Metric Name: Number of Compositions

Model Element	Values
Complete Conceptual Model	6

Recommendation: NIL

Metric Name: Number of Generalizations

Model Element	Values
Complete Conceptual Model	14

Recommendation: NIL

Metric Name: Depth Inheritance Tree

Model Element	Values
Complete Conceptual Model	2

Recommendation: NIL

Manual Metric Name: Number of cycles

Recommendation: Evaluate all cycles

Application Criteria (Metric Value): >0

Description: Existence of cycles signifies that information is duplicated. In class diagrams sometimes cycles are inevitable whereas sometimes it's just the design error. So whenever there are cycles in the class diagram they should be revisited to check if some redundant information exists and if yes then they can be eliminated.

Related References: NIL

Attribute Name
Semantic Complexity

Manual Metric Name: Number of clusters

Recommendation: Split the model into identified clusters

Application Criteria (Metric Value): >0

Description: If different clusters are identified in the model. Then the model should be divided in such a way that each cluster becomes an independent module. This will help in managing the semantic complexity of the model.

Related References: NIL

Pattern Name:
Model Completeness Quality Pattern

Attribute Name
Completeness

Metric Name: Degree of Named Associations

Model Element	Values
Complete Conceptual Model	0.5

Recommendation: Define missing associations labels

Application Criteria (Metric Value): 0.0 TO 0.99

Description: Proper and expressive association names enhance the understandability of the model. These names tend to help the reader in understanding the nature/type of association between the associated classes. Thus if there are unnamed associations in the model, then expressive names must be defined for all the associations.

Related References: NIL

Manual Metric Name: Requirements Coverage Degree

Recommendation: Incorporate missing requirements

Application Criteria (Metric Value): 0.0 TO 0.99
Description: Missing requirements pose threat to the success of the developing system. It is widely accepted that the earlier identification and incorporation of the missing requirements reduces the systems correction cost to a greater extent. It is advised that all the missing requirements must be identified and incorporated to the conceptual model.
Related References: NIL

Manual Metric Name: Degree of defined multiplicities

Recommendation: Define missing multiplicities

Application Criteria (Metric Value): 0.0 TO 0.99
Description: Multiplicity defines the number of objects taking part in the relationship. Multiplicities are important to understand the semantics behind the relationship of the related classes. Thus, if there are undefined multiplicities in the model, they must all be defined.
Related References: NIL

Appendix F
Résumé

Les systèmes d'Information (SI) créent, traitent et stockent l'information pour aider leurs utilisateurs à prendre les décisions adéquates [Gupta 01]. Ces systèmes peuvent être à caractère personnel ou professionnel ; ils peuvent aussi bien concerner des individus, des groupes de travail ou des entreprises en fonction de leur usage et de leur implémentation. Par exemple un SI d'entreprise s'adresse à l'intégralité de l'organisation en fournissant une information utile et précise nécessaire à la prise de décisions au niveau de l'entreprise. Cependant, les SI ne peuvent être utiles que s'ils sont capables de fournir l'ensemble des informations et des services pour lesquels ils ont été conçus. Dans le cas contraire c'est la position stratégique de toute l'entreprise qui est mise en péril et le système d'information est alors remis en cause et abandonné par ses utilisateurs.

L'autre aspect concerne l'évolution du SI à travers la prise en compte de nouveaux besoins et/ou l'évolution des ses fonctionnalités. Les opérations de maintenance sont coûteuses et leur coût dépend de l'ampleur des changements qu'elles induisent. Ce coût dépend également du stade du cycle de vie dans lequel elles interviennent. D'ailleurs, l'expérience a montré que le coût des opérations de maintenance peut avoir un impact décisif sur le sort du SI. En effet, l'échec des projets informatiques est un problème qui a été longuement étudié et des études montrent que, même si un projet a été conduit à son terme, la vie du SI peut s'arrêter prématurément si les coûts de sa maintenance sont élevés. Une étude a montré que le coût relatif aux opérations de maintenance peut atteindre 90% du coût total du projet [Erlikh 00].

En considérant les raisons citées précédemment et la position stratégique d'un SI, la qualité des SI est considérée comme un problème important aussi bien pour les équipes de recherche que pour les entreprises. Les problèmes liés à la qualité peuvent augmenter considérablement les coûts et les ressources nécessaires au développement et au fonctionnement d'un SI en plus des risques de défaillance qu'ils peuvent engendrer [Thiagarajan et al., 1994]. De plus, [Ackoff 67] et [Nelson et al., 2005] ont rapporté que la qualité d'un système d'information peut affecter la confiance des utilisateurs et avoir ainsi un impact direct sur son utilisation et son adoption.

Appendix F:

Résumé

L'évaluation des systèmes d'information a toujours été un sujet important et sensible. Beaucoup d'efforts sont consacrés à la recherche et au développement de méthodes visant à améliorer la qualité du logiciel. Divers chercheurs ont proposé des visions différentes et des méthodes pour évaluer le SI. De même, dans l'industrie on s'appuie de plus en plus sur des approches d'assurance qualité (Software Quality Assurance ou SQA) visant à améliorer la qualité du logiciel et à réduire le coût des changements. Toutefois, le problème majeur avec les approches SQA existantes est lié au fait que l'évaluation du logiciel est effectuée tardivement dans le processus de développement à un moment où le coût du changement est élevé. Le fameux test alpha est fait une fois le logiciel entièrement développé juste avant son déploiement. De plus les besoins manquants ou émergents sont souvent identifiés au cours des tests effectués sur le site du client avant l'acceptation du produit. Ces tests montrent que la majorité des changements concernent une mauvaise implémentation des fonctionnalités due essentiellement à une mauvaise compréhension des besoins. Des études montrent aussi que la détection de défauts dans les premiers stades du processus de développement peut être trente-trois fois plus rentable que les tests effectués à la fin du développement [Walrad et al., 1993]. Plus précisément, plus tôt nous pouvons mesurer la qualité du futur système, mieux nous pourrons l'améliorer en étant en mesure de corriger les erreurs au niveau des spécifications et moins élevé sera le coût de ces corrections.

Par conséquent, il est impératif d'introduire des mécanismes de mesure et d'amélioration de la qualité dès les premières phases du développement, donc dès l'analyse et la conception. Le principal livrable de ces phases que nous désignons par les modèles conceptuels (MC), sert de base à toute la suite du processus de développement. La qualité des MC a par conséquent un impact direct sur le futur système à produire. De plus, le fait que la génération des MC se fasse très tôt dans le processus développement rend ces modèles plus adaptés à la détection des erreurs liées à l'acquisition et la compréhension des besoins et à leur correction [Moody et al., 2003].

En considérant l'importance des MC, il devient crucial pour une méthode d'analyse et de conception d'assurer la qualité des modèles qu'elle produit. En effet, si une méthode est capable de détecter les erreurs à travers l'analyse des MC qu'elle produit et si elle propose ensuite les moyens de les corriger, alors elle pourrait prétendre réduire le nombre de demandes de changements pouvant survenir à la livraison du système et assurer ainsi une meilleure qualité de ses livrables. De plus, la détection de ces erreurs très tôt dans le processus de développement évite leur propagation tout au long du processus de développement impliquant ainsi une amélioration de la qualité de tout le SI et pas seulement des MC sous-jacents [Moody 05]. Par conséquent,

l'amélioration de la qualité des MC est la garantie d'une meilleure qualité du SI affectant sa performance (temps, coût, effort) et son efficacité (qualité des résultats).

Pour ces raisons, les méthodes de développement intègrent des guides pour assurer une certaine qualité des livrables. Dans le cadre de cette thèse nous proposons d'aller plus loin en intégrant le concept de qualité des SI (son évaluation et son amélioration) au processus de développement. Commençons par le problème de l'évaluation de la qualité qui n'est pas un problème facile et qui a été abordé à différents niveaux dans la littérature.

1. Revue de la littérature

Différentes propositions ont été faites afin d'assurer la qualité des SI dans les organisations. Par exemple, l'Organisation internationale de normalisation (ISO) a formulé plus de 500 normes pour assurer la standardisation des procédés dans divers domaines (production, distribution, etc.). Ces normes lorsqu'elles sont adoptées par un secteur, offrent une garantie de la qualité des services proposés. Ces normes intègrent les meilleures pratiques et ont tendance à proposer des critères d'évaluation de la qualité. Ainsi, la conformité d'un procédé ou d'un produit à une norme ISO est généralement garante de sa qualité et est considérée comme une adhésion à l'excellence *"quality as an excellence"* comme ça a tété défini par [Reeves et al. 1994].

Dans le domaine informatique, la qualité est traitée selon divers angles dont voici une liste non exhaustive:

i. Qualité de l'ingénierie des exigences (les processus et les produits tels que documents, etc.)
ii. Qualité des modèles (modèles conceptuels tels que les diagrammes de classes, diagrammes entité-relation, etc.)
iii. Qualité des systèmes informatiques
iv. Qualité des données
v. Qualité des services

Cette thèse s'intéresse à la qualité des modèles conceptuels mais l'étude de l'état de l'art a porté sur l'étude plus générale de la qualité dans un SI incluant la qualité des logiciels et la qualité des données.

Appendix F:

Résumé

Les Systèmes d'information (SI) sont caractérisés par des coûts élevés de leurs activités de maintenance. Par conséquent la qualité des logiciels est une question importante aussi bien pour les chercheurs que pour les entreprises.

Divers chercheurs ont proposé des méthodes d'évaluation des SI fondées sur des critères d'acceptation par les utilisateurs. Par exemple, si un utilisateur demande un logiciel pouvant être manipulé via une interface graphique, il n'acceptera pas un logiciel en ligne de commande. [Boehm 81] inclut, dans la satisfaction des utilisateurs, des facteurs comme la portabilité, la maintenabilité, la robustesse et la remise en forme en tant que composants prioritaires de la qualité ; alors que [Elion 93] soutient que la prise en compte des niveaux de satisfaction des utilisateurs est une mesure insuffisante de la qualité puisque la satisfaction des utilisateurs est subjective, varie d'une personne à l'autre et ne peut donc pas donner des résultats stables. De même, [Hamilton et al., 1981] soulignent l'insuffisance de cette mesure qui devrait, selon eux, être considérée comme un élément parmi d'autres dans la mesure de la qualité.

La littérature sur l'évaluation de la qualité des logiciels peut être subdivisée en quatre grandes classes:

i. Les approches sommaires d'évaluation des systèmes d'information. Par exemple, [Avison et al., 1993] a recensé différents modes d'évaluation tels que l'analyse d'impact, les mesures d'efficacité, les approches économiques, les objectifs, la satisfaction des utilisateurs, etc.

ii. Les approches de détection et de rectification des erreurs. Par exemple, [Ackoff 67] considère le nombre d'erreurs détectées comme un indicateur de la qualité. De même, le rapport Carnegie Mellon [Florac 92] tenant compte des résultats de [Ackoff 67] a proposé une classification des erreurs logicielles en plusieurs catégories qui sont les erreurs sur les exigences, les erreurs de conception, les erreurs de code, les erreurs de documentation, etc. Une autre classification des erreurs en erreurs d'exigences ou erreurs d'implémentation a aussi été proposée par [Lausen et al., 2001].

iii. L'identification des critères de qualité (dimensions, attributs, paramètres, etc.) pour l'évaluation. Par exemple, [Thiagarajanet al., 1994] distingue le système de qualité dans la qualité des produits et la qualité des processus. [Nelson et al., 2005] a proposé et validé empiriquement cinq dimensions des systèmes de qualité: accessibilité, fiabilité ou disponibilité, temps de réponse, flexibilité et intégration. De même, [Chang et al., 2000] a

évalué la performance d'un système d'information selon trois dimensions : la performance du système, l'efficacité et la performance des services d'information. [Stylianou et al., 2000] a identifié plusieurs attributs pour évaluer la qualité des produits et des processus. Comme pour le système de développement, il concerne le coût, le temps, les bugs, la facilité d'utilisation de satisfaction des utilisateurs, et la facilité de résoudre les problèmes liés à la qualité. De même, pour la maintenance du système, il propose le temps de résolution de problèmes, la qualité du service, le temps de cycle et la sensibilité aux changements.

iv. L'évaluation de la qualité de services. Par exemple, [Parasuraman et al., 1988] a proposé un instrument de mesure composé de 22 critères (SERVQUAL) pour évaluer la qualité de service perçue par les clients dans le domaine de la vente au détail. Divers chercheurs ont appliqué le modèle SERVQUAL aux systèmes d'information. Par exemple, [Jiang et al., 2002] a utilisé les critères proposés par SERVQUAL dans un contexte professionnel pour vérifier la validité de ces critères. Les résultats empiriques obtenus montrent que SERVQUAL peut être appliqué à l'évaluation de la qualité de services dans les SI mais cet avis n'est pas unanimement partagé. [Van-Dyke et al., 1997] donne un aperçu des différents problèmes concernant SERVQUAL qui sont mis en évidence par différents chercheurs.

Ces travaux ont abouti à la proposition de plusieurs normes telles que ISO/IEC-9126 pour la qualité du produit logiciel, ISO/IEC-14598 pour l'évaluation de produits logiciels etc. De même, des normes telles que ISO 9001 et ISO 9000-3 peuvent être appliqués pour la certification des processus, produits et services au sein d'une organisation [Wang 02]. Cependant, les normes proposées ne comprennent pas les informations sur les attributs et les métriques de mesure de la qualité puisqu'elles sont génériques et que les métriques ont tendance à être spécifiques aux logiciels.

De plus, en analysant ces normes, on se rend compte que les caractéristiques de qualité définies sont peu précises et souvent ambigües, rendant leur utilisation difficile [Cherfi et al. 2007]. Dans [Kilidar et al., 2005] les auteurs ont mené une expérience qui a montré que la norme ISO/IEC-9126 est incomplète à l'égard des caractéristiques de qualité à mesurer et qu'elle renferme des redondances en ce qui concerne les propriétés mesurées.

Appendix F:

Résumé

Concernant la qualité des données, les approches proposées s'intéressent à la qualité de la donnée tout au long de sa vie. Dans [Wang et al., 1996] les auteurs ont identifié quatre dimensions de qualité : la précision, l'accessibilité, la pertinence et la représentation des données. [Nelson et al., 2005] ont proposé d'autres dimensions: la précision, la complétude, la qualité et le format de présentation des données. [Pipino et al., 2002] a eu une vision plus large et a proposé une approche employant 16 dimensions de la qualité des données: l'accessibilité, la quantité de données appropriées, la crédibilité, l'exhaustivité ou la complétude, la concision de la représentation, la cohérence de la représentation, la facilité de manipulation, la correction, la facilité d'interprétation etc. Ces approches se sont attachées à définir le sens associé aux dimensions de qualité ainsi définies et à la définition de métriques permettant de les mesurer.

Par exemple, [Bouzeghoub et al., 2004], [Peralta et al., 2004], [Peralta 06b] se sont particulièrement intéressés à la fraicheur des données comme un attribut de qualité important du point de vue des consommateurs des données. Ils ont proposé plusieurs métriques pour la mesurer, par exemple l'actualité (currency) ou la promptitude (timeliness) des données.

En plus des approches mentionnées ci-dessus, [ISO25012, 2008] est une première version d'une nouvelle norme pour la qualité de données structurées. Cette norme est prévue pour définir les besoins en qualité des données, définir les métriques de mesure de la qualité ou planifier des évaluations de la qualité.

La qualité des SI a tout d'abord été considérée comme atteignable en améliorant la qualité de la programmation et la productivité. Plus tard, on s'est rendu compte que ces deux aspects n'ont qu'un impact limité sur la qualité des systèmes. [Thiagarajanet al., 1994]. [Avison et al., 1993] ont souligné l'importance de la prise en compte de la qualité à chaque étape du cycle de vie. Ils ont également insisté sur la nécessité de l'évaluation suivant un large éventail de facteurs, y compris ceux concernant les aspects sociaux et organisationnels. Dans [Bansiya et al., 1999] les auteurs ont souligné le fait que la plupart des métriques proposées dans la littérature ne peuvent s'appliquer qu'une fois le système fini et qu'il y a un besoin urgent et important de concevoir des métriques de qualité qui peuvent être utilisées dès les premières étapes du développement.

Les Modèles conceptuels (MC) sont l'abstraction de l'univers du discours [Cherfi et al., 2002b]. Ils sont conçus lors de l'analyse et servent de moyen de communication entre les utilisateurs et l'équipe de développement. Ils fournissent des descriptions abstraites et masquent les détails d'implémentation. Dans le contexte de cette thèse, nous avons utilisé le terme de

modèle conceptuel pour désigner toute spécification conceptuelle, quelle que soit la notation utilisée (modèles de classes, de cas d'utilisation, etc. en UML ou modèle de données en ER ou toute autre spécification).

Les problèmes de qualité dans un modèle conceptuel peuvent être très divers (cohérence avec l'univers du discours, conformité à la notation, etc.). Cependant les erreurs survenant au niveau des MC peuvent impacter lourdement tout le processus de développement et la qualité du système Les premiers travaux structurés sur la question remontent à la proposition de [Batini et al., 1992]. Ils ont été les pionniers en proposant des critères de qualité pertinents pour l'évaluation des MC. Dans [Lindland et al., 1994], la qualité des modèles est évaluée selon les trois dimensions: syntaxique, sémantique et pragmatique.

Une autre approche sur l'évaluation de la qualité de CM met en lumière l'importance de l'esthétique. Par exemple, [Achat et al., 2002], [Achat et al., 2001b], [Achat et al., 2000], [Eichelberger 02] ont insisté sur l'importance de l'esthétique dans un modèle. [Cherfi et al. 2007] et [Cherfi et al., 2002a] ont également utilisé certains aspects de l'esthétique comme la clarté et la lisibilité pour évaluer la compréhension des modèles.

Divers travaux se sont concentrés sur la définition de propriétés observables pour qualifier la qualité d'un modèle et sur la façon de mesurer ces propriétés. Dans [Cherfi et al., 2002a] les auteurs ont proposé trois dimensions (spécification, usage et implémentation) qui correspondent aux points de vue selon lesquels la qualité d'un modèle peut être considérée. Ils ont défini ensuite des attributs de qualité et des métriques pour les mesurer selon chacune des dimensions. [Bajaj 02] s'intéresse particulièrement à la lisibilité d'un modèle et définit pour cela trois dimensions: l'efficacité, l'efficience et la facilité d'apprentissage.

La plupart des recherches effectuées dans le domaine de l'évaluation de la qualité des modèles ont été consacrées à la définition de critères ou d'attributs de la qualité et la manière de les mesurer [Genero et al., 2004], [Genero et al., 2003], [Manso et al., 2003], [Marchesi 98], [En al., 2003], [Rufai 03], [Zhou et al., 2003], [Yi et al., 2004], etc.

Cependant, et après avoir analysé tous ces travaux et d'autres, nous arrivons aux constats suivants :

i. La plupart des travaux réalisés dans l'évaluation de la qualité des modèles sont concentrés sur la mesure de la complexité des modèles.

ii. Ces travaux souffrent d'un manque d' effort de fédération et de consensus. Par exemple, [Nelson et al., 2005] ont identifié différentes définitions des mêmes concepts de qualité. Par exemple, il existe neuf définitions différentes pour la "complétude". De même, on trouve les mêmes appellations pour des concepts sémantiquement différents [Purao et al., 2003]. Ces questions ont limité l'adoption des cadres de qualité existant dans la pratique [Moody 05].

iii. L'absence d'une démarche globale qui tiendrait compte de la qualité sous tous ses aspects.

iv. L'absence d'une aide outillée qui faciliterait l'usage des concepts existants (attributs, métriques etc.) surtout au vu de la diversité des propositions.

Dans ce manuscrit de thèse, nous avons tenté d'apporter un peu plus de visibilité aux diverses et nombreuses propositions de la littérature. Nous avons proposé une classification de ces propositions en s'appuyant sur un cadre proposé par [Krogstie et al., 1995]. Nous avons choisi d'utiliser ce cadre pour les raisons suivantes :

i. Il s'agit d'une version améliorée d'un autre cadre déjà proposé par [Lindland et al., 1994] et largement diffusé. Le cadre de Krogstie est une évolution qui tient compte de diverses critiques et il a, de ce fait, un certain niveau de maturité.

ii. Il est bien connu dans la communauté de la qualité des modèles et il a été employé par plusieurs chercheurs tels que [Schuette 91], [Cherfi et al., 2007], [Maes et al., 2007], [Nelson et al. 2005], etc.

iii. Il a été utilisé dans d'autres domaines tels que l'ingénierie des besoins ou l'ingénierie des processus d'entreprise.

Compte tenu des problèmes ci-dessus, nous proposons une solution qui englobe les éléments suivants :

i. Fédération des cadres existants de la qualité pour formuler une démarche de qualité globale intégrant différents critères d'évaluation.

ii. Proposition d'un moyen permettant de capitaliser les connaissances et pratiques dans le domaine de la qualité des modèles à travers le concept de Patron de Qualité (Quality Pattern). Ce concept a permis l'encapsulation des concepts tels que attributs de qualité,

métrique de qualité, amélioration de la qualité et aide à la mise en œuvre. Il a également été instancié en identifiant quelques patrons (16 patrons).

iii. Définition d'un processus pour l'évaluation et l'amélioration de la qualité. Ce processus est guidé de manière flexible, permettant à un analyste concepteur de définir un besoin de qualité par rapport à sa spécification conceptuelle et d'être guidé pas à pas jusqu'à l'amélioration de cette qualité conformément au besoin exprimé.

iv. Conception d'un prototype logiciel qui propose une aide outillée à l'application de l'approche proposée.

Nous décrivons ci-après la solution ainsi proposée.

2. La solution proposée

L'étude de l'état de l'art a révélé l'importance de prendre en compte la qualité des SI dès l'acquisition des besoins. Dans le cadre de cette thèse nous nous intéressons à la qualité des modèles conceptuels conçus au cours de la phase d'analyse et conception. La qualité des modèles conceptuels est cruciale et décisive dans le succès du système final. L'objectif principal de cette thèse est de développer une approche complète de la qualité des modèles conceptuels qui englobe les objectifs suivants:

i. Fédérer les travaux existants,

ii. Organiser et structurer la connaissance liée à l'évaluation de la qualité des modèles,

iii. Proposer un processus guidé pour l'évaluation et l'amélioration de la qualité,

iv. Proposer un outillage pour l'évaluation et l'amélioration de la qualité,

v. Valider l'approche proposée

Nous allons décrire chacun des objectifs énumérés ci-dessus, les problèmes associés et la solution proposée.

Le domaine de l'évaluation de la qualité des MC est assez jeune. Contrairement à la discipline du génie logiciel où il y a une prolifération de méthodes et standards pour évaluer la qualité du produit, il y a peu de littérature consacrée de manière significative à la qualité des modèles conceptuels [Cherfi et al., 2002b]. De plus, il manque de consensus sur les concepts proposés. Ce manque se traduit par l'absence de standards ou normes pour la gestion de la qualité au niveau des modèles conceptuels.

Appendix F:

Résumé

Même si l'on constate un certain nombre de propositions sous forme de cadres structurants, de métriques, de critères de qualité, ces travaux sont menés indépendamment les uns des autres. La conséquence est l'apparition d'une diversité de termes pour désigner les mêmes concepts ou, plus gênant encore, l'utilisation d'un même terme pour désigner des concepts différents. Cette situation rend complexe l'adoption d'une approche de qualité au niveau conceptuel [Moody 05]. .Par exemple, [Nelson et al., 2005] a identifié neuf définitions différentes pour qualifier la "complétude". Un autre problème connexe est lié à l'organisation des concepts de qualité identifiés. En effet, la mesure de la qualité nécessite l'identification de l'attribut de qualité à mesurer, un moyen de le mesurer, une façon d'appliquer cette mesure, etc. Cette caractéristique nécessite l'organisation de ces connaissances en utilisant des concepts clairs, identifiables et compréhensibles. La réalité est toute autre puisque l'absence de consensus a conduit à des modèles différents et indépendants. On trouve par exemple les termes de : attribut de qualité, critère de qualité, facteur de qualité, caractéristique de qualité, etc. qui sont pour certains des synonymes, pour d'autres des termes désignant un concept et ses affinements à des niveaux d'abstraction différents. A cette diversité du vocabulaire et surtout face à cette imprécision des concepts, il est important de faire une proposition d'un modèle permettant d'organiser les concepts liés à l'évaluation et à l'amélioration de la qualité qui soit clair, complet et facile à utiliser.

Un tel travail a nécessité un examen approfondi de la littérature afin de fédérer les travaux existants en un cadre global de qualité. Nous nous sommes appuyés pour cela sur la proposition de [Moody 05] qui fournit une synthèse des travaux existants. Nous avons mis à jour cette analyse et avons fait des propositions là où les approches existantes n'apportent pas de solution.

Ce travail de fédération a nécessité tout d'abord l'extraction la plus exhaustive possible des concepts proposés dans la littérature. Il a ensuite fallu analyser, organiser et filtrer ces concepts en s'appuyant sur les théories régissant la modélisation conceptuelle et la qualité, en tenant compte des sens attribués aux concepts par leurs auteurs lorsque des définitions claires et exploitables sont fournies.

Ce travail a abouti à la proposition d'un ensemble d'attributs de qualité génériques et qui représentent différents aspects des modèles conceptuels tels que la complexité, la maintenabilité, etc. .En outre, l'avantage de ce processus a été l'élimination des concepts redondants en plus de la proposition de nouveaux concepts pour les aspects de l'évaluation des MC non couverts par la

littérature. Ce travail a été validé par une étude menée auprès de professionnels. Un autre travail important a été celui de classer les travaux existants dans un même cadre issu de la littérature et largement utilisé. Ce travail difficile nous a permis par exemple de constater que seulement une poignée de chercheurs ont abordé la notion de qualité sociale dans les modèles. La qualité sociale est liée au consensus des parties prenantes sur les spécifications produites (développeurs et utilisateurs) qui est un point très important et qui conditionne lourdement toute la suite du processus de développement.

- **Structurer la connaissance sur la qualité**

Un des problèmes avec les cadres de qualité existants est qu'ils ne sont généralement pas applicables à un type de MC particulier tel que les diagrammes de classes, diagrammes ER, etc. Selon [Moody 05], seulement 5% des cadres de qualité existants sont généralisables (ils peuvent être appliqués à plusieurs types de modèles conceptuels). Nous nous sommes souciés du caractère générique des concepts proposés tout en conservant la simplicité du modèle proposé afin d'en faciliter l'utilisation.

Le deuxième problème soulevé est la complexité de la gestion de la qualité face à la diversité des concepts. Nous avons pour cela proposé un méta-modèle qui permet de structurer les divers concepts de la qualité. Nous avons aussi proposé une aide méthodologique et outillée pour assister non seulement l'analyste dans l'évaluation des modèles mais aussi un expert de la qualité souhaitant faire évoluer les concepts définis. Nous avons aussi organisé ces connaissances dans une base de connaissance unique qui s'appuie sur le modèle de qualité proposé.

Notre proposition est générique et complète puisqu'elle permet de tenir compte de diverses notations (modèles ER, diagrammes UML, etc.). Elle intègre aussi les diverses facettes de l'évaluation de la qualité : théorique, épistémologique et pratique.

- **Proposer une démarche guidée et flexible**

Pour compléter le modèle de la qualité et répondre à la complexité inhérente à l'évaluation de la qualité qui nécessite à la fois une expertise et une connaissance des propositions faites dans la littérature, nous avons proposé une démarche d'aide à l'évaluation de la qualité. La spécificité de cette approche est de guider son utilisateur depuis l'objectif de qualité souhaité, le dispensant ainsi de la connaissance précise du vocabulaire attendu. Cette approche s'inspire de l'approche

GQM (Goal- Question-Metric) proposée dans [Basili et al., 1994], [Basili et al., 1984]. GQM a été largement utilisée dans l'industrie pour de nombreux projets d'évaluation.

La démarche consiste à faire exprimer, par un utilisateur (un concepteur de SI), un objectif de qualité à atteindre lors de l'élaboration d'un modèle conceptuel. La démarche d'évaluation se charge du reste puisqu'elle guidera pas à pas l'appariement de ce but aux concepts de qualité contenus dans la base de connaissance, l'évaluation de la qualité ainsi que la proposition d'actions correctrices. Ce dernier point est d'ailleurs novateur puisque la majorité des approches étudiées s'intéresse essentiellement à l'évaluation de la qualité par rapport à un critère précis.

Les principaux concepts de notre approche sont: Objectif de qualité, Question, Patron de qualité, Attribut de qualité, Métrique et recommandation.

Objectif de Qualité

Un objectif de qualité est l'objectif recherché par un analyste / concepteur pour atteindre l'objet d'intérêt. Comme mentionné ci-dessus, un objectif de qualité peut être défini pour un modèle conceptuel dans sa totalité ou pour une partie de ce modèle. Cet objectif précise la raison ou le pourquoi de l'évaluation et intègre le point de vue de celui qui souhaite faire l'évaluation. Par exemple, un analyste / concepteur peut-être intéressé de vérifier son modèle conceptuel pour son exactitude, l'objectif dans ce cas est la vérification de la correction du modèle conceptuel.

Question

L'autre caractéristique empruntée à GQM est l'emploi de questions permettant de préciser l'objectif de qualité exprimé. Ces questions aident les analystes / concepteurs à cibler les critères d'évaluation vis-à-vis de l'objectif formulé. Les questions sont indispensables puisque l'analyste/concepteur formulera le plus souvent des objectifs avec un vocabulaire éloigné de celui des concepts de la base de connaissance. Ces questions permettent donc l'appariement entre objectifs de qualité et concepts de qualité (patrons de qualité, critères, métriques etc.).

Attribut de qualité

Un attribut de qualité désigne un groupe de propriétés observables sur le cycle de vie du produit [Preiss et al., 2001] ou un groupe de propriétés du service rendu par le système à ses utilisateurs. Le service rendu par un système est son comportement tel qu'il est perçu par ses utilisateurs [Barbacci et al., 1995]. De même, [SEI, CMU] lie les attributs de qualité à des repères qui décrivent le comportement du système au sein de l'environnement pour lequel il a été construit. Dans le domaine de l'ingénierie des systèmes, les attributs de qualité peuvent aussi

concerner les exigences non-fonctionnelles pour évaluer la performance du système. Dans notre approche, un attribut de qualité fournit l'abstraction d'un ensemble de métriques étroitement liées et mesurant la même caractéristique souhaitée du MC. Chaque attribut de qualité doit être générique dans le sens où sa définition ne doit pas dépendre de la notation utilisée pour le MC.

Nous avons choisi d'utiliser le terme "Attribut de Qualité" pour désigner les concepts de la littérature tels que : attribut de qualité, dimension, facteur, caractéristique, sous-caractéristique, critères, etc. Quelques exemples d'attributs de qualité sont: la complexité, la complétude, etc.

Métrique de Qualité

Les métriques sont les mesures ou les procédures d'évaluation qui attribuent des valeurs numériques ou symboliques afin de caractériser les qualités ou les caractéristiques des objets. Chaque métrique a une portée définie par l'ensemble des entités et des objets auxquels elle est applicable, une plage de valeurs décrivant l'ensemble des résultats de mesure possibles, et la propriété mesurée qui correspond à la caractéristique mesurée. La représentation explicite des propriétés des métriques permet de distinguer les métriques les unes par rapport aux autres, surtout lorsqu'elles permettent de mesurer le même attribut. En effet, un attribut de qualité peut employer plusieurs paramètres pour mesurer les différents aspects d'un modèle conceptuel. Par exemple, la complexité structurelle comme attribut de qualité emploie des métriques telles que le nombre d'associations, le nombre d'agrégations, la profondeur de hiérarchies maximale, etc.

Les recommandations

Nous considérons que l'évaluation de la qualité n'est pas un objectif mais que l'objectif est de pouvoir améliorer, si nécessaire et si possible, cette qualité. En effet, la majorité des approches étudiées se concentrent sur l'évaluation de la qualité en proposant des indicateurs et des métriques permettant de cibler les erreurs ou manques dans les MC. Peu d'approches s'attaquent au problème difficile de l'amélioration de cette qualité [Moody 05].

Les recommandations sont des suggestions, des propositions ou des conseils sur la façon de modifier les MC afin d'en améliorer la qualité. Les recommandations sont proposées dans notre approche en fonction des résultats obtenus par l'application des métriques. Les analystes / concepteurs peuvent employer les recommandations proposées pour améliorer la qualité des MC. Les recommandations peuvent être :

i. Textuelles, elles donnent dans ce cas des conseils que l'analyste/concepteur choisit d'appliquer ou non.

ii. Sous forme de règles de transformation. Dans ce cas, les améliorations sont précises et s'expriment sous la forme d'actions de transformation du modèle.

iii. Des propositions de patron de conception (design patterns) pouvant apporter une solution satisfaisante. L'analyste/concepteur a la responsabilité d'appliquer le patron.

Patron de Qualité (Quality Pattern)

Après l'étude approfondie des travaux de la littérature, nous avons retenu 21 attributs de qualité. Mais ces attributs permettent tout au plus la qualification de la caractéristique à mesurer. L'évaluation de la qualité nécessite la définition d'une métrique de qualité et il existe diverses métriques pour un même critère. Pour atteindre un objectif de qualité, plusieurs critères de qualité sont possibles, pour lesquels plusieurs métriques sont possibles ainsi que plusieurs actions correctrices. Manipuler et faire le choix parmi tous ces concepts nécessite un degré d'expertise qui explique l'utilisation jusqu'ici limitée des approches de qualité proposées dans la littérature. Notre réponse a été de proposer un mécanisme qui permettrait la capitalisation de l'expertise dans ce domaine. Ce mécanisme est le Patron de Qualité (Quality Pattern). Ce concept se rapproche du concept de Patron de Conception (Design Pattern) qui encapsule les bonnes pratiques de conception afin d'améliorer le résultat de la conception [Hsueha et al., 2008]. Nous avons donc proposé une solution similaire cette fois-ci pour le problème de l'évaluation et de l'amélioration de la qualité. Le concept de patron de qualité a été proposé pour la première fois par [Houdek et al., 1997] pour l'ingénierie des logiciels. Dans [Cherfi et al., 2008] une première proposition de ce concept pour la gestion de la qualité des modèles conceptuels a été faite. Le travail de cette thèse a été d'approfondir et de définir dans le détail ce concept et de le rendre opérationnel. Nous avons également entamé la délicate tâche d'identification de patterns de qualité ,tâche très délicate dans un domaine qui est récent et pour lequel les connaissances et les expertises sont peu structurées.

Un patron de qualité peut être formulé en utilisant notre modèle de qualité. Chaque patron de qualité adresse un problème, a un contexte d'utilisation et des mots clés qui permettent de le rapprocher d'un objectif de qualité lors de l'évaluation. Il décrit une solution sous la forme d'un ensemble de critères de qualité à évaluer et englobe les métriques permettant leur évaluation et les recommandations d'amélioration de la qualité appropriées.

Plus précisément chaque patron de qualité contient les informations suivantes: nom, contexte, problème, solution, mots-clés et patrons connexes.

Voici un exemple d'un modèle de qualité défini par notre approche.

Appendix F:

Résumé

Nom du patron: la complexité du modèle

Contexte:

i. La vérification de la complexité globale d'un modèle conceptuel, en respectant le nombre d'éléments (nombre de classes / entités / attributs, etc.) présents.

Problèmes:

i. Il est largement reconnu que la multiplication des éléments dans un modèle (classes / entités / cas d'utilisation, etc.) peut gêner la lisibilité du modèle. Miller ("The Magical Number Seven, Plus or Minus Two: Some Limits on Our Capacity for Processing Information", 1956) présente une étude défendant l'idée selon laquelle la mémoire humaine (pour un évènement récent) peut contenir 7 ± 2 objets rendant la compréhension d'une plus grande collection d'objets plus difficile.

ii. De même, l'existence de nombreux éléments peut augmenter la complexité.

iii. Cette complexité peut nuire à la maintenabilité, parce que maintenir ou corriger un modèle nécessite au préalable sa compréhension.

iv. Pour vérifier si le pattern est pertinent pour les problèmes actuels du modèle: Les métriques suivantes sont applicables aux diagrammes de classe seulement :

   a. Nombre de classes: nombre total de classes dans un modèle.
   b. Nombre d'attributs: nombre d'attributs dans le modèle.
   c. Nombre de méthodes: nombre total de méthodes ou de fonctions dans le modèle.
   d. Nombre de cycles: nombre total de cycles dans un modèle.
   e. Degré de non-redondance: Cet indicateur de mesure calcule le rapport entre les concepts non- redondant et les concepts totaux présents dans le modèle.

      Ci peut être {classe, association, un lien d'héritage, classe d'association, liens de agrégation, lien de composition},
      NB (Ci) correspond au nombre d'éléments de type Ci et NBR (Ci) concerne le nombre d'éléments redondants de type Ci dans le modèle M.
   f. Nombre d'associations: Nombre total d'associations dans un modèle.
   g. Nombre d'agrégations: Il calcule le nombre d'agrégations dans un diagramme de classes.
   h. Nombre de compositions: Il calcule le nombre de compositions dans un diagramme de classes.
   i. Nombre de généralisations: Il calcule le nombre total de généralisations dans un modèle.

j. Profondeur d'héritage (Maximale): Il calcule le plus long chemin de la classe à la racine de la hiérarchie dans une hiérarchie de généralisation.

Solution:

i. La division des modèles complexes en modèles plus simples peut contribuer à améliorer la compréhension
ii. La proximité sémantique des éléments contenus dans un modèle diminue la complexité de celui-ci en minimisant la multiplication des sujets et problèmes à assimiler. Par exemple, si l'on mélange dans un même modèle la gestion des formations et celle du recrutement des formateurs, on augmente la complexité du modèle et l'on diminue aussi probablement sa compréhension. Il est donc important de séparer les modèles en sous modèles dans certains cas pour en améliorer la compréhension.
iii. Les transformations suivantes peuvent être employées pour l'amélioration (Détail sur les transformations joint en annexe-C):
    a. Supprimer les éléments redondants
    b. Pour faciliter la suppression des associations redondantes il faut les factoriser.
    c. Diviser le modèle
    d. Fusionner les classes
    e. Diviser une classe
iv. Les patrons de conception suivants (design patterns) peuvent être utilisés pour améliorer la qualité du modèle:
    a. GRASP haute cohésion
    b. GRASP Polymorphisme

Mots clés: complexité; maintainabilité; modifiabilité; compréhension; taille.

Patrons connexes:

i. Maintenabilité des modèles (la complexité rend la maintenance des modèles difficile)
ii. Clarité des modèles (les modèles complexes sont difficiles à lire)

- **Un processus guidé pour l'évaluation et l'amélioration de la qualité**

Une lacune constatée dans les approches étudiées est l'absence d'un processus structuré permettant la mise en œuvre des concepts proposés. Les approches laissent aux analystes/concepteurs la charge de sélectionner les concepts adéquats, de les appliquer et d'en exploiter les résultats.

Appendix F:

Résumé

Un des apports de cette thèse est de proposer un processus complet et flexible qui guide pas à pas le processus de gestion de la qualité conformément à un objectif de qualité que formulera l'analyste/concepteur. Le processus proposé commence par rapprocher cet objectif des concepts de qualité contenus dans la base de connaissance. Puis, il a pour but de guider l'évaluation et l'amélioration de la qualité conformément au but souhaité. Il utilise les attributs, métriques, patrons et recommandations de la qualité prédéfinis tout en offrant une certaine flexibilité dans le choix des concepts à utiliser et du mode de guidage souhaité. Il ne s'agit pas d'un processus automatique mais d'une aide outillée facilitant le bon usage de la connaissance capitalisée et stockée dans la base de connaissance.

- **Une aide outillée pour le processus d'évaluation et d'amélioration de la qualité**

Nous avons constaté que malgré la multiplication des propositions concernant la mesure de la qualité dans la littérature, leur adoption et leur application restent très limitées. Malgré l'importance qu'avouent accorder les professionnels à la qualité des spécifications, ils n'adoptent pas pour autant ces approches. Nous pensons que cela est dû à la difficulté de maîtriser à la fois tous ces concepts et de les appliquer. A cela s'ajoutent la complexité des spécifications elles mêmes et la diversité des notations utilisées. Les expériences vécues dans d'autres domaines montrent que l'existence d'aides outillées peut aider à l'adoption des méthodes et techniques. Nous avons analysé ce que proposent les ateliers de génie logiciel du marché pour la prise en charge de la qualité. Voici nos conclusions :

i. Certains ateliers du marché intègrent quelques mesures très simples d'évaluation. Ces mesures ne peuvent cependant pas être modifiées ni enrichies.

ii. Ces outils ne proposent aucune aide à l'interprétation des valeurs obtenues.

iii. Les mesures proposées par ces outils ne sont pas toujours rattachées à des attributs de qualité et sont par conséquent difficiles à utiliser.

iv. Aucun des logiciels ne fournit de recommandations après l'évaluation, à l'exception de UMLQuality (logiciel d'évaluation) qui propose des recommandations succinctes.

Nous avons proposé, dans notre approche, un outil CM-quality qui prend en charge la totalité de la démarche proposée. Il offre un ensemble d'aides outillées pour la définition des concepts de la qualité (attributs, métriques, patrons, recommandations) mais aussi la prise en charge du processus d'évaluation et d'amélioration de la qualité dans son intégralité. Il a aussi l'avantage de

pouvoir s'interfacer avec les ateliers de génie logiciel du marché (les plus répandus comme Rational Rose, Objecteering, StarUML etc.).

CM-quality a deux objectifs principaux. Il permet, dans un premier temps, de démontrer la faisabilité de l'approche. Dans un travail futur, nous espérons l'utiliser à des fins de validation en le mettant à disposition d'étudiants et de chercheurs impliqués dans la qualité des MC.

CM-Quality est conçu pour deux types d'utilisateurs : les experts qualité et les analystes/concepteurs. Un expert qualité est un utilisateur ayant une connaissance approfondie des concepts de qualité. Il est chargé de définir les concepts de qualité tels que les attributs, les patrons de qualité etc. . L'analyste lui a la charge d'établir des spécifications conceptuelles et souhaite en étudier et améliorer la qualité. Les analystes ne peuvent qu'utiliser la connaissance définie par l'expert qualité. CM-quality contient une base de connaissances qui sert au stockage des différents concepts de qualité. La base de connaissances stocke également des sessions d'évaluation à des fins de trace, en vue notamment de l'amélioration des concepts déjà définis.

Les fonctionnalités suivantes sont proposées par CM-quality:

i. Il met en œuvre et stocke une hiérarchie des concepts de qualité, incluant les patrons de qualité, les attributs de qualité, les métriques, les recommandations, etc. dans une base de connaissances. Tous ces concepts de qualité peuvent être ajoutés / modifiés / supprimés de la base de connaissances.

ii. Il peut être utilisé pour évaluer un MC par un analyste / concepteur conformément à un objectif de qualité spécifique.

iii. Il aide l'analyste / concepteur dans l'identification des critères de qualité pertinents par rapport à l'objectif de qualité formulé.

iv. Il propose des informations post-évaluation sous forme de recommandations pour l'amélioration du modèle.

v. Plusieurs modèles peuvent être évalués ou comparés à l'aide de CM-Quality.

vi. Il peut être utilisé pour évaluer les modèles conçus en utilisant les ateliers de génie logiciel du marché, tels que Rational Rose, Objecteering, etc.

Il n'est cependant qu'une première implémentation de l'approche et comporte certaines limitations ou voies d'amélioration :

i. CM-Quality évalue la qualité du modèle complet et propose des recommandations pour l'ensemble du modèle. Ainsi si l'utilisateur est intéressé par l'évaluation d'une partie du modèle, il doit extraire un modèle partiel.

ii. Les transformations proposées ne sont pas exécutables sur le modèle et doivent être appliquées « manuellement » par l'analyste.

iii. CM-quality ne peut pour le moment communiquer avec les ateliers de génie logiciel que par l'import des spécifications. Une solution plus intégrée pourrait faciliter son utilisation.

- **Validation de l'approche proposée**

La plupart des travaux existants sur la qualité des MC peuvent être catégorisées en deux types:

i. Des propositions ayant une base théorique, mais sans validation pratique associée

ii. Des propositions avec des fondements pratiques et expérimentaux sans fondement théorique.

Les approches théoriques sont jugées difficiles à mettre en pratique et non exploitables alors que les propositions issues de l'expérimentation sont généralement considérées comme manquant de substance et difficilement généralisables. [Moody 05] rapporte que la plupart des cadres de qualité proposés pour la qualité de CM manquent de validation. Seulement 18% environ des propositions ont été validées.

Notre approche utilise comme fondement pratique le point de vue des professionnels. En effet nous avons mené une étude auprès de professionnels, étude dont le but était double. Le premier s'intéressait à étudier la stratégie d'évaluation de la qualité employée en pratique et le second visait la validation de nos propositions. Nous avons fait participer des experts universitaires et des professionnels au moyen d'enquêtes, interviews, etc. Par exemple, afin d'être sûr que l'ensemble des attributs de qualité retenus par l'approche sont des caractéristiques considérées comme importantes dans l'évaluation de spécifications conceptuelles, nous avons procédé à une enquête. Cette dernière consistait à recueillir les opinions des interviewés sur la qualité globale des modèles conceptuels, en plus de leurs commentaires sur un ensemble d'attributs de qualité extraits de la littérature. Leurs commentaires ont été analysés et des modifications ont été apportées à certains attributs et critères d'évaluation.

De même, nous avons essayé d'extraire des connaissances sur leurs pratiques en leur posant des questions ciblées, par exemple d'exprimer leur opinion sur ce qu'ils considèrent comme les caractéristiques importantes dans un modèle conceptuel sans orienter leur réponses. Cette partie de l'enquête a été intéressante puisqu'elle nous a permis de considérer les attributs de la qualité d'un point de vue purement pratique. Par exemple, plusieurs participants ont mentionné le fait que l'aspect pratique d'un modèle est important. Ils considèrent que certain modèles ne sont pas pratiques par le fait qu'ils exigent, pour leur implémentation, des ressources ou des technologies indisponibles ou difficiles à acquérir. La praticité a donc été ajoutée à nos attributs de qualité. Cet attribut est différent de l'implémentabilité que l'on rencontre dans la littérature et qui est essentiellement lié à l'effort d'implémentation alors que la praticité est liée à l'environnement du projet dans lequel est proposée la solution conceptuelle.

L'originalité de cette enquête réside aussi dans le fait qu'elle a impliqué des professionnels issus du monde de l'entreprise alors que les travaux de validations et les enquêtes concernant les travaux de la littérature sont essentiellement faits avec des universitaires et majoritairement avec des étudiants.

Le deuxième effort de la validation visait l'approche d'évaluation et d'amélioration de la qualité. Il a consisté en un travail en trois étapes :

i. La première étape a consisté à proposer aux participants un modèle conceptuel (diagramme UML) issu d'une application réelle. Ils devaient, en utilisant leurs connaissances en modélisation, analyser la qualité de ce modèle. Ils devaient ensuite relever les problèmes de qualité qu'ils détectaient et proposer un résumé des actions correctives qu'ils estimaient nécessaires à l'amélioration du modèle.

ii. Pour la deuxième étape, nous avons fourni aux participants 1) des valeurs de mesures de qualité que nous avions au préalable calculées sur le modèle et 2) des patrons de qualité. Ils devaient essayer d'exploiter ces nouvelles informations pour tenter d'améliorer le modèle initial. Le but de cette étape est d'évaluer la facilité de compréhension et d'utilisation des patrons de qualité.

iii. Enfin, lors de la dernière étape, les participants ont eu à évaluer le résultat de l'application de l'approche proposée sur le modèle initial et ils devaient donner leur avis sur la qualité du modèle obtenu et sur son amélioration. Le but de cette étape était de mesurer l'utilité des patrons de qualité et des actions correctives.

Pour les deux expériences, nous avons analysé les réponses. Nous avons également analysé les profils des participants (domaine, expérience en modélisation, etc.). Toutefois, ces deux expériences ont leurs limites que nous avons tenté de résumer ci-dessous :

i. La plupart des critères de qualité fournis par les participants en retour de la première expérience étaient déjà dans l'enquête et ces retours n'ont que peu enrichi la liste initiale.

ii. La taille de l'échantillon de la deuxième expérience est de vingt cinq participants. Ceci s'explique par la difficulté de l'expérience et sa longueur. Les résultats obtenus sont donc difficilement généralisables mais ils nous ont permis d'avoir un premier retour et aideront à organiser ultérieurement une autre expérimentation.

iii. A travers les retours attendus par la deuxième expérience, nous espérions avoir des connaissances complémentaires pouvant enrichir nos patrons de qualité. Ceci n'a pas pu être atteint essentiellement à cause du degré d'expertise élevé nécessaire en modélisation conceptuelle parmi les participants.

iv. Quelques-uns des problèmes identifiés par les participants n'existaient pas. Nous pensons que cela est dû au vocabulaire utilisé dans l'enquête qu'il faut revoir en fonction de la population interrogée.

v. La deuxième expérience s'appuie sur un seul modèle, ce qui est limité.

vi. La deuxième expérience a utilisé une seule notation de modélisation, ce qui est aussi une voie d'amélioration.

3. Conclusion

La solution proposée vise des problèmes liés à la qualité de la modélisation conceptuelle d'une manière globale. Afin de formuler une solution complète, nous avons proposé des concepts ciblant divers aspects liés à la qualité au niveau des spécifications conceptuelles. Ces concepts comprennent la formulation de critères de qualité (attributs de qualité, métriques, etc.) qui ont l'avantage de fédérer les travaux existants revus et corrigés à la lumière d'une expérience de validation. Nous avons aussi proposé et détaillé un concept novateur, le patron de qualité, visant à encapsuler les connaissances et les pratiques dans l'évaluation de la qualité des modèles conceptuels. Nous avons également proposé une approche complète qui guide l'utilisation de ces concepts de manière flexible et assistée. Enfin, nous avons développé un prototype qui met en œuvre la solution proposée.

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