Collaborative modeling, which is conceptually similar to Group Model Building (GMB), is a technique that is widely used to jointly develop models by stakeholders in information systems design and business process re-engineering projects. However, little is known about what “takes place in there, and how modelers do their thing”. To understand what happens and how the different participants in such a joint effort do whatever they do, one needs to recognize the different skills, expertise and knowledge that is brought on board. This diversity in skills, expertise and knowledge, sets stage for a communicative process in which modelers engage in an argumentative, negotiation and decision-making process to reconcile not only their perceptions and conception in their mental models, but also their priorities and preferences about the quality of the different modeling artifacts used in, and produced during, a modeling session.

This thesis has developed two frameworks: the Rules, Interactions and Models (RIM) framework, and the Collaborative Modeling Evaluation (COME) framework for, respectively, analysing what takes place in a modeling process, and for evaluating the different modeling artifacts by the modelers themselves through a communicative process. The two frameworks are integrated in a meta-model that helps us track the flaws in the RIM framework and pointing them using heuristics developed in the COME framework. Theoretical significance as well as practical relevance of the frameworks and the meta-model is demonstrated through explanatory and confirmatory modeling experiments.
Analysis and Evaluation of Collaborative Modeling Processes

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To:

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for making me always smile!
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Preface

Collaborative modeling, including, under our broad definition, modeling of enterprises and/or of associated business processes, brings together stakeholders with varying degrees of knowledge, expertise, skills and competencies. Such collaborative modeling brings with it a number of benefits and advantages. Although such benefits and advantages have been recognized in the literature, substantiating the success of these collaborative efforts is far from trivial. A number of factors come into play and need to be considered if we are to effectively and efficiently study, understand, analyze and evaluate modeling process quality and determine its successfulness. First, the different stakeholders have different priorities and preferences which need to be reconciled in a group problem-solving activity, especially during evaluation of the modeling process. Second, a number of modeling artifacts are used in, and produced during, the modeling process. All these impact on the success of the collaborative modeling effort and on the quality of the modeling process, especially its efficacy.

In the research reported in this thesis, we developed two frameworks: the Rules-Interactions-Models (RIM) and the Collaborative Modeling Evaluation (COME) frameworks for, respectively, analyzing and evaluating collaborative modeling processes. We also developed a meta-model that integrates these two frameworks. To determine how well a modeling process has been executed, we diagnose it and use heuristics and metrics which can help us identify the flaws in the modeling process. Communication, argumentation, decision theories as well as the Technology Acceptance Model (TAM), the Semiotic Quality (SEQUAL) framework and the Method Evaluation Model (MEM) provide theoretical concepts for our frameworks and meta-model. We provide a descriptive and explanatory theory which can be used to study, understand, analyze and evaluate collaborative modeling processes. We give guidelines for developing support-tools that integrate analysis and evaluation of collaborative modeling processes. We tested the practical relevance and significance of the frameworks and meta-model in a number of exploratory, controlled explanatory modeling sessions and explanatory and confirmatory experiments with IT experts.

The journey that has led us to where we are hasn’t been rosy! The road has been muddy and, at times, bumpy. There were those moments when my academic world seemed to have come to an abrupt close; when that idea did not seem to make academic sense or when that data analysis method proved fraught with a number of difficulties. There are quite a number of people to whom I will forever be indebted and for whom it will be hard to pay back or reward! All that I can afford for now is a “Big Thank You”! Thanks to my supervisors that they were always available to guide and direct me
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Nijmegen, October, 2012

Denis Ssebuggwawo

Scire tuum nihil est, nisi te scire hoc sciat alter!
Introduction
Chapter 1 starts, in Section 1.1, with an overview of the research and outlines the problem that this research addresses in Section 1.2. The research questions which guide and direct our research are given in Section 1.2.1 and objectives which point to what our research is intended to achieve are discussed in Section 1.2.2. Within the same chapter we give, in Section 1.3, the research approach we followed while executing this research. Due to many concepts and terms in Information Systems Design that are often used interchangeably, we disambiguate our approach by giving some basic definitions and terminologies in Section 1.3.1 and argue our philosophical position and orientation in Section 1.3.2. Sections 1.3.3 and 1.3.4, respectively, outline the major concepts of the Design Science and Group Model Building approaches followed in this research. In Section 1.3.5 a research cycle, in relation to Design Science cycles, is given that shows how the research was executed from the time of problem identification to the time of validation. We give a road map, in Section 1.4 that outlines the structure of the book and we end the chapter with a summary that gives key points from this chapter in Section 1.6.

Chapter 2 looks at some of the existing theories and frameworks, especially, those that we feel can provide a theoretical anchor for the analysis and evaluation of collaborative modeling processes. The chapter starts with a general overview about these theories and frameworks in Section 2.1. Section 2.2 looks at the four social interactions which include: collaboration, coordination, cooperation and communication. Section 2.2.1 looks at collaborative modeling while Sections 2.2.2 and 2.2.3 discuss collective intelligence and how collaborative modeling is grounded in communication. Theories about communication and decision-making which play a vital role in understanding the communicative process in collaborative modeling are introduced in Section 2.3. We, specifically, single out Argumentation Theory in Section 2.3.1 and Negotiation Theory in Section 2.3.2 as key theories that can help us to study and understand what takes place during a collaborative modeling effort. In Section 2.3.3 we identify Group Decision Making, from Decision Theory, as yet another theory on which to anchor collaborative decision-making and consensus building during the evaluation and selection of the best modeling artifacts and modeling procedure. Section 2.4 introduces two frameworks that can help us evaluate the modeling artifacts in collaborative modeling. One of these frameworks is the Semiotic Quality (SEQUAL) framework which is introduced in Section 2.4.1 and the Quality of Modeling (QoMo) framework introduced in Section 2.4.2. A comparison of these two frameworks in view of collaborative modeling rules/goals, strategies and evaluation of the modeling artifacts is given in Section 2.4.3. Modelers’ attitudes, perceptions, beliefs and behaviour about the quality of the modeling artifacts, use and adoption of the modeling procedure are introduced in Section 2.5. These can be anchored on the Theory of Reasoned Action (TRA) in Section 2.5.1, Theory of Planned Behaviour (TPB) in Section 2.5.2, the Technology Acceptance Model (TAM) in Section 2.5.3 and the Method Evaluation Model (MEM) given in Section 2.5.4. The chapter is ended with some concluding remarks in Section 2.6 about these theories and frameworks.
1 Background, Context and Motivation

[S]omething important happens in group interaction ... [but] there is little agreement ... what that “something” is.

– Hackman & Morris, 1975

1.1 Overview

Most conceptual modeling approaches [DET11, Oli07] that lead to generation of business process models, enterprise models, enterprise architecture models, Information Systems (IS) design models, etc., tend to be prescriptive rather than descriptive [Rit07]. Such approaches have tended to concentrate on the end-product – the model being developed without paying due attention to the process that generates the models [HPR05, HPW05a, PHB06]. The same situation is observed in [HW10] where it is noted that “little attention is given to the matter of the process of creating model content in view of focus on its context of use: the conceptualizations that are expressed by means of a modeling language (pragmatic focus)”. This approach is fraught with a number of inherent problems. First, it assumes that a single expert (systems analyst) can produce the model by strictly following the syntax and semantics of the chosen modeling language. Yet, the model has to be taken back to the domain expert to be agreed upon. Second, exclusion of the domain expert from the modeling process means too much time will be wasted in trying to reach a shared meaning and shared understanding about what has been produced by the analyst. Third, there are always questions raised about the “quality” of the produced model since the process that generates it is not well-structured and excludes other modeling artifacts that may impact on the quality of the entire modeling process.

Being part of so many system development and enterprise engineering projects, especially those that are executed collaboratively and interactively, see for example [BKV09, GKF05, SP07], conceptual modeling needs to be unwrapped by a process which reveals the specific details that give birth to the models. Collaborative modeling, which is conceptually similar to Group Model Building (GMB) [AVRR07, RA95, RVM02, Ven96], is one of the approaches to guide us towards understanding the process of modeling. Such a collaborative process can help construct agreement and a sense of ownership among the different stakeholders – domain experts, system analysts, model builders, systems engineers, etc. In view of an increasing demand for efficient and effective group modeling and support for people with relatively low expertise in formal modeling, tools are needed that provide specialized, process-oriented support for formal modeling, see for example, the Collaborative Modeling Architecture (COMA) tool [Rit08a]. However, these tools can only be developed if the process (act) of modeling is adequately understood. This requires collaborative modeling to go through the rigours of study, test, analysis and evaluation.

As a basis for understanding such a collaborative modeling process, there is a need to analyze not only the communication dialogues [SHP09d] that take place between the dif-
ferent stakeholders in the group modeling process, but also a need to evaluate the different modeling artifacts that are used and developed within this collaborative process. Their interdependencies and impact on the overall quality – efficiency and effectiveness – of the modeling process need to be determined. Analyzing the communication process, which is a key component of any collaborative modeling process, will identify detailed steps that have to be guided and later supported by a support-tool. Often, during an interactive modeling process, members engage in different types of communicative dialogues, e.g., negotiations, including but not limited to: propositions, argumentations (for or against), (dis)agreements with the propositions, acceptances/rejections of propositions, withdraws of propositions, challenging of propositions, etc. Because of this communication dialogue, collaborative modeling can therefore be looked at as a negotiation where members work on proposals [Rit07].

Embedded within a collaborative modeling process, are the different modeling artifacts that are used in, or produced during, the modeling session. Such artifacts include the modeling language, modeling procedure, the intermediary and end-products (models) and media or support-tools [SHP09b] used. Determining the efficacy (effectiveness and efficiency) of collaborative modeling or group model building not only requires an analysis of what takes places during the modeling process but also an evaluation of the artifacts with respect to a set of quality attributes – factors or dimensions. Analysis involves looking at the communication: negotiation, argumentation, agreement, decision-making, consensus, etc., between and among the modelers in view of the rules and goals, interactions, and models produced. Analyzing the modelers’ interactions, rules that drive the modeling process and goals strived for, will help us have a deeper understanding of the process of modeling. Evaluating the different artifacts in a number of modeling approaches will help us select the most appropriate one for meeting the modelers’ quality goals. The modeling environment being multi-actor and the evaluation being multi-criteria, requires use of a Multi-criteria Decision Aiding/Analysis (MCDA) method, e.g., using the “Analytic Hierarchy Process (AHP)” [Saa80, EM07].

In such a multi-actor and multi-criteria environment, there are a number of factors – internal or external – that impact and influence the modelers’ communication, priorities and preferences; attitudes, beliefs/perceptions, intentions and behaviour [Ajz91, FA75]. The analysis and evaluation need to consider such factors. To do this, there is a need to identify performance factors – to measure the success or (actual) efficiency and effectiveness of collaborative modeling, perception and intention factors – to measure perceived ease of use, perceived usefulness and intention to use any of the modeling artifacts mentioned above, and behaviour factors – used to measure the actual production and/or usage of the modeling artifacts, especially the selection and use of a modeling language, modeling procedure and support-tool. In light of the above background, context and motivation we outline, in the subsequent sections, our research problem statement, research questions, objectives and research approach.

1.2 Research Problem

The identified research problem that this research is trying to address is lack of a well-structured methodology to study, analyze, understand and evaluate the process (act) of modeling in an interactive and collaborative modeling environment. To facilitate this collaborative modeling process with a support-tool, there is need to first study, analyze and
understand the detailed communicative acts (conversations) of the stakeholders involved in such a process with respect to negotiations, propositions, argumentations and decision-making. It should be noted that studying, analyzing and evaluating the solution is itself a problem which can be referred to as a wicked problem [Con01, RW73] or a messy [Ven99], ill-defined problem. Wicked problems are ill-structured problems that can not successfully be analyzed or solved using traditional linear and analytical methods – the classical “water-fall” or System Development Life Cycle (SDLC)-like methods. A tame problem is, on the other hand, “relatively well-defined, has a stable problem statement, has a definite stopping point, we know when the solution is reached, the solution can be tried and abandoned, the solution can objectively be evaluated as either right or wrong, belongs to a class of problems and can be solved in a similar manner” [Con01].

Thus, studying, analyzing and evaluating a collaborative modeling session, with a view of trying to understand the act (process) of modeling is a wicked problem. It is hard to know how the different stakeholders within the modeling process “do their thing”, i.e., how they communicate, how they negotiate, reach agreement and consensus and how they decide collectively. In such a social environment or network, there are often rules set and strived for, goals and objectives to realize, individual and/or group priorities and preferences to reconcile [SHP09b]. The question to ask is: how do the modelers go about all these? An answer to this necessitates a study, an analysis and evaluation of the modeling process. Also, a solution to this can neither readily be found nor can the classical linear and analytical methods be employed. Innovation and creativity in solution creation and/or design takes center stage. The rigour and relevance of the methods, constructs, theories, artifacts, designed and constructed, etc., can then be established through use of Design Science [Hev07, HMPR04, MS95].

The success-solution will be measured only when the quality of the different modeling artifacts used in, and produced during, the modeling process is established. This, in a way, is a practical problem with a number of knowledge questions to address. It is a practical problem since it requires design or development of a well-structured methodology to study, analyze, understand the modeling process, see the “Rules-Interactions-Models (RIM) framework in [SHP09a, SHP09d], and guidelines to develop a support-tool that includes the identified modeling artifacts. It is practical since it aims to develop a “Collaborative Modeling Evaluation (COME) framework” for the collaborative modeling process evaluation, see [SHP10a, SHP09b]. It contains knowledge questions since we are not only trying to provide the missing knowledge by identifying the different concepts and their relationships during a collaborative modeling process, but we also aim to describe or explain what takes place during a collaborative modeling session, determine the success factors (efficacy – efficiency and effectiveness) of the modeling process and the acceptance or adoption of the developed methodology and framework.

Figure 1.1 shows the conceptual framework that guides this research in trying to solve this wicked problem. As seen in this figure, we study and analyze the collaborative modeling sessions through the RIM framework. This is done through a triage of the following things: the rules and/or goals, the interactions and the models. All these are realized through the modeling artifacts that are used in, and produced during, a modeling process. These are the modeling language, the modeling procedure, the modeling products and the support-tool. To evaluate the success of the modeling process we have to evaluate the quality of these modeling artifacts through modelers’ Perceived Quality of the Modeling
Chapter 1. Background, Context and Motivation

Language (PQML), Perceived Quality of the End-Products (PQEP), Perceived Ease of Use of the Modeling Medium (EOUM) and Perceived Usefulness of the Modeling Procedure (PUMP). To determine how the modeling process has gone, we diagnose (evaluate) it and determine heuristics (quality criteria, factors or dimensions) which can help us to identify the flaws in the modeling process. The diagnosis (of process data) helps us identify weak spots and occurrences of flaws where things (could) have gone wrong during the modeling process and which lead to low assessment of the quality of the artifacts by the modelers or evaluators. Through this conceptual framework we hope to be able to explain what happens during a collaborative modeling process, suggest improvements in achieving success of a collaborative effort and develop guidelines that can help development of a support-tool. Our contributions, as discussed in Chapter 9 are in form of a theory that describes and explains what happens, how to analyse the modeling processes and how to evaluate them.

![Conceptual framework](image)

**Figure 1.1: Conceptual framework.**

1.2.1 Research Questions

The following main research question and the associated sub-questions (design questions) will guide and direct us towards solving the above problem and realization of our research (design) objectives.
1.2. Research Problem

RQ What is an adequate methodology for the analysis and evaluation of collaborative modeling?

To further guide our research in general, and problem investigation in particular, we shall have the following sub-questions within the context of understanding and supporting collaborative modeling. These sub-questions provide our design choices.

RQ1 How can the detailed steps resulting from the communicative and collaborative dialogue of the participants in the modeling process be studied and analyzed and what are the key-drivers of a collaborative modeling process in view of the communicative nature of the modeling process?

RQ2 What are the relationships between the key-drivers of a collaborative modeling process and which theoretical model describes these relationships?

RQ3 How can the quality of the collaborative modeling process be measured and what is the theoretical framework that describes and links the analysis and evaluation framework?

In order to understand what takes place during the modeling process there is need to identify the detailed steps of the communicative process that modelers are engaged in. This involves analyzing and categorizing not only the communication at a macro-level, but also the conversational speech acts at a micro-level. The study and analysis require identification of categories and patterns of communicative speech acts. This identification and categorization helps us in determining the key-drivers (RQ1). These drivers not only guide and direct the modeling process but also motivate the modelers. We hypothesize that these drivers do not work in isolation but work in an integrated way to keep modelers engaged in the collaborative modeling process. This relationship between drivers may be captured in a theoretical framework. Identification of the key-drivers helps us identify the causal relationships so as to study how these affect and impact each other. This causal relationship can be established via a theoretical model (RQ2). Studying and analyzing the collaborative modeling process requires an evaluation of a number of modeling artifacts. These, as pointed out already, include the modeling language, the modeling procedure, the models and the medium or support-tool.

We further hypothesize that the quality of a collaborating modeling effort can be determined via the modeling artifacts. Evaluating such modeling artifacts helps to pinpoint the success factors of a collaborative modeling process. We theorize that the evaluation process is linked to the analysis of the modeling process via some of the key-drivers of the modeling process. The link between the analysis and the evaluation framework via the key-drivers can be established via a theoretical framework (RQ3). We posit that such framework traces the quality flaws in the evaluation back to the analysis of the collaborative modeling effort. In most multi-actor modeling processes, priorities and preferences differ among the stakeholders. Their levels and/or degrees of perceived usefulness of the modeling procedure, perceived ease of use of the medium and perceived quality of both the modeling language and models may be significantly different. This research tries to address this in addition to finding out the acceptability and adoption of the analysis and evaluation methods in practice. The analysis and evaluation frameworks are supposed to give blueprints on which to base the development of a support-tool that encompasses the
analysis and evaluation of the modeling effort. Guidelines are also needed to facilitate the development of this support-tool.

### 1.2.2 Research Objectives

By providing solutions to the above questions, this research achieves the following main research objective:

**OBJ** Development of a theory that explains and describes what takes place during a collaborative modeling effort and describes a well-structured methodology for evaluating a collaborative modeling process.

This objective is achieved by developing, analyzing and validating conceptual as well as theoretical frameworks, models and meta-models through the following sub-objectives. Each objective is linked to a research question as indicated below.

**OBJ1** To develop a framework for studying and analyzing the detailed steps that result from a communicative and collaborative dialogue and identification of key-drivers of a collaborative modeling process [RQ1].

**OBJ2** To identify and establish relationships between the key-drivers and a theoretical model that describes these relationships [RQ2].

**OBJ3** To develop a framework that helps us to evaluate the quality of a collaborative modeling process and helps determine the success factors and a meta-model that integrates the analysis and evaluation framework [RQ3].

### 1.3 Research Approach

Before giving the approach followed in this research, we give some definitions of a few terms, concepts and notions that are often mixed up. Some of these are often used interchangeably or as synonyms in specific Information Systems Development (ISD) studies. This use often blurs the meaning of the terms if it is not properly defined. The terms that cause this mix up are: paradigm, methodology, approach, method, technique, and tool, see for example [Bri96, Lyy87, Min01].

#### 1.3.1 Basic Definitions and Terminologies

**Research Paradigm**

A paradigm is a general set of philosophical assumptions that define the structure of the research and the proposed intervention [IHK98, Min97, TT98]. A paradigm covers the ontology (a set of entities assumed to exist), epistemology (nature of the valid knowledge) and axiology or ethics (proaxiology – what is taken to be right).

**Research Methodology**

A methodology is a well-structured set of activities, guidelines, concepts, beliefs, methods, values and normative principles which assist in the undertaking of a research [HKL96, IHK98, Min01, Min97]. Three connotations for a methodology are distinguished by [Min01]: 1) general meaning – where the methodology refers to a study of methods or
1.3. Research Approach

A research approach consists of classes of similar research methodologies [IHK98]. A research approach is a family of research methodologies that share goals, guiding principles, fundamental concepts that drive the actions and interpretations in a research approach.

Research Method or Technique

A research method or a technique is a specific activity with clear and well-structured ways of performing activities in a research methodology. While a methodology specifies what to do, a method specifies how to do it, see for example [IHK98, Min01, Min97]. This research takes this view. It should, however, be noted that [Bri96] takes a slightly different view of a method. He, in fact, distinguishes a research method from a research technique.

Tool

A tool is an artefact, i.e., a computer software or program, that is, an automated means used to support or perform certain activities in a research technique or a research methodology [Bri96, IHK98, Min97].

1.3.2 Philosophical Position

In order to choose the most appropriate research strategy we have to be guided by: 1) the nature of the research question(s) and the research objective(s), 2) whether the research is theory-testing (theory proving) or theory development (construction), and, 3) the underlying philosophical foundations that underpin research methods. We briefly review the extant literature related to guidelines (1) - (3) before stating explicitly the research approach followed in this research. To select a research approach using a research question, Yin [Yin03] gives a classification of research approaches by categorizing research questions into how, what, why, where, how much, how many questions. Similar to Yin’s (ibid.) approach, Järvinen [Jü08] underscores the importance of research questions in guiding the selection of a suitable research method. His taxonomy extends an earlier classification of research methods by March and Smith [MS95] which differentiates between natural and design sciences, theoretical and empirical studies, theory development and theory testing studies, see also [HMPR04].

Related to research questions is the notion of theory testing (confirmatory) and theory development (construction). The object of research could be testing a-priori hypotheses in order to prove a theory about an observed phenomenon or to develop a theory that is empirically grounded in the data [GS67]. To select a suitable research approach, one has to determine whether the object of the research is to test or develop a theory [Gal91]. A
Chapter 1. Background, Context and Motivation

further taxonomy for theory in research, its structure and the associated research questions is given by Gregor [GJ07, Gre06]. Gregor’s taxonomy distinguishes between: i) analysis theories – that answer the what is question and whose aim is to analyze and describe, ii) explanation theories – answering the what is, how, why, when and where questions and whose aim is to provide explanation, iii) prediction theories – answering what is and what will be questions and are aimed at predictions, iv) explanation and prediction theories – answering the what is, how, why, when, where and what will be questions and aiming at explanations and predictions, v) design and action – answering the how to do something questions and aiming at giving prescriptions (methods, techniques and form of function) of how to construct the artifact. It should be noted from the main objective of our research that the intended theory is at the intersection of the analysis, explanation and design and action theories. This is explained further in section 8.3.

To give our research philosophical position, we need to look at the available taxonomies and or dichotomies. The first taxonomy of research methods was given by [GL87] where the “object” on which the research effort is, is differentiated from the “mode” by which the research is carried out, see also a revised taxonomy in [Gal91]. The object refers to the society, organization (group), individual, technology or methodology in which the problem is situated while mode refers to the research approach by which the problem is investigated. Two opposing positions have long been recognized in IS research: the hard positivist and the soft interpretivist positions, see for example [CH04, FH98a, Gal91, GL87, IHK98, OB91]. Fitzgerald and Howcroft [FH98a] give an excellent dichotomy of each of these positions at the paradigmatic, ontological, epistemological, methodological and axiological levels. At each of these levels the underlying philosophy that underpins the positivist and interpretivist positions are outlined as follows: i) Paradigmatic level: positivist vs. interpretivist; ii) Ontological level: realist vs relativist; iii) Epistemological level: objectivist vs subjectivist, etic/outsider/objective vs emic/insider/subjective; iv) Methodological level: quantitative vs qualitative, confirmatory vs exploratory, deductive vs inductive, laboratory vs field, nomothetic vs idiographic; v) Axiological level: rigour vs relevance.

With the above in mind, we are now in a position to explicitly state the research strategy followed in this research. This helps us to use appropriate research designs and instruments. From the nature of our research questions and objectives, it is clear that our research follows an interpretive paradigm. The aim is to understand the collaborative modeling process from the researchers’ own and the stakeholders’ perspective without assuming any universal truth but within the identified frame of reference. This research is ontologically relativistic and epistemologically subjective. This means that in trying to study, analyze, understand and evaluate the collaborative modeling process, we assume pre-existing structures within the domain and research findings are assumed to emerge from the interactions of the researcher, the stakeholders in the modeling process and the domain mediated by the attitudes, beliefs/perceptions, intentions, values and behaviour of the researcher and stakeholders. This research is methodologically qualitative and exploratory. This means that our research tries to find out what exists in, or what happens during, a collaborative modeling process, what the patterns or categories in the data are. To understand the modeling process, we aim to describe and explain what takes place during a modeling process and to describe and explain how quality can be attained.

Still on the methodological level, this research falls under an inductive approach. This
1.3. Research Approach

means that to achieve our main objective, there is need to move from the specific observations that are strongly grounded in the data to generalizations and eventually to the theory. Although this is apparently the preferred approach, this research intends to apply a more focused approach – abduction [Pei8a, Pei60, Sta93] to data exploration, classification and categorization. Abduction is the process that aims at providing an explanation for a new or surprising fact, pattern, etc., without any a-priori presuppositions, hypotheses or theories [Pei55, SC96]. Abduction forms an explanatory hypothesis from an observation requiring explanation [Pei60]. The data analysis for this research is exploratory and aims at uncovering patterns and categories in the data. This fits well the conceptual and qualitative analysis and understanding of a collaborative modeling process whose product is the theoretical insight into what takes place, the patterns and categories of the communicative dialogues and the quality insight of the modeling artifacts and the overall quality of the modeling process. The preference for abduction to induction comes from the observation that induction leads to generalization of empirical laws not theoretical laws [Car52] while abduction leads to hypotheses and propositions which can be tested [Sul91] not ones that can be asserted. Our aim is to have an explanatory and descriptive theory that is strongly grounded in data, i.e., in observations, patterns, categories, etc. Yu [Yu94] nicely summarizes the debate about abduction, induction and deduction as follows: “abduction creates, deduction explicates and induction verifies”. In view of the above discussion, we now summarize our philosophical positions in Table 1.1.

<table>
<thead>
<tr>
<th>Philosophical Assumptions</th>
<th>Position</th>
<th>Aim</th>
</tr>
</thead>
<tbody>
<tr>
<td>Paradigm</td>
<td>Interpretive</td>
<td>To understand the collaborative modeling process from the researcher’s own and the stakeholders’ perspective without assuming any universal truth.</td>
</tr>
<tr>
<td>Ontology</td>
<td>Relativist</td>
<td>To study, analyze, understand and evaluate the collaborative modeling process, without assuming pre-existing structures within the modeling domain.</td>
</tr>
<tr>
<td>Epistemology</td>
<td>Subjectivist</td>
<td>To have research findings that emerge from the interactions of the researcher, the stakeholders in the modeling process and the domain mediated by the attitudes, beliefs/perceptions, intentions, values and behaviour of the researcher and stakeholders.</td>
</tr>
<tr>
<td>Methodology</td>
<td>Qualitative - Exploratory</td>
<td>To explain and describe what happens during collaborative modeling. To find out what exists in, or what happens during, a collaborative modeling process, what the patterns or categories in the data are.</td>
</tr>
<tr>
<td></td>
<td>Abductive</td>
<td>To have an explanatory and descriptive theory that is strongly grounded in data.</td>
</tr>
<tr>
<td></td>
<td>Field</td>
<td>To execute the research using exploratory and explanatory controlled experiments and/or case studies involving stakeholders in the field.</td>
</tr>
<tr>
<td></td>
<td>Relevance &amp; Rigour</td>
<td>To have research findings that have practical implications and are accepted and adopted by practitioners, and to execute the research using rigorous research methods/techniques and tools.</td>
</tr>
</tbody>
</table>

Like we have argued for abduction, we argue for both relevance and rigour at the axiological level despite the obvious choice for relevance due to the interpretivist paradigm taken. Although we want our results to be relevant for practice, we would also like to conduct the research in a rigorous way. This is in no way a contradiction to the stance
already taken but shows a slight degree of divergence where we are likely to have some degree of “mixed methods”. This is healthy and has been advocated for by a number of researchers, see, for example [Min01, Min97]. Moreover, this research takes a design science approach to research [HMPR04, MS95, Wie10, Wie09] which emphasizes both rigour and relevance.

1.3.3 Design Science Research Approach

In this work we follow a Design Science (DS) approach [HMPR04, MS95, Sim96] to construct the so-called design artifact. An “artifact” in design science refers to a novel (technological) tool, method, technique, framework, model or developed theory that makes information systems more effective and efficient. Different aspects of design science do exist in the literature, e.g. paradigms and theses [Iiv07], framework and guidelines [Hev07, HMPR04], taxonomy and theory [GJ07], method and process [PTRC08, KTG06], patterns [KV08, VK08, VK04], and design evaluation [PHBV08] and all/or some of these different aspects may be investigated and reported in a DS research. In this research we intend to develop a meta-model, as our main artifact, that builds on two frameworks (RIM and COME) and an explanatory and descriptive theory about the analysis and evaluation of collaborative modeling processes. Design science identifies four design artifacts and two major processes [MS95]. The design artifacts are the constructs – which provide the language in which the problem and solution are defined, models – use the constructs to represent the design problem and its solution space and aid problem and solution understanding, methods – provide the processes of how the problem should be solved and how the solution space should be searched, and instantiation – which shows how the constructs, models and methods are implemented. The two processes are build – developing or constructing theories, artifacts, frameworks, etc., and evaluate – for assessing and justifying the designed solution by analytical, case, field, experimental, simulation studies, etc.

In [Hev07], see also [HC10, ch.2], three cycles of a design science research are identified which are: the relevance cycle, rigour cycle and the design cycle. The relevance cycle initiates the research by identifying the requirements to the research, e.g. the problem or opportunities faced by the stakeholders and defines evaluation criteria for the acceptance of the solution. After the solution is designed it is tested in the problem environment to see whether it solves or improves the situation faced before. The rigour cycle identifies, from the knowledge-base, existing knowledge in the literature, theories, methods, frameworks, etc., that can be used to tackle the problem or upon which a novel solution may be based. The designed solution which may be in form of new knowledge, new methods, theories, frameworks, meta-models, etc., becomes new addition to the knowledge-base. The design cycle is concerned with the actual design of the artifact and is where the hard-work is done. It iterates between the relevance and rigour cycles. Simon [Sim96] calls it “generation of design alternatives and evaluating them against the requirements” until a required and satisfactory artifact is obtained.

Although there has been, and still there is, tension and conflict between rigour and relevance, see for example [BW96, BZ99, MM07, Wie10], and whether one should emphasize rigour or relevance in any research, we apply, in Chapters 6 and 7, the approach suggested by Fällman and Grönlund [F00] to show how we attained rigour and relevance in our research design. Their view takes rigour as “denoting a structured and controlled
way of planning, carrying out, analyzing and evaluating and producing products of research” while relevance refers to the effort of carrying out research that “is of concern to a perceived audience”. Relevance requires, therefore, validation of the designed artifact with the intended audience while rigour requires a methodical and meticulous execution of the research design. This augurs well with the design science rigour and relevance cycles.

Figure 1.2: Design science rigour and relevance cycles applied to CMG.

Figure 1.2 shows how the design science cycles were applied to the collaborative modeling games (CMGs) through exploratory, explanatory and confirmatory modeling experiments. CMGs are modeling session experiments in which we study the relationships between modelers’ interactions using the communicative process under rules, goals and the models. By measuring and evaluating the quality of the different artifacts within the CMGs we determine the effectiveness and efficiency of the modeling process. In section 3.2 we discuss the metaphorical approach to collaborative modeling – hence the use of the term collaborative modeling games. We identify and define constructs as concepts and/or meta-concepts for the two frameworks: the Rules-Interactions-Models (RIM) framework and the Collaborative Modeling Evaluation (COME) framework and the meta-model which integrates the two frameworks. We construct novel methods for analyzing the communicative process in order to understand what takes place therein and evaluating the different artifacts used in, and produced during, the collaborative modeling process. We construct as models, two frameworks and a meta-model that can be used to study, analyze and understand the modeling process and for evaluating the different artifacts used in, and produced during, the modeling process. It should be noted that in this research we
do not go as far as implementing the designed solution into a workable (technological) artifact. Therefore the instantiation phase is not reached.

□ Designing the CMGs. This is the first phase in the cycle in which we analyze the available methods, theories, methodologies and frameworks, etc., in the conceptual modeling knowledge-base to identify the current state of knowledge and gaps that need to be bridged. Identified gaps are studied and analyzed by designing Collaborative Modeling Games (CMGs). In our approach different modeling artifacts that are crucial to conceptual modeling in general, and collaborative modeling in particular, are identified. These include the modeling language, modeling procedure, modeling products/outcomes and medium or support-tool.

□ Execution and Analysis of the CMGs. This second phase involves carrying out modeling sessions using the CMGs and analyzing them within the “Rules-Interactions-Models” (RIM) framework to determine the different (micro and macro) conversational and interactional categories and themes of the interactions, rules and model-related conversational scripts. A number of exploratory and (controlled) explanatory modeling experiments are designed and carried out to study, analyze, evaluate and understand the modeling process.

□ Measuring and Evaluating the CMGs. The third phase in the cycle involves measuring and evaluating the modeling process using an evaluation framework, the Collaborative Modeling Evaluation framework (COME), employing mainly the Analytic Hierarchy Process [Saa80]. To determine the quality of the different modeling artifacts and the efficiency and effectiveness of the modeling process, we evaluate the different artifacts in the modeling process using a number of quality dimensions (criteria, attributes or factors). To achieve this, a number of exploratory and (controlled) explanatory modeling experiments are carried out to help in the evaluation of the modeling artifacts and the whole collaborative effort.

□ Validating the CMGs. The fourth phase involves carrying out the modeling sessions with experts in the field to tap their expertise and skills and getting their views about the modeling process thus completing the relevance cycle. This helps us to get a real feel about what is done and required in practice and it also helps us improve the whole modeling process via CMGs. This phase helps us to empirically test and validate our theoretical hypothesis and propositions. The results from this phase lead to either of the two phases: improving the CMGs or (re-)designing the CMGs.

□ Improving the CMGs. The last phase in the cycle involves working on the identified flaws and suggestions from field experts which may require re-execution and analysis of the CMGs. The developed theories and frameworks about the modeling process or act of modeling are normally new additions to the knowledge-base of conceptual modeling, in general, and collaborative modeling in particular. Through the design science approach with the theories being grounded in the data, theories explaining the modeling process and frameworks for studying, analyzing and evaluating this process are established.
### 1.3.4 Group Model Building Approach

In some of the modeling experiments, we use the Group Model Building (GMB) approach [AVRR07, RA95, RVM02, Ven96] to elicit the knowledge that is stored in the mental models of the participants and to help all the stakeholders involved in the modeling approach share this knowledge. GMB is an approach that uses the Systems Dynamics (SD) methodology [For93, For87, For61] to help the participants exchange their perceptions of the problem. Through this exchange, which is communicative in nature, they come to determine and define the problem they are tackling, determine how the problem came about, how the situation arose and what the underlying causes are and how they can tackle the problem. Some of the underlying assumptions of GMB which we make use of in this work include the following [Ven96]: (i) its use in eliciting the knowledge stored in the mental models of the participants taking part in the modeling process, (ii) helping group members exchange their perceptions about the problem by asking and answering questions that lead them to the required course of action, (iii) increasing group members’ understanding of the problem and their commitment to the solution or devised course of action by building the (systems dynamics) model rather than building the model of the required system, (iv) supporting a group decision-making process about the wicked or messy problem being faced, and, (v) fostering or creating consensus after sufficient communicative exchange. The skilled facilitator [Sch94] helps modelers achieve these goals.

In [Ven96], the importance of consensus rather than compromise is emphasized. Consensus, unlike compromise which refers to “settlement reached after mutual concessions”, refers to “unanimous agreement” and once reached, creates sufficient basis for not only a commitment of the stakeholders to such a decision but also their commitment to its implementation. As we argue later on, collaborative modeling brings together different stakeholders with different skills, expertise and competencies and knowledge stored in their mental models which brings about their-often-noticed bias and subjectivity manifested through their individual priorities and preferences. Using a GMB approach coupled with a communicative process such bias and subjectivity is reduced when modelers reach a shared meaning, and understanding of the problem or when they reach consensus about the quality to attach to a given artifact being evaluated when they agree on the final score, weight or rating. Thus, use of the group model building approach helps us guide modelers to reaching knowledge sharing, developing a model that is a result of their knowledge sharing and reaching group consensus through a decision-making process and committing themselves to the group decisions. All this is done through a communicative process. It should be noted that our over-riding goal is more the use of the GMB approach by exploiting the benefits that accrue from such use than by developing systems dynamics models in which feedbacks and causal processes, stocks and flows, etc., are studied using the common language – “Systems Thinking”. Thus, models developed, see Figure 6.9 and Figure 6.12, are obtained using a simple System Dynamics tool – Vensim [Ven11] – rather than using more advanced tools such as iThink [iTh11] or STELLA [STE11].

### 1.3.5 Research Cycle

The research approach (and the research cycle) that guides our research is shown in Figure 1.3. We use the regulative cycle [Str97b, Wie96] to show how the different research phases (Phase 1 – Phase 6) are executed. Design Science [HMPR04, MS95, Wie09,
Chapter 1. Background, Context and Motivation

Wie10] is used to guide the design and evaluation of the different artifacts and processes. In Figure 1.3, the Design Science cycles are shown in relation to the research execution phases.

Figure 1.3: Research execution cycle.

Phase 1. In this phase the problem is investigated together with its environment using a combination of literature study and the unit (domain) of study. The current knowledge about the problem is probed from the literature and gaps are identified. The owners of the problem (stakeholders, etc.) are identified, the research goal is formulated, the unit of study is identified, and research questions and objectives are formulated. Investigating the problem from the literature and the unit of study helps us to ascertain the relevance of the anticipated solution design. In this phase, we study and analyze empirically the collaborative modeling process. The deliverable out of this phase is a conceptual Rules-Interactions-Models (RIM) framework which helps us to study and analyze collaborative modeling.

Phase 2. The developed RIM framework is further studied empirically in an exploratory collaborative modeling session in this phase. Relationships between the different aspects of the framework are established. Literature study continues in phase 2, this time aiming at identifying the quality constructs and their dimensions, the success factors of a collaborative effort and quality frameworks on which collaborative modeling evaluation can be anchored. We further probe the literature to determine the models on which modelers’ perceived quality, ease of use and usefulness of the modeling artifacts that are used in, and produced during, a collaborative effort are anchored. This helps us to determine the
acceptability and adoption in practice (relevance issue) of the framework. The outcome of this phase is a tightened RIM framework that can be used to study and analyze a collaborative modeling effort.

**Phase 3.** In this phase, the design phase continues with the design of the Collaborative Modeling Evaluation (COME) framework anchoring it on the Technology Acceptance Model (TAM) [Dav89, DBW89] which is based on the Theory of Reasoned Action (TRA) /Theory of Planned Behaviour [Ajz91, FA75, Mat91] and the Method Evaluation Model (MEM) [Moo03, MSBS02]. Anchoring the COME framework on the TAM model helps us to not only measure the attitudes, beliefs/perceptions, intentions and behaviour of the modelers about the their perceived usefulness of the modeling procedure, ease of use of the modeling tool, their perceived quality of the modeling language and models, but also their intention to use the modeling procedure and tool. Anchoring it on Moody’s MEM Model helps us determine the success factors and the acceptability and adoption of the analysis and evaluation framework in practice. The SEQUAL framework [KSJ06, LSS94] gives a theoretical anchor for the evaluation of the modeling artifacts. The evaluation is done in two parts: using Multi-criteria Decision Analysis (MCDA) [HTAB98, TF07] techniques, e.g., AHP [Saa80], where the modelers reconcile their differences about the priorities and preferences in assigning scores to quality dimensions and reaching an overall agreed upon quality score for the quality dimensions and the modeling artifacts. Using the AHP approach helps us to study the communicative process through the negotiations and see how modelers reach agreement and, possibly, consensus on the quality of the modeling artifacts. The second part in the evaluation framework consists of using a designed research instrument (questionnaire) where the perceived quality, ease of use, usefulness and intention to use are measured. This technique validates the COME framework using an MCDA technique.

**Phase 4.** This phase starts one of the two explanatory modeling sessions. Here we execute and validate both the RIM and COME frameworks, first with a large group of students in a controlled experiment (Controlled Expt.1), and then with IT experts (Validation Expt.1). We test the reliability and validity of the instruments using Exploratory Factor Analysis (EFA) [AH08, Bro06], Confirmatory Factor Analysis (CFA) [AH08, Bro06, DXT94] with Structural Equation Modeling (SEM) [GSB00, RM06]. The outcome of this phase is a validated research instrument to use in measuring the perceived quality of the modeling language and models, ease of use of the modeling tool and usefulness of the modeling procedure, adoption and acceptability of the RIM and COME frameworks.

**Phase 5.** The explanatory collaborative modeling investigation is continued in this phase by investigating and validating the RIM and COME frameworks with a large group of students (Controlled Expt.2) and then with IT experts (Validation Expt.2). This is aimed at concretizing the results in Phase 4. The outcome of this phase is a meta-model that integrates the RIM and COME frameworks. The purpose of having an integrated model is two-fold: 1) to help us trace the flaws in the evaluation process back to the analysis process, as shown in our conceptual framework in Figure 1.1, 2) to help us derive guidelines that can be used in the development of a support-tool for collaborative modeling that incorporates analysis and evaluation issues.
Phase 6. This phase is concerned with the development of the theory that is both descriptive and explanatory for collaborative modeling. This theory is grounded in the data obtained in phases 2 - 5. In this phase practical implications of the analysis and evaluation frameworks and generalizations are explored. Guidelines for developing a tool are also stated. Additions to the knowledge base are stated in form of constructs, models, procedures and guidelines for tool support.

1.4 Thesis Road Map

The thesis is organized into four parts and its structure is shown in Figure 1.4.

Part I. Introduction
Chapter 1. Context, Background & Motivation
Chapter 2. Existing Methodologies, Theories & Frameworks

Part II. Analysis & Evaluation of Collaborative Modeling Processes
Chapter 3. The RIM Framework
Chapter 4. The COME Framework
Chapter 5. Meta-model for RIM & COME Frameworks

Part III. Meta-model Validation (Design & Solution Validation)
Chapter 6. Modeling Sessions: Controlled Experiments
Chapter 7. Modeling Sessions: Validation Experiments

Part IV. Discussion & Conclusion
Chapter 8. Discussion (Findings, Theory & Tool)
Chapter 9. Epilogue (Contributions & Final Notes)

Figure 1.4: Thesis structure.

Part I contains and unifies the introductory chapters. Chapter 1 mainly deals with the problem, research questions and objectives and the research approach. Chapter 2 surveys related work, especially that, related to conceptual and collaborative modeling analysis and evaluation. Part II contains three chapters that contain conceptual frameworks designed to address the research questions and to realize the objectives. More specifically, Chapter 3 introduces the RIM framework used to analyze, study and understand the modeling process. It addresses research questions RQ1, RQ2 and and objectives OBJ1 and OBJ2. Chapter 4 introduces the COME framework that helps us to evaluate the modeling process and determine the efficacy – efficiency and effectiveness, the success factors of a collaborative effort, the modelers’ perceived quality, perceived usefulness and perceived ease of use of the modeling artifacts and the acceptability and adoption in practice. It specifically, addresses research question RQ3 and objective OBJ3. Chapter 5 introduces a meta-model that unifies and integrates the RIM and COME frameworks. This chapter addresses research questions RQ3 and objectives OBJ3. Part III has two chapters that deal with collaborative modeling activities done to validate the frameworks and the meta-model. Chapter 6, specifically, describes the explanatory controlled experiments while Chapter 7 describes the confirmatory and validation experiments. Part IV, which also has two chapters, discusses the main observations and findings of the research in Chapter 8, the theory for studying, analyzing and evaluating the collaborative modeling processes, and the support-tool requirement. Chapter 9 summarizes the research contributions.
## 1.5 Research Publications

Some of the chapters given in this thesis are extended versions of the following research publications.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Chapter(s)</th>
<th>Title</th>
<th>Details</th>
</tr>
</thead>
</table>
1.6 Chapter Summary

This chapter has highlighted a number of key observations on which our research is based. It has been observed that to determine the efficacy of a collaborative modeling or group model building effort there is need to analyze what takes place during the modeling process. It has been pointed out that analysis involves looking at the communicative process of the modelers which may include negotiation, argumentation, agreement, decision making, consensus, etc., in view of the rules and goals, interactions, and models produced. It has been further pointed out that in this research, we develop and use a Rules-Interactions-Models (RIM) framework for this analysis. The goal of this analysis is to help us have a deeper understanding of the process of modeling, i.e., know what takes place during collaborative modeling so that we can support it with a tool.

It has further been observed that within a collaborative modeling process, there are different modeling artifacts that are used in, or produced during, the modeling session. Such artifacts include the modeling language, modeling procedure, the intermediary and end-products (models) and medium or support-tool. Due to the their interdependencies and impact on the overall quality – efficiency and effectiveness – of the modeling process, it is claimed that there is a need to determine the overall quality and success of the modeling effort as aggregation of the quality of these artifacts. We develop and use a Collaborative Modeling Evaluation (COME) framework for this purpose and a meta-model for the integration of the RIM and COME frameworks. We posit that such a meta-model helps us to trace the quality flaws in the evaluation back to the analysis of the collaborative modeling effort.

In summary, this chapter has set the stage for the work to be done and explored in the rest of the chapters. The problem to be addressed as well as the objectives to be achieved are stated. The philosophical (ontological and epistemological) positions that underpin this research are stated from the outset. This chapter has clearly pointed out that we follow a subjectivistic epistemological orientation due to our belief that we understand the world according to our prior knowledge and experiences. The chapter has further highlighted the research approach, methodology, methods and techniques that are followed for a relevant and rigorous scientific inquiry. To position the research problem within a wide spectrum we explore, in the next chapter, some of the related frameworks, theories and methodologies on which our approach, developed frameworks and theories can be anchored.
2 Existing Theories and Frameworks

To avoid the “Yet Another...” syndrome, the past should inform the present so that the future is predicted with hard facts...

– Anonymous

2.1 Overview

This chapter discusses some of the existing theories and frameworks which we use to give our research a theoretical underpinning. We look at the main tenets of Communication Theory and discuss how it can help us study and understand what takes places during a collaborative effort. We, specifically, look at Argumentation Theory and Negotiation Theory as key components in helping us understand the communicative process between, and among, the different stakeholders in a collaborative modeling process. Decision Theory, especially group decision-making, is brought into play to help us understand the negotiation process and how collaborative modelers reach consensus.

To evaluate the different modeling artifacts, collaborative modelers need to have a method that helps them assign weights to the quality dimensions. In this regard, we discuss some of the existing Multi-criteria Decision Analysis (MCDA) approaches. We single out, specifically, the Analytic Hierarchy Process (AHP). We discuss the strengths and limitations of some of the most common quality frameworks, notably: Semiotic Quality (SEQUAL) framework, Guidelines of Modeling (GoM) and the Quality of Modeling (QoMo). Evaluation of the quality of the modeling artifacts is subjective and is dictated by a number of factors, mainly psychological factors. In this regard, we discuss the Theory of Reasoned Action (TRA)/Theory of Planned Behaviour (TPB) in relation to modelers’ attitudes, perceptions, intentions and behaviour. Although other theories and frameworks exist, mainly about evaluation of conceptual models, we synthesize only those whose concepts we build on and apply in our analysis and evaluation frameworks as will be shown in Chapter 3 and Chapter 4.

2.2 Social Interaction – The Four Cs

Thus far, we have interchangeably used the terms: participants, stakeholders and modelers to refer to persons taking part in a collaborative modeling process. Although such persons can collectively be referred to using the well-established social entity terms, e.g., group, team [Har92] and community or social network [GK07, Wol10], we prefer not to draw a sharp distinction between a group and a team since the collaborative modeling process being looked at in this research does not “involve long-term activities that may range from a couple of weeks to a number of years where people must establish and maintain an ongoing awareness of other’s actions, plans, goals, and activities” [NCR04]. For such long-term activities, a group has task structures with limited role differentiation, and
group performance is an aggregation of individual efforts whereas a team has members with specialized roles, and the team works together to accomplish common goals. Where the term group or team is used, it refers to participants, stakeholders or modelers involved in a short-term modeling activity. We have, similarly, used collaborative modeling in its broad sense and from an intuitive perspective. However, collaboration, if not properly contextualized, its meaning may be obscured by its three “sister cousins”: “cooperation, coordination, and communication” or what [Den03] calls: “The CCCs of Togetherness”. Colloquial English uses some of these terms synonymously, something that creates ambiguity and obscurity. Therefore, before looking at the role played by communication in collaborative modeling, we look at these concepts first.

**Collaboration.** The term collaboration can be traced from the Latin etymology of the Latin verb “labor” – which refers to: “work, effort or burden” and the Latin word “collaborare” – which refers to: “working together”. However, the English translation leads to a different meaning of this term. Wolf [Wol10, p.58] summarizes a number of these meanings from a few dictionaries. For example, the Oxford dictionary defines collaboration as: “the act of working with someone to produce or create something”, the Collins English dictionary defines it as: “the act of working together with another person or others on a joint project” and “something created by working jointly with another or others”. The Merriam-Webster’s Online Thesaurus defines collaboration as: “state of having shared interest and efforts” and as: “The work or activity of a number of persons who individually contribute towards the efficiency of the whole”. From these definitions we can say that this research takes the meaning of the Collins English dictionary and that of the Merriam-Webster Online Thesaurus which emphasize, respectively, the “process and product”, and “team-work” aspect of collaboration. As we explain later, collaborative modeling is a negotiation (process) that results in the generation of models (products) by a team or group of modelers (working together), who although initially have different (but complementary) skills, expertise, knowledge and divergent views and interests, the process helps them reconcile these, and they end up not only with a shared view but also with a shared meaning and understanding. This stance is in line with that given by Schrage [Sch90], see also [Den03] about collaboration.

“...collaboration is the process of shared creation: two or more individuals with complementary skills interacting to create a shared understanding that none had previously possessed or could have come to on their own. Collaboration creates a shared meaning about a process, a product, or an event. In this sense, there is nothing routine about it. Something is there that wasn’t there before” (italics not in original) [Sch90, p.140]

**Cooperation.** Cooperation can also be traced from the Latin word: “cooperatio” – which means: “assistance or willing to assist” or “the action of acting or working with another(s)” and “association of persons for common (mutual) benefit” [Wol10]. Cooperation is more of a (social: group, team, corporate, enterprise, organization, etc.) culture than a (social) behaviour. The message is always clear with cooperation: “get with the group” [Den03] and “team playing” is one of the catch words. Cooperation does, however, have its down-side and at times can be paradoxical. Being with the group and being a team player are some of the required social cultural norms to adhere to. But as Denise
tartly observes: “much of creativity comes from the sparks of disagreement, dissent, and even conflict” [Den03, p.2]. This is where the paradox is. How can the stakeholders cooperate, be with the rest of the group or team and be team players when they are allowed to present divergent views or opinions? This is nicely answered by Denise when he rests the argument by stating that “Cooperation too often becomes a call for increased socialization to a culture, not a prompt for high performance” (ibid.). It is for this reason that we have phrases such as “competitive or comparative advantage” associated with cooperation. In collaborative modeling we take a game metaphorical view (see section 3.2.2) to study, analyze and understand what happens during modeling. We emphasize the cooperative nature (be with the group – participate or contribute) to modeling rather than the competitive nature, but still encouraging and recognizing the divergence in views and opinions which are eventually reconciled for mutual benefit and shared understanding.

□ **Coordination.** Since the seminal work of Malone and Crowston [MC94, MC90] on “coordination theory”, a number of definitions of coordination have surfaced over years. A nice summary of these definitions is given in Crowston et al. [CRH06], see also [Kle01]. Rather than giving all these definitions, we single out only the following definitions that are pertinent to collaborative modeling. Coordination is “the integration and harmonious adjustment of individual work efforts towards the accomplishment of a larger goal”. They describe “coordination mechanisms as relying on other necessary group functions, such as decision-making, communications and development of shared understandings and collective sense-making”. They further observe that “to develop a complete model of some process would involve modeling all of these aspects: coordination, decision-making and communications” [CRH06]. These definitions are not far from the intuitive definition of coordination which is to harmonize and synchronize for greater efficiency. This is the view taken by Denise [Den03] who observes that: “Coordination begins with an assumption of differences”. It “looks to inform each unit or part of the whole as to how and when it must act”. “Coordination is a framework used to ensure that otherwise disparate forces will all pull in harness”. “Coordination is about efficiency”. The question to ask is how do collaborative modelers coordinate their activities (here and after referred to as: “structuring the modeling process”)? In this research, we studied how this is done in view of the communicative process and the collaborative modeling process. Section 8.2.1 reports about this finding.

□ **Communication.** Communication is one of the terms that is most met on a daily basis but as observed by Denise [Den03], “We ... act as if ideal communications will forge agreement. In reality, when people accurately communicate, they can learn just how far apart they really are. Communication begins with an assumption of differences”. This can be likened to the paradox we observed with cooperation. Communication is aimed at helping people exchange messages, information, etc. The goal of the sender (of the message) is to inform the receiver and he/she expects the receiver to understand him/her through the message communicated. But the irony is that there is always bound to be disagreement. We can ask whether communication has failed in its goal. The answer is a definite no! Communication as a process of exchanging messages, ideas, opinions, information, etc., generates a series of of other communicative processes, e.g., argumentation, negotiation, decision-making etc., that may result into agreement or disagreement. This is the situ-
ation with collaborative modeling and communication plays a major role in reconciling the different positions so that in the end, disagreements are reconciled and consensus is reached. Clarke [CB91] observes that for effective communication the content and the process of communication must all be “grounded” and both must be coordinated. These definitions clearly point out the interplay among the terms: communication, collaboration, coordination and cooperation. This interplay is emphasized in [EGR91, p.40] when he observes that: “The effectiveness of communication and collaboration can be enhanced if a group’s activities are coordinated”.

2.2.1 Collaborative Modeling

**Collaborative modeling – The CPI Approach.** This research follows the definition of collaborative modeling which is given in Renger et al. [RKV08]. Collaborative modeling is looked at “as a joint creation of models”. Taking this, as our working definition, helps us not only require that everyone participates in the modeling process, but also brings on board the three social interactions: communication, coordination and cooperation. These social interactions allow collaborative modeling to follow a “CPI” (collaboration, participation or interaction) modeling approach [Bar09] where, as argued therein, each aspect is a dimension: “the collaboration aspect represents the Experts (analysts) dimension; the participation aspect represents the Users (stakeholders) dimension; and the technology aspect represents the Technology (tools) dimension” (emphasis in the original). For an effective and efficient collaborative modeling process, modelers need to utilize their collective intelligence so as to overcome the forces of fragmentation within the CPI modeling environment.

According to Conklin [Con07], collective intelligence “is the creativity and resourcefulness that is brought to the complex and novel problem solving activity” by a group of collaborative modelers. For a collaborative modeling group to have a socially shared cognition, collective intelligence, which is taken as a natural enabler of collaborative and interactive modeling, should be relied upon and should maximally be utilized. There are, however, forces which Conklin calls “centrifugal forces” that pull apart the stakeholders in the CPI or joint group process and often prevent them from using their collective intelligence. These forces manifest themselves mainly in three forms: problem wickedness – which affects mainly the collaboration dimension of the CPI modeling approach, social complexity – which affects mainly the participation dimension in the CPI modeling approach, and technical complexity – which affects and influences mainly the interaction dimension in the CPI modeling approach, see Figure 2.1.

Due to these forces attributable to social complexity, collaborative modeling process effectiveness and efficiency’s “quality-meter” is lowered even further since the problem is now more wicked. One remedy to the social complexity force is to use communication in form of a natural language, especially, where skills, expertise, and knowledge are divergent. Frederiks et al. [FW05] explored the required competencies and skills of modelers and observed that communication plays a vital role in bridging the gap between the different stakeholders. The effect of group size in a collaborative modeling process has been studied in a number of studies. Avouris et al. [AMK04a] for example, studied a correlation between communication and modeling activity. One striking discovery is the reduction in communication when the size of the group grows bigger but with an increase in activity output and an increase in communication when the size is small but
2.2. Social Interaction – The Four Cs

Figure 2.1: Fragmentation and de-fragmentation forces for collective intelligence.

with a reduction in activity output. Although there should be a trade-off between communication and output quality, noting that collaborative modeling is process-oriented and communication-driven, the desirable situation would be to have improved communication where everyone contributes to the modeling activity, reconciles their priorities and preferences with those of the group and is committed to the group decisions.

2.2.2 Collective Intelligence

In order for collaborative modelers to maximally utilize their collective intelligence, there is need to diffuse the centrifugal forces pulling the collaborative modeling effort. This is what Conklin [Con07] refers to as the “defragmentation process” – aimed at weakening the fragmentation forces (wickedness, social and technical complexities). The defragmentation is achieved by taking a leap and have a look into collaborative modeling sessions – which are, in a way, form of meetings where modelers exercise collective intelligence. Such collaborative modeling sessions or meetings could be held synchronously or asynchronously, collocatedly or remotely. This parallels the approach used in Group Model Building (GMB) where Face-to-Face (FTF) meetings with a facilitator to guide the group in eliciting the model structure and to help them engage in problem conceptualization, formulation, analysis and decision-making are a common occurrence, see for example [AVRR07]. Modeling sessions are centers of communication where shared understand-
ing, shared commitment and coherence are the remedies to the fragmentation forces.

♦ **Shared understanding.** Shared understanding (also referred to as: common ground, socially shared cognition or distributed cognition) refers to mutual knowledge, beliefs and assumptions [CB91, MSK02]. Within the group of collaborative modelers, shared understanding means that they are not only aware of the differences in their concerns, goals, priorities, preferences, etc., but are also aware of the differences in their skills, expertise and knowledge. This awareness creates trust and commitment between and among the different stakeholders within the modeling session. Because of this, they know that they need to collaboratively and interactively share and tap from the different wells of their knowledge, agree on the known and unknown, reach consensus as a group and decide as a group. For this to be achieved, there are bound to be rules set and goals to strive for.

♦ **Shared commitment.** While shared understanding is focused on where the group stands as far as mutual knowledge, beliefs and assumptions are concerned, shared commitment is concerned with where the group intends to go [Con07]. Modelers’ commitment is about adherence to the group’s collaborative modeling direction, about group decisions, and promises that are kept by team members.

♦ **Coherence.** Coherence means that the different stakeholders within a collaborative modeling process have a shared meaning not only about the concepts and terms used in the modeling process but also they have a shared understanding, background and history of the problem.

### 2.2.3 Grounding Collaborative Modeling in Communication

Effective communication is one way to help the group of stakeholders in a collaborative modeling session to defragment the modeling activity and aid collective intelligence. This means that for us to fully understand the dynamics of the modeling process and what takes place in such a process, there is need to open the lid and look inside the black-box. Collective intelligence can be applied only when there are effective and efficient channels of communication between and among the modelers in the modeling process. Grounding collaborative modeling in the modelers’ interactions (communication, negotiation, decision-making, rules and goals, etc.,) has the potential to help us not only overcome the problem of social complexity but also helps us understand the process of modeling. Grounding a joint activity in communication is further elaborated in [CB91] where the stakeholders collaborating on a joint activity through communication need to coordinate not only the content but also the process. If we are to fully understand the modeling process we need to pay much attention to the process that generates the models.

Earlier work about effective communication between the users and specialists or experts is found in [BT84]. Their work involved development of a theoretical model that explains the success of the development of an information system. Success is measured by explaining the circumstances under which the interactions of users and experts occur. The strongest point of their theoretical model is that it is indirectly based on interpersonal communication and cooperation, interpersonal communication and persuasion, and on interpersonal behaviour and conflict avoidance. Two important factors affecting effective communication and factors affecting the effectiveness of system development using third
party intervention were empirically studied and tested. Although a nice starting point, we believe there is more in communication that needs to be addressed. For example, how system development is driven by rules and goals, interactions, model propositions, negotiation, consensus and agreement, decision-making, etc., needs to be further explored. Chapters 3 and 4 investigate some of these concepts.

2.3 Communication and Group Decision-Making

If we are to fully understand and analyse collaborative modeling and what takes place therein in view of the communicative process, we need to first understand what communication is and what role it plays, especially, in group interactions. System modeling and information systems modeling has long been recognized as a communicative process [DGLR98, HP04, HPR05, HPW05b, PHB06, RMD99, VHP04] that is collaborative and a structured dialogue [BHPW06, HLP06, HPW05a]. Although there has been this acknowledgement, not much has been done in opening the “blackbox” to reveal all the details of this communicative process. It is on this basis that we break the seal of the blackbox so as to look into the structure of this communicative process with respect to collaborative modeling. Figure 2.2 gives a glimpse of what takes place inside this blackbox.

![Figure 2.2: A communicative collaborative modeling environment.](image)

Communication – Metamodel and Metadiscursive

Understanding human communication is complicated by the fact that there is a very broad constituency of fields which include, among others, cybernetics, rhetoric, sociology, journalism, anthropology, psychology, philosophy, semiotics, communication and information sciences, etc., which employ communication theory. Communication, among scholars in these fields, is understood in different ways. Craig [Cra99] gives an excellent summary of communication theory in a number of fields and argues against each of these diverse definitions. Craig reconstructs communication theory as a *dialogical - dialectical* field with two components: “the constitutive model of communication as a metamodel, and theory as metadiscursive practice” [Cra99, p.119]. Craig’s reconstruction of communication theory invites us to consider the role played by communication in studying,
analyzing and understanding human communication.

**Dialogic, Dialectic and Constitutive Communication**

Craig’s definition of communication theory, in our view, gives leverage over other communication theory definitions in view of collaborative modeling processes. It identifies the three main ingredients: dialogic, dialectic and constitutive that are needed to study, analyse and understand what takes place in a communicative collaborative modeling process. The difference between dialogic and dialectic can be likened to the difference between illocutionary and perlocutionary in speech act theory of Searle [Sea69]. In a dialogic communicative process there is exchange of information between the communicator and the listener and the goal is to exchange ideas, views and opinions. There are, however, situations when we are interested not only in the exchange of information but also in some action that needs to be taken by the listener(s). This could, for example, be a reaction to, and evaluation of, the proposals put forward. In this case a dialectic communicative process in initiated.

As noted by Cosier et al. [CRA78], see also [Jar96], in a dialectic communicative process, members of a group look at all possible solutions and the underlying assumptions or bases, evaluate each solution and then generate counter-solutions based on the evaluations of the negative solutions, thus generating a pool of more acceptable solutions. A dialectical process, thus, describes the interactions between and among the group members, leads to resolution and clarification of the different percepts and concepts (mental-models [Pid04]), merges the different solution proposals and counter-proposals in order to forge a compromise and reach some sort of agreement. We anticipate this engagement between collaborative modelers. Modelers often have different “weltanschauung” or world views [Inw95, p.909] about the problem being addressed. These world views need to be reconciled and disentangled from the mesh of the mental models through a communicative process.

The other component of Craig’s definition is the constitutive nature of communication. The best definition of communication as a constitutive force that can be applied to the study, analysis and understanding of collaborative modeling is that given by Poole and Hirokawa [PH96]. What makes this definition stand out, and thus a candidate for collaborative modeling study and analysis, is that it regards communication as having an interpretive component that is concerned with “social realities as experienced by the participants” (p.8). The constitutive component of communication is one of the two perspectives from which we can view communication:

i. as a *medium* of group interaction – thus a channel of the effects of a number of factors on group processes and outcomes.

ii. as constitutive of group processes – thus a means of creating social reality in which these processes are constructed [PH96, p.6].

Modelers in a collaborative process draw upon their vast knowledge and experiences accumulated from social realities. This could, for instance, be in decision-making or in negotiations as discussed in section 2.3.2 and section 2.3.3. Thus, the second view of communication offers fertile ground to study, analyse and understand collaborative modeling processes.
Speech Acts: Language Action Perspective

The study, analysis and understanding of collaborative modeling processes requires us to analyse, annotate and categorize the conversational moves or “speech acts” that occur during collaborative and interactive modeling sessions. Speech Act Theory (SAT) originally formulated by Austin [Aus62] and then extended by Searle [Sea69] and Harbemas [Har84] has the potential to help us look into this analysis and categorization. SAT posits that the minimal unit of an utterance is not a word or sentence but a “speech act”, which according to Macagno [Mac08] is a conversational move. Among the successful frameworks that try to apply speech act theory to business process modeling and information systems modeling is the Language Action Perspective (LAP) [FL80, WF86, Win87] which applies Harbemas’ Theory of Communication Action (TCA) [Har84] to look at (business) communication conversations. Figure 2.3 shows a diagrammatic overview of the conversation-for-action states as formulated by Winograd and Flores.

![Figure 2.3: Conversation-for-action [WF86, p.65].](image)

LAP approaches are built upon two theoretical cornerstones [Gol03, TANJB04]:

1. communication is action in accordance to generic speech act types
2. communicative acts are organized and framed in accordance with predefined “communication patterns”

The emphasis of LAP is on what stakeholders in, for example, a collaborative modeling process do when they are communicating, how language is used to create a common reality for these stakeholders, and how their activities are coordinated through language. LAP recognizes that the language used is not only for the exchange of information but
also for performing actions. It is this recognition that gave rise to the DEMO methodology [BDL01, Die03, RMD99] – one of the most successfully LAP-based methodologies and Enterprise Ontology by Jan Dietz [Die06]. A list of a number of applications that have been designed by the LAP community to facilitate, design and model business conversations and processes as conversations may found in [Gol03, TANJB04].

Although communication, as seen above, is a dialogical-dialectical interaction that leads to exchange of information and can be used to create social reality, there is need to go beyond this and look at the structure and nature of this communication. Often, such communication involves putting forward proposals by the initiator and then the other members are required to accept or reject the put-forward proposals [Rit09c, Rit07], see also, Figure 2.2. Acceptance or rejection occurs after a protracted “debate” where members put forward arguments for or against before accepting or rejecting such proposals. If we are to fully study, analyse and understand this argumentation process, from the perspective of collaborative modeling, we need to look at the structure of this argumentative communication process. Argumentation theory is one of the theories to help us study, analyse and understand this argumentative process. There are, however, a number of factors which may impede smooth communication between and among those involved in a communication process. Some of these factors are mentioned in [BT84] for information development. The argumentative communication process often results in negotiation and decisions are made based on personal and group priorities or preferences. In the next sections we discuss argumentation theory, negotiation theory and some of the decision-making approaches we feel are key to studying, analyzing and understanding collaborative modeling processes.

2.3.1 The Argumentation Theory

Argumentation theory which, initially, attracted attention of philosophers and logicians [Mac79], linguists, legal scholars and speech communication theorists has, over the years, found practical applications in a number of other fields, e.g. computer science, artificial intelligence, information systems, human-computer interaction, computational linguistics, etc., see for example [BDL91, BGG05, Hul00, RN04, Ver03]. The work of Walton and Krabbe [Wal90, WK95], see also the work of Eemeren et al. [EG04, EGH+96], especially the typology of dialogues, has led to the popularization of argumentation theory in most of these areas. This typology combined with dialogue games can be used in collaborative modeling, especially, in studying and analyzing the arguments and dialogues that occur therein. Such arguments and the different types of dialogues are central to the communicative interaction between the participants involved.

Argumentation theory, if seen from the perspective of arguments and dialogues – especially dialogue games – has the potential to help us study and analyze the interactions between the modelers in a collaborative modeling session, see for example [SHP10b]. Such collaborative interactions consist mainly of communicative interactions in form of propositions, counter-propositions, arguments (for or against), questioning and answering, acceptances and rejections, withdraws, etc., [Rit07]. The collaborative modeling process is centered around such interactions. The quality of such interactions in a collaborative, communicative and argumentative process influences not only the quality of the modeling process as a whole, but also the quality of the products.
Arguments and Dialogues
Argumentation theory is built on two pillars which are defined below:

**Argument.** An argument is a social and verbal means of trying to resolve or at least content with a conflict or a difference that has arisen or exists between two or more parties [Wal90, WK95, WRM08].

**Dialogue.** A dialogue is an interaction between two or more participants where each participant makes moves according to a defined set of rules [MEPA03, WK95].

These two definitions have clear relationships with communicative arguments and dialogues in collaboration modeling where “interaction” between, and among, the different modelers is central to the whole modeling process. This is further discussed in Chapter 3.

Table 2.1: *Types of dialogues [WK95]*.

<table>
<thead>
<tr>
<th>Dialogue Type</th>
<th>Initial Situation</th>
<th>Participant Goal</th>
<th>Dialogue Game</th>
</tr>
</thead>
<tbody>
<tr>
<td>Persuasion</td>
<td>Conflict of opinion</td>
<td>Persuade other party</td>
<td>Resolve or clarify issue</td>
</tr>
<tr>
<td>Inquiry</td>
<td>Ignorance</td>
<td>Find and verify or falsify evidence</td>
<td>Proof or disproof</td>
</tr>
<tr>
<td>Negotiation</td>
<td>Conflict of interest</td>
<td>Get what you most want</td>
<td>Reasonable settlement that both can live with</td>
</tr>
<tr>
<td>Information Seeking</td>
<td>Unequal spread of information</td>
<td>Acquire or give information</td>
<td>Spreading knowledge</td>
</tr>
<tr>
<td>Deliberation</td>
<td>Dilemma or practical choice</td>
<td>Influence and contribute to outcome</td>
<td>Decide best course of action</td>
</tr>
<tr>
<td>Eristic</td>
<td>Personal conflict</td>
<td>Verbally hit out at opponent</td>
<td>Reveal deeper basis of conflict and reach some accommodation</td>
</tr>
</tbody>
</table>

Dialogue Games
Dialogue games concern a special branch of argumentation theory. In addition to participants engaging in arguments and dialogues, they pursue individual and group goals under a given set of conditions or rules. Although dialogue games date back to the time of Aristotle [Ros28], two publications of Levin and Moore [LM77] titled: *Dialogue Games: Meta-communication Structures for Natural Language Interaction* and that of Mann [Man88] titled: *Dialogue Games: Convention of Human Interaction* have had a profound impact on the way dialogue games are applied in other areas. The definition of a dialogue game is given below.
Dialogue game. Let P be the proponent and R the respondent in the dialogue. A dialogue game is a triple, $(IP, GR, CC)$, where

- $IP$ A goal of P called the illocutionary point (IP) of the game.
- $GR$ A non-empty set of goals of R called the goals-of-R.
- $CC$ A set of state descriptions of P called the conventional conditions of the game [Man88, p.513].

Levin [LM77] points out the difference between dialogue games, see also [RMS10, Rav07], and “language games” of Wittgenstein [Wit58]. The language game concept aims to bring out the fact that speaking of language is part of an action or a task being executed. This concept is similar to the concept seen already in Habermas’s theory of communication action [Har84] and the language action perspective [FL80, Win87]. Dialogue games, in stark contrast, “represent knowledge people have about language as used to pursue goals” [LM77]. They are abstract elements of a theory of the discourse structure of human dialogue, bilateral in nature and each dialogue accounts for the aspects of the speech of both parties to a dialogue [Man88]. In dialogue games participants have intentions and pursue goals. This forces the dialogue to proceed in the manner that shows this goal pursuit and shows it to the participants. The definition of a dialogue game fits within our analysis of collaborative modeling processes due the goals and rules that are pursued and set by the modelers. We have, before, referred to this – metaphorically – as a collaborative modeling game [SHP09a]. This concept is again explained and illustrated in Chapter 3 – section 3.2 – where we discuss the analysis of modeling sessions using the RIM framework.

2.3.2 Negotiation Theory

The strategies that are followed, goals that are pursued by the modelers, either individually or collectively, and the rules that drive the entire modeling session are key components of a “negotiated settlement” during a modeling session. The key question to ask is: why should modelers reach a negotiated settlement during a collaborative modeling session? In this section we look at negotiation theory which will help us answer the above question.

Before delving into the details of negotiation and the different approaches associated with it, we need to reflect, once more, on the role played by communication in negotiation. Perhaps the best starting point is Walton and Krabbe’s [Wal95, WRM08] definition of negotiation which already presupposes an argumentative process, see Table 2.1, and hence communication. This definition already paints a picture of the conflicting interests that exist among the participants and the (individual or collective) goals pursued. These notwithstanding, the overriding goal is to reach the most reasonable settlement that every party can live with. This is the situation collaborative modelers find themselves in. Collaborative modeling brings on board stakeholders – including, but not limited to: users and problem owners (domain experts), systems analysts and system designers (model builders), etc., – with different skills and competencies [FW05]. These conflicting interests partly result from their different weltanschauung or world views. This brings about individual priorities and preferences which need to be reconciled in a collaborative and
2.3. Communication and Group Decision-Making

communicative modeling process. This is only possible if the modelers engage in negotiations.

Negotiation Approaches
The field of negotiation – from the view of economic, sociological and psychological perspectives – is thought to have been greatly influenced by the works of four prominent researchers in negotiation: Walton and McKersie - *A Behavioural Theory of Labour Organizations* [WM65]; Zartman – *Negotiation Theory* [Zar78]; Fisher and Ury – *Getting to Yes* [FU81] and Raiffa – *The Art and Science of Negotiations* [Rai82]. It has over the years also drawn insights from a number of fields which have greatly informed this field. It is not surprising, then, that “the resulting theories are diverse and frequently highlight salient concerns from the perspective of the disciplines from which they came” [TA08, p.6].

<table>
<thead>
<tr>
<th>Table 2.2: Summary of negotiation approaches.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Structural Negotiation Approach</strong></td>
</tr>
<tr>
<td>Features: Negotiations are seen as conflict between opponents who maintain incompatible goals (&quot;positions&quot;); parties bring their own different &quot;means&quot; to negotiation; each party brings their own &quot;power&quot; to negotiation.</td>
</tr>
<tr>
<td>Assumptions: Uses strategies that are distributive or predatorial. Focus is on: win-lose (zero-sum or competitive).</td>
</tr>
<tr>
<td><strong>Strategic Negotiation Approach</strong></td>
</tr>
<tr>
<td>Features: Are normative in nature. Have roots in mathematics, decision theory and rational choice theory. Focus is on role of ends (&quot;goals&quot;), rationality and positions.</td>
</tr>
<tr>
<td>Assumptions: Win-lose, rationality of decision makers and existence of optimal solutions.</td>
</tr>
<tr>
<td><strong>Behavioural Negotiation Approach</strong></td>
</tr>
<tr>
<td>Features: Focus is on the role of negotiators' personalities or individual characteristics, looks at negotiations as interactions between &quot;personality types&quot;.</td>
</tr>
<tr>
<td>Assumptions: Win-lose, role of perceptions and expectations.</td>
</tr>
<tr>
<td><strong>Processual Negotiation Approach</strong></td>
</tr>
<tr>
<td>Features: Looks at negotiation as a “learning process” in which parties react to the others’ &quot;concession behavior&quot;. Focus is on concession making behaviour and positions.</td>
</tr>
<tr>
<td>Assumptions: Win-lose, moves as learned (reactive) responses.</td>
</tr>
<tr>
<td><strong>Integrative Negotiation Approach</strong></td>
</tr>
<tr>
<td>Features: Frame negotiations as interactions with win-win potential. Emphasize group problem-solving, cooperation, joint decision-making and mutual gains. Negotiators look for ways to create value, develop shared principles as a basis for decision-making. They look for mutually agreed upon principles on which to base agreement. Focus is on joint problem-solving, creating value, communicating and win-win solutions.</td>
</tr>
<tr>
<td>Assumptions: Win-win potential.</td>
</tr>
</tbody>
</table>

The preceding observation requires us to select, from the outset, the most suitable approach that fits within a communicative, argumentative and collaborative modeling process that we investigate. A number of approaches have been suggested that classify the main schools of thought in negotiation. Notable among these are: Raiffa’s symmetry-asymmetry and prescription-description typology of approaches [Rai02, Rai82] and Zartman’s core approaches to negotiation: structural, strategic, processual, behavioural and integrative [Zar78]. Zartman defines negotiation as a joint decision-making process and within the integrative approach, he frames negotiation as interactions with a win-win potential. We identify this as the most suitable approach to apply and study the communicative and argumentative collaborative modeling process. The main features of these
Chapter 2. Existing Theories and Frameworks

approaches adopted from the summary given by Zartman, see also [TA08], are summarized in Table 2.2.

In any collaborative modeling process, the focus of the modelers is not to compete but to cooperate so that they jointly solve the problem at hand. However, due to the differences in their world views, they hold priorities and preferences that need to be reconciled through an argumentative and negotiation process so that they can reach a shared meaning and understanding [MSK02] of the concepts that bring about the conflicting views. This negotiation process results in a group decision-making process that requires modelers to reach agreement and consensus. The decision-making process and the associated approaches that can be employed are discussed next.

2.3.3 Group Decision-Making: MCDA Approaches

What is a “Decision” and what is “Group Decision-Making”?

Decision-making, like we have seen with negotiation, cuts across a number of disciplines and is thus plagued with problems of terminology. We start by defining a few terms suitable to our approach in this research. These terms include: decision, decision-making, group decision-making, decision-making techniques, decision-making methods and multi-criteria decision analysis approaches.

Decision and Decision-Making

Although [PH96] observes that defining a decision is straight forward and defines decisions as: “discrete events, clearly distinguishable from other group activities” (p.9), we still find this a bit ambiguous, especially if looked at from our perspective of collaborative modeling processes where modelers are engaged in a communicative process and have to evaluate a number of factors of the modeling artifacts, reconcile their priorities and preferences and reach some sort of consensus about the quality of the modeling artifacts. A definition of a decision and decision-making that is more suitable and fits well within our research is that given by Ofstad [Ofs61], see also [Eil69].

To say that a person has made a decision may mean (1) that he has started a series of behavioral reactions in favor of something, or it may mean (2) that he has made up his mind to do a certain action which he has no doubts that he ought to do. But perhaps the most common use of the term is this: to make a decision means (3) to make a judgement about what one ought to do in a certain situation after having deliberated on some courses of action [Ofs61, p.15]

Related to Ofstad’s definition of decision-making is one in [BG92, BWWK87, SA92] who look at decision-making as a process of evaluating and choosing among alternatives. These two definitions assume that decision-making is a result of some psychological reactions and is a cognitive process with affective biases which result in personal priorities and preferences. These psychological reactions and cognitive processes have both a positive and negative impact on the whole decision-making process and the outcomes.

Group Decision-Making

Group decision-making is a participatory process in which a number of individuals – decision makers/evaluators – collaboratively analyse a given problem or situation, consider
and evaluate alternative courses of action and select the best alternative from among these alternatives [HN04, Lut05, VD74]. Group decision-making therefore is aimed at distilling the best that each member can offer to the group thus creating a resonance of ideas and a synthesis of the different viewpoints, i.e., priorities and preferences [PH96]. In any group activity, including for our case setups for collaborative modeling, members are not only concerned with exchange of ideas – communicating – but they are also engaged in performing some actions as already referred to in the preceding sections as “speaking means acting”, see Speech Act Theory [Aus62, Har84, Sea69]. We, therefore, expect collaborative modelers’ conversational moves to result in some action which may be acted upon individually or as a group. One of these actions is (group) decision-making in which members reconcile their different positions, views, priorities and preferences [SHP09c]. It is, therefore, quite befitting to discuss group decision-making within the context of communication which gives birth to the conversational moves one of whose end-result is the decision-making action.

If speaking means acting, then we need to situate decision-making within the entire communicative process. This, as observed by [PH96, HEH96], is due to two reasons. First, communication can be looked at as a medium of group interaction and thus acts as an avenue for the effects of a number of factors that impact group decisions and outcomes thereof. Such factors include (a) factors describing inputs into the context of the decision, e.g., group size, group composition, members’s preferences or task type, see also [NZ09, RKV08], (b) factors that determine the nature of interactional processes, e.g., group polarization or leadership styles [Bar96]. This view is important since it shifts the emphasis from communication per se and puts it on the factors or processes that impact the communicative decision-making processes – thus mediating a number of psychological, social, situational and task-related factors [PH96]. The second perspective, of looking at communication in view of the decision-making process, is to regard it as constitutive of group decisions [HEH96, PH96]. This constitutional view, in contrast to the mediational view, regards communication as playing a more instrumental role in the decision-making process. It regards communication as “more than a convenient channel or conduit that transmits the effects of exogenous factors...but a social tool that members use to create the social context within which decisions are made” [HEH96, p.285].

**Decision-Making Techniques and Methods**

There are many methods and techniques, see for example [BBH+02], that group decision-making participants in a communicative and collaborative modeling session can use to reach a decision. Among the techniques from which they can make their choice include the: brainstorming technique, nominal group technique, delphi technique, devil’s advocacy techniques and dialectic inquiry technique [Poo91, Seb92]. We acknowledge that there are other techniques but these are the most commonly used techniques. It is not our intention, however, to go through these techniques. The main features are summarized in Table 2.3 and details may be obtained from the references given therein. In addition to selecting the appropriate technique(s) from among those mentioned, modelers need to find a method or process to help them reach a final decision from their decision-making communicative process. Johnson and Johnson [JJ00] give about seven methods or processes that can help them in this regard. These methods are given in Table 2.4.
### Table 2.3: Decision-making techniques.

<table>
<thead>
<tr>
<th>Technique</th>
<th>Features</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Brainstorming</strong></td>
<td>Let group members, independently, generate as many ideas as possible in a “freewheeling” fashion. Suspend criticisms of the ideas and suspend evaluations until all ideas and/or alternatives have been suggested. This technique primarily focuses on generation of ideas rather than choosing alternatives [Jar96, Osb57].</td>
</tr>
<tr>
<td><strong>Nominal Group</strong></td>
<td>Let members, independently, list their ideas. Allow members to present their ideas in a round-robin fashion and let the members discuss the ideas and evaluate them. Allow members to vote on the ideas, independently, using a rank-ordering or rating procedure. Mathematically, pool the individual votes and finally adapt the ideas. This technique integrates both individual and group interaction and is used where members must pool their judgements to determine a satisfactory course of action [DH88, DVG75, Jar96].</td>
</tr>
<tr>
<td><strong>Delphi</strong></td>
<td>Using survey instruments, solicit expert opinion, i.e., gather judgements of experts for use in decision-making. Summarize experts’ judgements and report back to them and let them rate the alternatives. Continue until experts’ judgements are systematically refined and until consensus emerges through feedback. This method avoids group interaction and participants do not meet face-to-face since the experts can be miles apart. [Del67, HR88].</td>
</tr>
<tr>
<td><strong>Devil’s Advocacy</strong></td>
<td>Let one individual or group develop solutions and let another individual or group (devil’s advocate) criticize the facts and assumptions on which solutions are based to arouse further discussion and thought. This technique avoids the tendency of members to allow their personal urge to agree to interfere in the decision-making process [CRA78, Jar96, SC80, SSR86].</td>
</tr>
<tr>
<td><strong>Dialectical Inquiry</strong></td>
<td>Let one group consider possible solutions and their underlying assumptions and allow them to present arguments in support of them. Let another group explore counter-solutions so that they can generate more counter-solutions based on the negative forms of the assumptions of the first group. Allow debate about the implications of the assumptions for the two groups until a decision possibility is identified. This technique allows the two groups to confront and question the implications of their assumptions [CRA78, SC80, SSR86].</td>
</tr>
</tbody>
</table>

One of the methods that was applied in this research is method 7 details of which are explained in Chapters 4, 6 and 7. Participants in a collaborative and communicative decision-making process are often faced with the problem of reconciling their individual priorities and preferences. This reconciliation is necessary if they are to reach some sort of agreement and/or consensus so that a final decision can be taken. This, however, requires some method to evaluate and synthesize their different judgements, priorities and
### 2.3. Communication and Group Decision-Making

**Table 2.4: Decision-making methods (strategies).**

<table>
<thead>
<tr>
<th>Method 1. Decision made by authority without group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process:</strong> The group leader makes all the decisions without consulting group members.</td>
</tr>
<tr>
<td><strong>When to use:</strong> Little time available, low group commitment to implement decision.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 2. Decision by the expert</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process:</strong> Here the presumed expert is selected from group members, looks at problem issues and makes a decision on behalf of others.</td>
</tr>
<tr>
<td><strong>When to use:</strong> There is need for specific expertise, low group commitment to implement decision.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 3. Decision by averaging individual member's opinions</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process:</strong> Each member is, separately, asked about his/her opinion and these are averaged to get the group opinion.</td>
</tr>
<tr>
<td><strong>When to use:</strong> Little time is available for decision, group involvement required, lengthy interaction not necessary, low group commitment to implement decision.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 4. Decision made by the authority after group discussion</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process:</strong> The group leader calls a meeting, presents the problem to be discussed, the group generates ideas and engages in a discussion. The group leader listens to the discussion and he/she eventually makes the final decision and announces it to the group.</td>
</tr>
<tr>
<td><strong>When to use:</strong> Available time is enough for group interaction but not for reaching agreement, consensus determined by authority, moderately low group commitment to implement decision.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 5. Decision by minority</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process:</strong> A minority of the group, constituting less than 50% makes the decision on behalf of the group.</td>
</tr>
<tr>
<td><strong>When to use:</strong> Not enough time for entire group to meet, use of minority group is a clear choice, moderately low group commitment to implement decision.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 6. Decision by the majority vote</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process:</strong> Here the issues are discussed by the group members until 51% or more have made their decision.</td>
</tr>
<tr>
<td><strong>When to use:</strong> Time limitations dictate decision, group consensus supporting voting process, moderately high group commitment to implement decision.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method 7. Decision by consensus</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Process:</strong> In this method the collective or group decision is arrived at after an effective and fair communicative process, where everybody is assumed to have been given a chance to speak, and he/she was listened to and their contributions are valued.</td>
</tr>
<tr>
<td><strong>When to use:</strong> Time available allows consensus to be reached, group members are skilled to reach consensus, high group commitment to implement decision.</td>
</tr>
</tbody>
</table>

preferences. In this research, the modeling artifacts that are evaluated and on which the negotiation and decision-making processes are based, have selected multi-criteria quality factors or dimensions. We describe next some of the multi-criteria decision analysis (MCDA) techniques that can be used to synthesize their priorities and preferences.

**MCDA Approaches**

Although the role played by communication in collaborative modeling has been outlined in the preceding sections via argumentation, negotiation and decision-making processes, it is not yet clear how Johnson and Johnson’s method 7, see Table 2.4, can be used to synthesize the priorities and preferences after modelers have reached an agreement and consensus. To achieve this, we need to understand collaborative modeling as a “multi-actor and multi-criteria decision-making process” [SHP09c]. There is a need, therefore, to search for an approach and a methodology for aggregating the modelers’ preferences and priorities in this multi-actor and multi-criteria collaborative modeling environment. To achieve this, we focus on the application of Multi-criteria Decision Analysis (MCDA) methods from the area of Operations Research (OR).

There are quite a number of MCDA methods available from OR and selecting a par-
Chapter 2. Existing Theories and Frameworks

ticular MCDA requires an analysis of the pros and cons, the problem being addressed and the context in which the problem is being solved. We motivate our choice by looking at some of the available MCDA methods. MCDA can broadly be categorized into two main classes: (i) continuous, and, (ii) discrete methods [GM98]. In the continuous methods, there is a finite and explicit set of constraints in the form of defined functions that define an infinite number of alternatives to consider in the evaluation and decision-making process by the decision makers or evaluators. Decision-making problems in this class are referred to as continuous multi-criteria decision-making problems or multi criteria optimization (MCO) problems [VGAS04]. In the second class, the discrete case, there is a finite number of alternatives normally defined in tabular form with their corresponding evaluation criteria. Decision-making problems in this class are referred to as discrete multi-criteria decision-making problems or multi-criteria analysis (MCA) problems.

The decision-making problem we study in the evaluation of collaborative modeling belongs to the discrete case and is therefore an MCA problem. For collaborative modelers to evaluate the modeling artifacts and decide on the best modeling approach that meets the quality goals they need, at both individual and group levels, to indicate their preferences among the alternatives through the evaluation of quality criteria. To achieve this, there is a need to apply a preference model or approach to the MCA problem. There are three approaches to choose from: (i) the single synthesizing (weighting) criterion preference approach, (ii) the outranking synthesizing preference approach, and, (iii) the interactive local-judgement preference approach.

The single weighting criterion preference approach consists of a number of methods including the Analytic Hierarchy Process (AHP) [Saa80], the Multi-attribute Utility Theory (MAUT) and Multi-attribute Value Theory (MAVT) methods [Dye05, KR76] with the Simple Multi-attribute Rating Technique (SMART) as prominent representatives. The outranking synthesizing preference approach includes the: “Elimination Et Choix Traduisant la Réalité”, i.e., Elimination and Choice Expressing Reality (ELECTRE) methods [Roy91] and the Preference Ranking METHod for Enrichment Evaluation (PROMETHEE) methods [BV85] with different variants as the most prominent representative. The interactive local-judgement preference approach has the Multiple Objective Mathematical Programming Methods (MOMP) [NVGV03] as the most prominent representatives. A number of guidelines have been proposed [GM98] and a number of comparative studies done to help in selecting the most appropriate MCDA method from the categories above, see for example, [BBH+02, BKAA10, MSBV04, Ste92]. For collaborative modeling, modelers have to evaluate the different collaborative modeling artifacts using a set of defined criteria. They take decisions individually and as a group. This requires their preferences and priorities to be aggregated using group decision methods employing any of the MCDA methods mentioned above.

Considering the pros and cons, given in [LS97, MSBV04], of each of the representative methods for the weighting, outranking and interactive methods, and following the guidelines in [GM98, Ste92], we have boiled down to the single synthesizing (weighting) criterion preference approach with AHP as the appropriate method to evaluate the collaborative modeling process quality and thus helping in selecting the best collaborative modeling approach. This should, however, not be interpreted to mean that AHP is superior to the other methods in all aspects. It is its flexibility and the availability of the mathematical axiomatic principles in the aggregation of individual preferences and priori-
2.4 Quality Frameworks for Evaluation of IS Models

The preceding discussions have mainly emphasized the role played by communication, especially, argumentation, negotiation and deciding on evaluation in a collaborative modeling process. The communicative process results in analyzing sessions and evaluating modeling artifacts used in, or produced during, such a collaborative session. Such artifacts, as pointed out already, include: the modeling language, the modeling procedure, the end-products or models and the support tool or medium. The argumentation, negotiation and decision-making is about determining which artifact’s quality factors or dimensions satisfy the modelers’ quality requirements. Information systems modeling is, in general, based on theoretical assumptions, some of which we have argued above, that it is a decision problem, see also [Sch99]. The question, however, is whether the evaluation of the artifacts, that are used in, or produced during, a collaborative modeling process could be done based on the philosophical (ontological and epistemological) assumptions and concepts defined for information systems models as proposed by Wand and Weber [Web87, WW93, WW90]. We discuss in the following sections some of the frameworks and models that have been developed based on these philosophical assumptions and we point out where gaps still exist.

2.4.1 The SEQUAL Framework

The SEmiotic QUALity (SEQUAL) framework of Krogstie, Lindland and Sindre is one of the versatile quality frameworks that can be used to evaluate some of the artifacts mentioned above. This framework, originally started with the work of Lindland [LSS94] and further developed by Krogstie [Kro95, KLS95a, KLS95b]. Because of its versatility, it has found application in a number of cases, see for example [KS03, KJ02, Kro01a, Kro01b]. The main feature of this framework, which makes it fit within our arguments for collaborative modeling analysis and evaluation, is that it is based on a communicative process that employs the six rungs of Stamper’s semiotic ladder [SLHA00, SLS+04, Sta00a, Sta00b, Sta73], see also the work of Ketcheng Liu [LCA+02, Liu00, LSDN01]. These rungs or levels of the semiotic ladder are: the physical, empirical, syntactic, semantic, pragmatic and social levels. SEQUAL’s main theoretical, philosophical assumptions and world views are that reality is socially constructed [Dah91] and it combines ontological realism and epistemological idealism [Sch99] – thus orienting itself towards subjectivism. This philosophical orientation underlies our assumptions that modelers in any collaborative modeling are subjective when evaluating the modeling artifacts. It is on this basis that the evaluations are clouded with biases, personal priorities and preferences.

We base our discussions on the recent version of the SEQUAL framework [KSJ06] which is depicted in Figure 2.4. The choice of this version of the SEQUAL framework is based on the observation that it overcomes the limitations identified in the original framework and subsequent revisions prior to this version and the premise that SEQUAL is more than just a quality framework for models. As the figure shows, SEQUAL framework in-
cludes not just the model as the end-product, but also the knowledge of the modelers both actual and knowledge still needed; the domain modeled which includes the actual domain and the optimal domain; the activities which include learning, modeling and other actions that may change the model, the current knowledge and the actual domain. The key terms of SEQUAL and quality dimensions (along the semiotic levels) relevant to this research are explained below. More details may be found in [BHP07, KSJ06].

**SEQUAL Key Items**

- **M**: Model – can be changed by the modeling activity.

- **D**: Domain – current situation of organization, i.e., universe of discourse (UoD), that is to be changed. May be changed by actions taking place in the domain. This change may be facilitated by the model or directly by the modeling activity.

- **DO**: Optimal domain – the situation the organization would or should have wanted.

- **K**: Knowledge of the people in the organization before the modeling activity – this may change due to the learning activity, possibly, facilitated by the model or even caused by the modeling activity itself.

- **KN**: Knowledge need – the knowledge needed by the organization to perform its tasks.
2.4. Quality Frameworks for Evaluation of IS Models

SEQUAL Quality Definitions

It should be noted here that the revised SEQUAL framework, unlike earlier SEQUAL versions, see for example [LSS94], puts more emphasis on the two levels of SEQUAL: semantic and pragmatic as these are deemed more problematic than on the other levels [KSJ06]: physical, empirical and syntactic. Social and organizational levels are not considered in the revised SEQUAL framework. Due to our desire to look at the quality of the modeling language artifact and the desire to study the social interactions within a communicative process, we include syntactic and social quality in addition to those given in the revised SEQUAL framework.

- **Semantic quality**: How well M reflects K. Covers the correspondence between actors’ interpretation of the model (M) and their current knowledge (K) of the domain (D). Goals: validity – all statements in the model are correct and relevant to the problem; and completeness – the model contains all statements that it would be correct.

- **Ideal semantic quality (descriptive)**: Validity: $M/D = \phi$; Completeness: $D/M = \phi$.

- **Ideal semantic quality (prescriptive)**: Validity: $M/D^O = \phi$; Completeness: $D^O/M = \phi$.

- **Pragmatic quality (Overall learning)**: The new knowledge acquired by the organization, which is also within the knowledge need. The overall learning of the model is given by: $\Delta K^M \cap K^N$, where $\Delta K^M$ is the increase of the set K, the current knowledge. A similar knowledge gain associated with a modeling activity is given by: $\Delta K^m \cap K^N$, where $\Delta K^m$ is the increase of the set K caused by the modeling activity.

- **Pragmatic quality (local learning)**: Knowledge transfer between and among the participants of the modeling activity. One or more people know something and there is a need to transfer this to (share with) others who lack this knowledge, i.e., $(K_l/K_j) \cap K_j^N$, there is knowledge held by a person or group l but not by a person or group j, although it is within the knowledge need of j. The improvement in the knowledge need of j will be: $\Delta K_j^M \cap K_j^N$.

- **Syntactic quality**: Conformity (of the models) to the syntax of the modeling language.

- **Social quality**: The level of agreement about the model among stakeholders (individuals or groups), i.e., about the statements of M.

Since our aim is not only studying the detailed steps in the modeling process by looking at the communicative process – including argumentation, collaboration, negotiations, decision-making and cognition of the participants – but also evaluating the different artifacts used in, and produced during, a collaborative modeling session, the SEQUAL framework offers a good environment to do this. Chapter 4 extends some of the concepts of SEQUAL to develop an evaluation framework that takes into account the modeling artifacts used in, and produced during, collaborative modeling sessions. It should be noted
that although SEQUAL has a niche over other frameworks in evaluating the models and the modeling language, it does not bring on board the modeling processes and the medium which we consider to be key components in understanding the impact modeling artifacts have on the overall efficacy of the collaborative modeling effort. Moreover, the organizational goals that SEQUAL mentions need to be differentiated from the modelers’ goals and rules that are set in, and for, the modeling session and the strategies used in the process. One SEQUAL-based approach that overcomes these limitations is the Quality of Modeling (QoMo) framework which is described next.

### 2.4.2 The QoMo Framework

The Quality of Modeling (QoMo) framework [BHP07] is a SEQUAL-based framework that takes into account both the product of modeling and the processes it results from. It is based on knowledge state transitions, cost of the activities bringing such activities about, and a goal structure for the activities of modeling. When used appropriately, QoMo results in a comprehensive set of main modeling process goal types rooted in the semiotic view of modeling. In QoMo, goals in modeling can be linked to a rule-based way of describing the processes for modeling, see for example [SHP09a, SHP09d]. The descriptions hinge on the strategy descriptions and can be used descriptively for studying and analyzing the real instances of the processes and also prescriptively for guiding the modeling process. The descriptive utility of QoMo is important for the analysis and quality evaluation of the processes. In Chapter 3 we explore further the rules, goals and strategies from QoMo in developing an analysis framework for collaborative modeling. The concepts are extended further in Chapter 6.

### 2.4.3 Guidelines of Modeling

The Guidelines of Modeling (GoM) [RSS01, Ros98, Sch99, SR98a], see also [BRU00], is a model-quality evaluation framework the aim of which is to go beyond the syntactical rules in model evaluation. Like the SEQUAL and QoMo frameworks, it is derived from the levels of the semiotic ladder, mainly the syntactic, semantic and pragmatic levels. However, it integrates concepts from other quality frameworks e.g., the earlier SEQUAL framework of Lindland et al. [LSS94] and that of Moody and Shanks [MS94, MSD98]. The theoretical and philosophical orientation, as observed in [Sch99], is towards moderate constructivism, ontological realism and epistemological idealism. The GoM framework goal is to improve the quality of information models (product quality) and that of the information modeling (process quality). It gives six guidelines to achieve this which are: correctness, relevance, economic efficiency, clarity, comparability and systematic design which are further classified as basic guidelines (correctness, relevance, economic efficiency) – meaning they are essential – and optional guidelines (clarity, comparability, systematic design) – meaning they are desirable or additional features. These quality guidelines are explained below.

**Basic Guidelines**

- **Correctness (syntactic):** Correct use of the modeling language’s syntax as specified in the underlying meta-model. The model is consistent and complete against a meta-model it is based on.
2.4. Quality Frameworks for Evaluation of IS Models

- **Correctness (semantic):** The model’s structure and behaviour is consistent with the real world, i.e., inclusion by the model of all important elements and relationships of the extract of the real world (external relevance) and inclusion of elements and relationships that are of importance for the individual purpose.

- **Relevance (external):** Selection of a relevant system (UoD), taking a relevant mod-
eling technique or configuring an existing meta-model and developing a relevant minimal model system.

- **Economic efficiency**: Feasibility or cost/benefit analysis of achieving the required model quality. Further benefits should equal further required efforts. Can be achieved by use of reference models, appropriate modeling tools or re-use of the models.

**Optional Guidelines**

- **Clarity**: Understandability or readability of the model by the user. The model should be graphically and conceptually readable and self-explanatory.

- **Comparability**: Identical application of all other guidelines to all models, e.g., sticking to the naming and layout conventions throughout the modeling project.

- **Systematic design**: Well-defined relationships with other models belonging to other views, e.g., identifying or establishing relationships between process models and data models.

GoM, like SEQUAL, has been revised and a number of terms re-defined. In Schuette and Rotthowe [Sch99, SR98a], for example, correctness and relevance were re-defined into *language adequacy* and *construction adequacy*. The meta-model of the re-defined GoM is shown in Figure 2.5. It is this refined version that fits within our definition of model quality and process quality. Construction adequacy which refers to the evaluation of problem representation in the model [SR98a], requires *consensus* from the problem owners and users about the way the problem is represented in the model. This, however, presupposes that the model is developed by a systems analyst who has to seek endorsement from the problem owners. In collaborative modeling, however, consensus has to be from all the participants in the modeling process. In addition to the problem to be constructed, there is need for *agreement* about the model representation. From this definition of construction quality adequacy we clearly see how the communicative process (argumentation, negotiation and decision-making) comes into play between the different modelers engaged in the modeling effort. It is through this communicative process that they reach consensus and agreement. This, as we have argued in the preceding sections, is the case during collaborative modeling.

The second guideline that was re-defined in the revised GoM framework is that of correctness which is referred to as language adequacy. Language adequacy mainly focuses on the interrelation between the model and the utilized language used to create that model [Sch99]. Whereas correctness in earlier versions of GoM concerned mainly the syntactic and semantic quality, language adequacy looks at the *language suitability* and *language correctness*. Language suitability relates to selection of (appropriate) *modeling techniques* and the selection of relevant model constructs. This is dependent on the knowledge of the modelers and their experience with a modeling technique, their subjectivity and language comprehensibility. It is argued in [SR98a] that *tool support* is an evaluation of language comprehensibility. Two things come out of this observation: 1) modelers must determine and/or select the most appropriate technique(s) to use in the modeling process, 2) the tool-support has an impact on the quality of the modeling process. The question, however, remains: how the modelers choose or select the most appropriate technique that meets their quality goals and which quality factors or dimensions can be used
2.4. Quality Frameworks for Evaluation of IS Models

to assess the impact of the modeling technique and the support-tool. It is on this basis
that we investigate these as part of the four modeling artifacts. The communicative part
is discussed in the analysis framework in Chapter 3 and the evaluation of the modeling
language and support-tool is discussed in Chapter 4.

2.4.4 Moody-Shanks Framework

The Moody-Shanks data model quality evaluation framework [MS94], which originally
was meant to evaluate the quality of data models, especially entity - relationship models,
has found application in a number of model quality evaluation studies. A number of
improvements were made on the earlier framework that made it possible to be applied
in practice [MS98]. The introduction of the metrics in [Moo98] made it possible to
evaluate a number of quality factors that relate to the models. This framework is oriented
towards an ontological realism and a subjectivistic epistemological view. The goal of
Moody-Shanks framework “is to evaluate models using individual criteria with the help
of metrics so that after having weighted results, the evaluation can be done on model
level” [Sch99, p.494] [italics ours]. This framework consists of four major constructs
[MS94, p.97]:

1. **Qualities**: represent desirable properties or dimension of value for a data model.
The goal of the evaluation is to maximize the value of the model with respect to
these qualities.

2. **Metrics**: provide ways of measuring each quality in a consistent and objective
manner. There may be multiple metrics for each quality.

3. **Weightings**: define the relative importance of different qualities in a particular
problem environment. It is a value assigned to a quality and represents its relative
importance in the context of the project.

4. **Strategies**: are methods for improving the quality of data models with respect to
one or more qualities.

This framework is built on eight quality factors: completeness, integrity, flexibility, un-
derstandability, correctness, simplicity, integration and implementability [Moo98, MS94,
Sch99]. These quality factors are explained in Table 2.5.

The framework builds commitment among the participants by involving all stake-
holders in the modeling process who may include: end-users, management, data admin-
istrators, application developers, etc. Looking back at the framework discussed so far:
SEQUAL, QoMo and GoM, we can see an explicit mention of quality criteria, but not
metrics and weights or how the evaluation can be done with respect to these. Moody-
Shanks framework brings this out explicitly. Moody and Shanks observe that: “in the
absence of formally defined and agreed criteria, the representation is usually done in an
ad-hoc way, based on personal opinion” [MS94, p.94]. Moody argues that quality crite-
ria alone are not enough to ensure quality in practice since different evaluators will have
different interpretations of what these quality criteria mean. The aim, therefore, of any
framework should be to substitute the different intuitive perceptions of quality with quan-
tifiable measures so as to reduce subjectivity, bias and personal opinion in the evaluations.
Table 2.5: Moody-Shanks quality factors.

<table>
<thead>
<tr>
<th>Quality Factor</th>
<th>Evaluation</th>
<th>Metric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completeness: Inclusion of all information required by user in the model.</td>
<td>Checking (with participants) whether each user requirement is somewhere in the model.</td>
<td>Quality measures take the form of mismatches with respect to user requirements.</td>
</tr>
<tr>
<td>Integrity: Extent to which business rules are enforced by the data model.</td>
<td>Translating rules into natural language and users check whether each rule is true or false.</td>
<td>Quality measures take the form of mismatches between data models and business rules.</td>
</tr>
<tr>
<td>Flexibility: Ease with which data model can cope with business change.</td>
<td>Identifying what requirements might change in future, their probability of occurrence and their impact on the data model.</td>
<td>Quality measures focus on the areas where the model is potentially unstable.</td>
</tr>
<tr>
<td>Understandability: Ease with which the data model can be understood.</td>
<td>Checking, with users, whether the model is understandable.</td>
<td>Quality measures take the form of ratings by different stakeholders and testing understandability.</td>
</tr>
<tr>
<td>Correctness: Conformity to the rules of data modeling techniques.</td>
<td>Checking whether the model obeys the rules or it does not.</td>
<td>Quality measures take the form of defects with respect to the data modeling standards (syntactic rules).</td>
</tr>
<tr>
<td>Simplicity: Data model contains minimal constructs.</td>
<td>Simple counting of data elements.</td>
<td>Quality measures take the form of complexity measures.</td>
</tr>
<tr>
<td>Integration: Level of consistency of the model with organization's data.</td>
<td>Comparing the application data model with the enterprise data model.</td>
<td>Quality measures are in the form of conflicts with the company data model or with existing systems.</td>
</tr>
<tr>
<td>Implementability: Ease with which the data model can be implemented.</td>
<td>Providing important reality checks by the application developer on what is technically possible or economically feasible.</td>
<td>Quality measures take the form of ratings (on technical risk, schedule risk and development cost estimate) by the application developer.</td>
</tr>
</tbody>
</table>

In this thesis, we develop an evaluation framework based on the AHP approach to measure each quality of the modeling artifact and determine the relative importance of each quality through the weights that modelers assign to the quality criteria of these modeling artifacts. The AHP eliminates the effects related to personal subjectivity, bias/opinion by aggregating the individual judgements and eventually the individual priorities and preferences into group priorities and preferences. The details are given in Chapter 4. Figure 2.6 gives a meta-model for model quality evaluation using the Moody-Shanks framework.

2.5 Attitudes, Beliefs, Intentions and Behaviour

Subjectivity, bias and personal opinion are a result of the modelers having different attitudes, beliefs and perceptions about what is being evaluated. This comes from a wealth of experience they have acquired or accumulated over time. In any collaborative modeling process, this behaviour will be exhibited when the modelers are engaged in the different facets of the communication process. Their acceptance and adoption of the quality measures, models or the method used in the evaluation is dependent upon these psychological factors. There is therefore a need in the evaluation process to look at the impact these might have on the quality of the modeling artifacts. In the next sections we look at two theories from social psychology which can help us deal with these psychological factors. Before delving into the details of these theories, a few definitions are in order. These
2.5. Attitudes, Beliefs, Intentions and Behaviour

Attitude. A person’s attitude refers to behaviours that are favourable or unfavourable. For collaborative modeling such attitudes are shown when modelers are asked to evaluate the different quality constructs. Attitudes are therefore predispositions to behave by following a particular path during the evaluation of a modeling artifact or any other object at hand. This path may lead to a favourable (positive) or an unfavourable (negative) evaluation of the modeling artifact or object in question.

Belief. The belief represents the information (opinion, etc..) held by the modeler/evaluator about the modeling artifact or any other object. This belief links the modeling artifact...
or any other object to some attribute which, in this case, is the characteristic, property, quality-factor or construct that is used to assess the modeling artifact or the object. It is here that stakeholders involved in the evaluation process will differ in their “belief strength”, i.e., the perceived likelihood that the modeling artifact possesses the characteristic or quality factor. A stakeholder’s belief is measured by subjective probability where the modeling artifact is evaluated on its quality-factors, attributes, dimensions, etc.

**Intention.** Intention is a special case of belief. It is the cognitive representation of a person’s readiness to perform the behaviour, and it is the immediate antecedent of behaviour. The shift here is from the object to be assessed or evaluated (modeling artifact) to the modeler or evaluator him/herself (i.e., behaviour of that stakeholder) and from the attributes (quality factors, quality dimensions, etc.) that are used to evaluate the modeling artifact. We may be interested in knowing about the stakeholders’ intention in, for example, using or adopting the models, the modeling technique (method) or support-tool. Intention, intuitively, is (a person’s behaviour) about acceptability and adoption of the models, method, technique or support-tool. The measure is determining the subjective probability whether the person will perform that behaviour or action again, i.e., accept/adopt.

**Behaviour.** An overt behaviour is some observable act that may be studied in its own right and is used to infer attitudes, beliefs and intentions. To evaluate the quality of the modeling artifacts, we might ask collaborative modelers to fill out a prepared questionnaire or to answer some questions in an interview schedule. By doing so, we are measuring overt behaviour of the participants in the questionnaire or interview.

It should be noted that Fishbein [FA75, p.12] classifies the above four definitions along four categories: affect – which refers to the person’s feelings about the evaluation of some object; cognition – which denotes the person’s knowledge, opinions, beliefs and thoughts about the object; conation – which refers to the person’s behavioural intention and his/her actions with respect to the presence of the object; behaviour – which is the observed overt act. This classification brings out the key observation that the measurement, assessment or evaluation of the modeling artifacts is either evaluative or affective. Therefore evaluation of the modeling artifacts should capture these psychological factors. Two theories that can help in this regard are explained next.

### 2.5.1 Theory of Reasoned Action

The Theory of Reasoned Action (TRA) [AF93, FA75, Fis67] is a well documented model from social psychology which is often used to study consciously intended behaviours. It postulates that the person’s “behaviour (B)” is driven by his/her “behavioural intentions (BI)”, and these behavioural intentions are a function of the person’s “attitude towards that behaviour (AB)” and the “subjective norms (SN)” surrounding the performance of that behaviour. Regression can be used to estimate this behaviour using Equation 2.1:

\[
B \approx BI = \omega_1 AB + \omega_2 SN
\]  

(2.1)

where \(\omega_1, \omega_2\) are weights representing the importance of each term. TRA’s conceptual model is shown in Figure 2.7.
Subjective norm refers to whether people important to that individual think that the behaviour should be performed. It represents perceived opinions of others and relates to social expectation [HMR97]. There are a few important observations about this model. First, a person’s attitude toward’s behaviour (AB) is determined by the “salient behavioural beliefs (bbi)” of that person about the consequences for performing that behaviour multiplied by the “outcome evaluation (oei)” of those consequences i. Equation 2.2 depicts this.

\[
AB = \sum_{i=1}^{nb} bbi \text{oei}
\]  

(2.2)

where nb is the number of salient outcomes and the outcome evaluation term refers to the implicit evaluation response of the consequence, i.e., rating of the desirability of the outcome [FA75, Mat91]. What this means is that external environment variables/stimuli (uncontrolled factors) influence attitude only indirectly through changes in the person’s belief structure. For collaborative modelers, the changes in their beliefs that influence their attitude towards the quality of the different modeling artifacts or the acceptance/adoptions of a certain modeling technique, method, model or support-tool are drawn from their prior personal experiences or knowledge which may be a result of some (uncontrolled) situational or environment factors. But, through a communicative process that involves argumentation, negotiation and/or decision-making, their attitudes may change due to some shared meaning and understanding now attached to the concepts.

The second observation from the TRA model is that the person’s subjective norm (SN) – which refers to the individual’s perception of whether people important to the individual think that the behaviour should be performed – is the sum of the product of his/her “normative beliefs (nbj)” multiplied by his/her “motivation to comply (mcj)” with

**Figure 2.7: The conceptual model of TRA [FA75].**
those expectations $j$ [FA75, p.309]. Subjective norm can be computed from Equation 2.3:

$$SN = \sum_{j=1}^{n_o} nb_j mc_j$$  \hspace{1cm} (2.3)

where $n_o$ is the number of salient others and a normative belief is the perceived expectations of some specific individual(s) or group(s) whereas motivation to comply is the extent to which the person wants to comply with the wishes of the others [FA75, HMR97, Mat91]. We again observe from Figure 2.7 that the uncontrolled external/environmental variables indirectly impact on the person’s subjective norm, this time, unlike for the case of attitude where the influence was through behavioural beliefs and outcome evaluations, the impact is through normative beliefs and motivation to comply. Modelers in collaborative modeling are bound by the (unwritten) group rules to abide by the group decision. There is a sense of commitment to abide by this and each individual modeler has some degree of motivation to comply as a result of what the rest of the group members expect from that individual. Each member’s perception is that this commitment should be shown, i.e., the behaviour should be exhibited or performed.

2.5.2 Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) by Ajzen [Ajz85] is an extension of the TRA and was developed to overcome some shortcomings of TRA. TRA was observed not to be 100% valid in representing behaviour and these behaviours were not under control. To remedy this, “perceived behavioural control (PBC)” was introduced to the model. TPB predicts deliberate behaviour since behaviour can be deliberative and planned [Ajz91]. As already observed, TRA assumes that a persons behaviour is determined by his/her intention to perform that behaviour and that intention is, in turn, the function of his/her attitude toward that behaviour (AB) and his/her subjective norm (SN). But as argued by Mathieson [Mat91, p.175], intention is determined by three things: (i) attitude towards a specific behaviour (AB), (ii) subjective norms (SN), and, (iii) perceived behavioural control (PBC). TPB posits that only specific attitudes toward that behaviour in question can be expected to predict that behaviour. TBP’s conceptual model is shown in Figure 2.8.

Perceived behavioural control (PBC) refers to people’s perceptions of their ability to perform the behaviour in question. That is, it is the individuals perception of his/her control over performance of the behaviour. PBC refers to the individual’s perception about the presence or absence of the requisite resources and/or opportunities to perform the behaviour [Ajz91, Ajz85]. Harrison et al. [HMR97] look at PBC as relating to resources to overcome any obstacles and depends on “control beliefs ($cb_i$)” and “perceived facilitation ($pf_i$)” where a control belief is the perception of the availability of resources, skills and opportunities whereas perceived facilitation refers to the individual’s assessment of the importance of those resources to achieving the outcome [Mat91]. PBC is thus given by Equation 2.4:

$$PBC = \sum_{i=1}^{n_o} cb_i pf_i$$  \hspace{1cm} (2.4)
2.5. Attitudes, Beliefs, Intentions and Behaviour

Figure 2.8: The conceptual model of TPB, adapted from [Ajz91, Ajz85, HMR97, Mat91].

where $n_c$ is the number of salient skills, resources or opportunities. We should observe that in group activity, e.g., collaborative modeling, there is a deliberate and planned behaviour by the participants to engage in the exchange of views before they arrive at the final decision. Everyone comes to the modeling session well aware that this engagement is going to take place and everyone’s intention is to perform that communicative act. Their perception is that they have the skills to engage in this exchange and to produce whatever end-product is required, resources are available and everyone will be availed the opportunity to either air-out their views or use the resources available. Despite these perceptions, beliefs and intentions, there is a likelihood that the efficiency and effectiveness of the modeling session will be affected by these psychological factors. We can, intuitively and on the surface, analyze the communication logs to find traces of these psychological factors but the most effective way is to trace them through the evaluation of the modeling artifacts since many of these are overt behaviours which can be assessed via perceptions. Acceptability and/or adoption of modeling language, the modeling procedure and/or the support-tool is key in determining not only the quality of the modeling products but also the quality of the overall modeling process. More details are given in Chapters 4, 6 and 7. In the next section we look at a model that operationalizes concepts from the TRA/TPB and can help us to evaluate the modelers’ perceptions and also determine the acceptability and/adoption of some of these modeling artifacts.

2.5.3 Technology Acceptance Model

The Technology Acceptance Model (TAM) [Dav86], see also [Dav89, DBW89], is one of the few most successful models to have applied the concepts of TRA to study the acceptance of information systems by users. One of the key goals of TAM is to provide a model for tracing the impact of external factors on the person’s psychological factors: attitudes, beliefs and intentions. TAM posits that two beliefs: “perceived usefulness” and “perceived ease of use” are key in determining computer acceptance. The conceptual model of TAM is given in Figure 2.9. Perceived usefulness (U) is the prospective user’s probability that using a specific application system will increase his/her performance and
perceived ease of use (EOU) is the degree to which the prospective user expects that target system to be free of effort.

**Figure 2.9: Technology acceptance model (TAM) [Dav86, Dav89, DBW89].**

TAM, like TRA, posits that a person’s behaviour is determined by “behavioural intention (BI)” which is jointly determined by “attitude towards using (AU)” the system and perceived “usefulness (U)”. Thus, BI can be computed from Equation 2.5:

\[
BI = \omega_1 AU + \omega_2 U 
\]  
(2.5)

The attitude towards use (AU) of the system is determined by perceived usefulness (U) and perceived ease of use (EOU) as shown in Equation 2.6 and \(\omega_1\) and \(\omega_2\) have the same meaning as in Equation 2.1.

\[
AU = \omega_1 U + \omega_2 EOU 
\]  
(2.6)

In Chapter 4 we describe, within the collaborative modeling evaluation framework, a quality construct that is informed by concepts from TAM. We show, in Chapter 7 how this can be used to trace the collaborative modelers’ use of the modeling procedure, medium (support-tool) and the acceptance or adoption of these modeling artifacts among the modelers in a collaborative modeling session and/or within an organization.

### 2.5.4 Method Evaluation Model

Moody’s Method Evaluation Model (MEM) [Moo01] is a theoretical model for evaluating information systems methods. It is informed by the methodological pragmatism [Res77] – a theory for validating theoretical knowledge and incorporates concepts from the TAM model [MSBS03]. It includes both aspects of the method’s success (efficacy – efficiency and effectiveness) [Moo03] and its adoption in practice (relevance issues). These are strong and quite desirable features of the MEM model. The other feature of the MEM model is that it measures the behaviour of the users by capturing the actual usage of the method [Moo01, MSBS02]. The approach is quite relevant to collaborative modeling evaluation since one would be interested in measuring the success of the modeling effort in addition to measuring the behaviour of the modelers in the modeling process. MEM’s main concepts are summarized in the conceptual model given in Figure 2.10.

In the MEM model, actual efficiency (which is the extent to which the method is required to perform the act) and actual effectiveness (which is the extent to which the
2.6 Concluding Remarks

In this chapter we have managed to survey the current “state-of-the-art” literature that gives our research a theoretical framework and backing. It has been observed that although a lot of research about conceptual modeling exists, there is little that touches on the act or process of modeling. The chapter has revealed that there is an interest and an ongoing research to try to establish and develop methodologies and tools that can be used to study, analyze and understand the act of modeling and enhance the quality of the process of modeling. To this end, a thesis has been proposed by a number of researchers to come up with descriptive methods and tools which can model the process of modeling and guide the same process. From the identified gaps we feel an urge to take up the task of contributing to this noble yet often neglected part of conceptual modeling.

Some of the existing theories and frameworks surveyed are not only relevant to the analysis and evaluation of collaborative modeling processes, but they also provide the theoretical concepts to be used and applied within the analysis and evaluation frameworks and the meta-model we aim to develop. For the analysis part, the chapter has argued that communication in all its different facets (argumentation, negotiation and decision-making) is key in helping us study, analyse and understand what takes place during a collaborative modeling process. The chapter has appealed to speech acts (conversational
Chapter 2. Existing Theories and Frameworks

moves), dialogue games and dialogue types and argued that they are key in removing the seal off the collaborative modeling black-box. Argumentation, negotiation and group decision-making have been identified as necessary communicative processes that can help us understand collaborative modeling better with the aim of supporting it.

Since flaws that might occur during a collaborative process may be hard to track and trace, the chapter has looked at some of the existing frameworks and models on which we can anchor the evaluation and assessment of the quality of the different modeling artifacts with the aim of tracing these back to the analysis process. The chapter has argued that psychological, behaviour and situational factors (such as attitudes, beliefs, intentions, behaviour and other external/environment factors) have a bearing on the communication and evaluation process. Factors that may be measured in this regard have been identified within the theory of reasoned action, theory of planned behaviour and method evaluation model. In the next chapter we explore the framework that can help us study, analyse and understand collaborative modeling processes.
PART II

Analysis and Evaluation of Modeling Processes
Chapter 3 introduces the RIM framework used to analyze, study and understand the modeling process. It starts with an overview in Section 3.1 and introduces the game metaphor in Section 3.2. The metaphor is discussed in Section 3.2.1 and reasons for a game metaphorical approach are given in Section 3.2.2. The strategy for structuring the modeling process is discussed in Section 3.3 first, by looking at the task and its complexity in Section 3.3.1 and determining the nature and type of the collaborative modeling task in Section 3.3.2. Two approaches for structuring the modeling process are introduced in Section 3.3.3. The rules, interactions and models are introduced in Section 3.4. The rules types and topics are introduced in Section 3.4.1 while the types and topics for the interactions are introduced in Section 3.4.2. Implicit and explicit model actions are introduced in Section 3.4.3. The relationship between the rules, interactions and the models is discussed in Section 3.5 and a RIM framework that captures this relationship is introduced in Section 3.5.1. In Section 3.5.2 we show how the RIM framework can be used to analyze the modeling process. The chapter ends with some concluding remarks in Section 3.6.

Chapter 4 introduces the COME framework. It starts with an overview in Section 4.1. The conceptual model of the COME framework is introduced in Section 4.2 while the modeling artifacts are introduced in Section 4.3. Specifically, the modeling language is introduced in Section 4.3.1, modeling procedure in Section 4.3.2, end-products in Section 4.3.3 and support-tool in Section 4.3.4. We introduce the AHP evaluation method with its three phases: structural decomposition in Section 4.4.1, comparative judgement in Section 4.4.2 and synthesizing in Section 4.4.3. Group negotiation and decision-making with AHP is introduced in Section 4.5. Aggregation of the modelers’ judgements is introduced in Section 4.5.1 while the technique used to aggregate their priorities is introduced in Section 4.5.2. Consistency check for group decisions is introduced in Section 4.5.3. Modelers’ attitudes, beliefs and behaviour towards quality are introduced in Section 4.6. Application of the COME framework is given in Section 4.7 while Section 4.8 concludes the chapter with some remarks about the COME framework.

Chapter 5 introduces a meta-model. It starts with an overview in Section 5.1 and goes on to explain, in Section 5.2, why we need such a meta-model. Section 5.2.1 introduces some of the concepts in meta-models and meta-modeling while section 5.2.2 discusses the concepts of the meta-model from both the RIM and COME frameworks. The ORM methodology is introduced in Section 5.2.3. Section 5.3 introduces the collaborative modeling analysis part of the meta-model. Specifically, Section 5.3.1 looks at the rule model, Section 5.3.2 looks at the interaction model while Section 5.3.3 looks at the model-propositional model. In Section 5.4 we introduce the evaluation part of the meta-model. The structure of the modeling artifact is introduced in Section 5.4.1 while the role of the interactions is introduced in Section 5.4.2. The meta-model that integrates the RIM and COME frameworks is finally presented in Section 5.5 while final conclusions are given in Section 5.6.
3 The RIM Framework

Interaction is ... a rule governed activity which may ... be regarded as a game.
– Stathis & Sergot, 1996

3.1 Overview

This chapter introduces the “Rules-Interactions-Models (RIM)” framework that we use to study, analyse and understand collaborative modeling processes. In order to understand the concepts in the framework, we introduce a “game metaphor” for collaborative modeling where we identify similarities and differences between classical competitive, cooperative and collaborative games and collaborative modeling. The choice of this metaphor is based on our argument that collaborative modeling is like a game. We identify the modeling task and its complexity as one of the platforms upon which communication and collaboration is based when playing the modeling game. In this regard, we place the collaborative modeling task on the right axis within the McGrath’s Group Task Circumplex, see Figure 3.1. Putting it within McGrath’s Circumplex helps us determine what type of task collaborative modeling is. It also helps study and identify the procedure or strategy that modelers employ while solving the modeling task before them. We discuss one methodology that uses planned pro-active rule setting procedures and ad-hoc reactive rule setting procedures that modelers use to structure the modeling process as a result of playing the modeling game. We discuss the rules set in, and set for, the modeling game and the goals modelers strive for, the interactions in view of the communicative process and the explicit and implicit model actions that are a result of the rules and interactions. We, formally, identify the different relationships that exist between the rules, interactions and the end-products (models). We, finally, show how the RIM framework can be used to analyse the modeling process.

3.2 The Game Metaphor for Collaborative Modeling

The gaming approach has, in the past, been applied to system development, particularly for interface design in Human-Computer Interactions (HCI) [ASK+94, Eri90, SS96, Woz89], group decision-making [NAO98], and in education learning [Rav06]. Recently, information systems development has been referred to as a (modeling) “game” [HBJ08, Hop08] and collaborative modeling is, in particular, found to be a game with rules of play that can be set to govern the activities of this game [HWR09, SHP09a]. This gaming approach to modeling is taken as a result of discovering that modeling is often goal-driven, interactive and playful due to the collaborative nature of the approach taken [Wil08] and viewing method engineering as game may even help to design a tool/game

This chapter is an extended version of the following publications: [SHP09a, SHP09d].
that allows non-experts to make a formal description of a process [Sch09]. Despite this observation, questions abound about the differences and similarities between the classical (computer, board or field) games, see for example [SZ03, ZR06], and system development or collaborative modeling when viewed as a game. It is against this backdrop that we want to draw a line between a classical game and a collaborative modeling game. First, it should be noted that we use the word game “metaphorically” which still raises a number of questions due to the not-so-clear meaning. Although there are a number of authors, especially interface designers in the HCI field who have tried to define it, ambiguity still exists.

3.2.1 Metaphor

There are a number of authors who have argued for the use of metaphors in scientific theories and models. Brown [Bro03], for example, argues that metaphorical thought is deeply rooted within scientific thinking, reasoning and communication. He presents a series of systems ranging from atoms in biology and chemistry to global warming. Following the same line of thought, Goschler [Gos07] observes that our thinking is metaphorically structured, and so is the language used. He demonstrates how metaphors can be used in a scientific language and what they mean for scientific arguments and theories. Lakoff and Johnson [LJ03] observe that metaphors are rhetorical, heuristic and cognitive and they are pervasive in scientific language and scientists use them to explain their theories and their work [Ren05]. Metaphors are, thus, unavoidable in science [Bro03, LJ03, Mac00]. From these observations, it is worth to look at the definition of the metaphor and how it relates to concepts discussed for collaborative modeling. According to Wozny [Woz89], a metaphor is “the process of representing the computer system with objects and events from a non-computer domain”. Lakoff and Johnson [LJ03] refer to a metaphor as “understanding one domain of experience in terms of another domain”. Erickson [Eri90] gives a nice example of a metaphor by comparing the communicative and argumentative process between two participants as sort of a “war” with a lot of military jargon. He observes that:

Arguments have two sides: can be defended and attacked. Facts can be marshalled to support one’s position, strategies can be employed. If a position is indefeasible one can retreat from it. Arguments can even have weak points – they can even be destroyed; arguments can be right on target; arguments can be shot down. [Eri90, p.66].

Erickson’s metaphorical view of an argument and war (or conflict) brings out salient features which we observe in collaborative modeling when modelers engage in a communicative and argumentative process. Engaging in war is “like” playing a game as is engaging in an argument. There are rules to follow and goals to strive for. There are positions taken and strategies devised to “win”. Similarly, modelers engage in arguments by putting forward proposals which are argued for or against, which are agreed with or against, they could be withdrawn, accepted or rejected [Rit08a, Rit07]. Thus, metaphorically, collaborative modeling is “like” playing a game. Modelers draw on their cognitive processes to play this game. By so doing, they “play” by the rules of the game and they are guided by the goals set. Unlike classical games where there is a winner and a loser, in collaborative modeling it is typically a win-win situation, see Table 2.2 in section 2.3.2.
3.2. The Game Metaphor for Collaborative Modeling

Thus, by looking at collaborative modeling in this way, we allow collaborative modelers to bring their attended experience with an already familiar conceptual system from their mental cognitive processes [Mil79]. Therefore, a game metaphor can help us understand the concepts we study in collaborative modeling. This metaphorical view of collaborative modeling as a game is explained next.

3.2.2 Why a Game Metaphorical Approach?

From the preceding definitions of a metaphor, we now have a clear picture. We can, thus, state explicitly why we take a game metaphorical approach to collaborative modeling. As discussed in Hoppenbrouwers et al. [HBJ08], instantiated collaborative modeling sessions can be analyzed as if they are games. This approach is rooted in the observation that operational collaborative modeling is an interactive process that is “played out” within the boundaries of specific constraints (rules). This observation was earlier noted by Stathis and Sergot who referred to “interaction” in an interactive system as a rule-governed activity which may be thought of as a game [SS96]. Interactions made by the participants of such an interactive system are looked at as “moves” selected by the players of a game. This is the same observation in collaborative modeling where the communicative dialogues (interactions) are interpreted to be moves of the players in the dialogue game played under certain conditions (rules), see dialogues and dialogue games, section 2.3.1.

Though the current analysis presented in this chapter does not typically involve gaming as an overt activity, our analysis is based in the idea of viewing the modeling session that is studied as a game. Games can be understood from many perspectives: systems, cognition, emotion, see for example Järvinen [Jö7]; entertainment as well as utility – “games with a purpose” or “serious gaming”. Games are by definition rule and goal-oriented. Järvinen developed a Game Design Theory (GDT) which can be applied to method engineering [HBJ08]. The analysis concepts described for the RIM framework follow the same line of thought. Games Theory (GT) [LS01], which we do not directly employ, analyzes strategies for playing and winning games, whereas GDT describes design concepts and principles underlying good game design. In a modeling context, GDT may contribute to good method design. For the collaborative game aspect, Zagal and Rick [ZR06] make a clear distinction between competitive, cooperative and collaborative games.

- Competitive games force players to identify strategies that are diametrically opposite.
- Cooperative games contain a set of enforceable rules that govern and direct the negotiation and bargaining of the players.
- Collaborative games force players to work as a team or group and sharing the payoffs or outcomes of this collaborative effort with a win-win objective.

Our work embraces the cooperative and collaborative views and applies them to collaborative modeling by identifying a set of rules and goals governing and directing the modeling process, and studying the interactions in view of those rules, goals and strategies, see for example, [SHP09a, SHP09d]. Thus, we view collaborative modeling as a
multi-player game [Man02] in which a set of rules and goals direct and govern the collaboration of the players (modelers). This view is, however, metaphorical. Playing this modeling game requires looking at the type or nature of the modeling task and the method or strategy used to play this game. In the next section, we explore what type or nature a task collaborative modeling is. Knowing this, helps us to study and analyse the kind of rules and goals and the approach that can be used to play this kind of game.

3.3 Structuring the Modeling Process

Analyzing what takes place in collaborative modeling and understanding how stakeholders in a collaborative modeling effort do whatever they do requires knowing two things: i) the type of the task at hand, and, ii) the method used to solve that task. It is the task that gives the platform upon which communication and collaboration occur in a collaborative modeling session. This means that the method chosen by the modelers is determined by the type of the modeling task before them which may either be a self-assigned task or a task given to them by a modeling session facilitator or an experimenter. Before looking at the method that modelers use to play the modeling game, we need to determine what type or nature the collaborative modeling task is. Borrowing concepts from group research, especially small groups [BWWK87], we position the modeling task on the correct task axis of McGrath Task Circumplex [McG84]. We look at some of the well-established task typologies or taxonomies from small group research that direct us us towards this placement.

3.3.1 Task and Task Complexity

It is perhaps important to start by looking at what is meant by a “task”, although our intuition and common sense may tell us already what it is. The definition of a task that fits within our research is that given by Hackman [Hac69]:

A task may be assigned to a person (or group) by an external agent or may be self generated. It consists of a stimulus complex and a set of instructions, which specify what is to be done vis a vis the stimuli. The instructions indicate what operations are to be performed by the subject(s) with respect to the stimuli and/or what goal is to be achieved (p.113). [Italics not in original.]

This definition identifies three important components for a task: i) the stimuli present in the task – (the task objects and components); ii) the instructions about operations – designed to define objectives, rules, contexts, and processes; and, iii) the instructions about goals – designed to direct subjects to the stimuli and instructions, see also [MW93a, MW93b]. Group research literature contains a number of task typologies which have been developed to study the impact the task and its complexity can have on group performance and effectiveness and a number of methods have been proposed for solving tasks of certain complexities. The first task typology can be traced to the work of Roby and Lanzetta [RL58] whose typology posits that a task has two properties: objective properties – which represent the inherent and quantifiable characteristics of the task and model properties – which represent those behaviour that can be depicted by the individual or group while executing the task. Many of the typologies that were developed later, e.g., Hackmann’s
3.3. Structuring the Modeling Process

Task typology [Hac69, Hac68], McGrath’s Group Task Circumplex [McG84] and Wood’s task typology [Woo86] are based on this first typology. Hackman’s task typology [Hac69] gives task description definitions which are given in Table 3.1 and identifies three task types based on behavioural and performance processes that are required to complete the task which include [Hac68, HM78, HM75]:

Table 3.1: Task description frameworks [Hac69].

| Task Qua Task: What pattern of stimuli are impinging on the subject? These are the objective dimensions of the task such as the physical nature of the task, its subject matter, characteristics of the stimuli. |
| Task As Behavior Requirements: What responses should the subjects emit, given the stimulus situation, to achieve some criterion of success? These are the critical success factors that are needed to complete the task successfully. |
| Task As Behavior Description: What responses does the subject actually emit, given the stimulus response? These are the actual behaviors that people engage in when they are confronted with the task. |
| Task As Ability Requirement: What are the patterns of personal abilities or traits which are required for successful task completion? These are the individual physical, psychological, and background characteristics which are necessary for successful job performance. |

(i) production task types – associated with production and presentation of ideas or images, i.e., idea generation tasks.

(ii) discussion task types – which require the evaluation of issues.

(iii) problem solving task types – which require the specification of the course of action to be taken so as to resolve the problem, i.e., planning tasks.

Hackman’s task typology is based on the conceptualization and on the notion that participants in a group task will always redefine the task and devise strategies to solve the task. He points out that the task becomes “what the group members subjectively define it to be” [Hac69, p.102] rather than that which the researcher necessarily intended the task to be. His framework maps: i) the inputs, which are brought into a task scenario (e.g., the task stimuli, instructions, individual characteristics), ii) the redefinition process (individual interpretation of the task), iii) the development of strategies and tactics for completing the task, iv) execution of the task, and, v) the impact task execution has on outcomes, perceptions, and learning, see also [Dar06].

Steiner’s task typology [Ste72] is concerned with group productivity and group performance effectiveness and focuses on the outcome that is to be obtained and the task constraints that govern the generation of the outcome. Steiner’s task view distinguishes between unitary tasks which are solved by the group as a whole, i.e., they are indivisible and divisible tasks which are accomplished through division of labour. Unitary tasks are further categorized as disjunctive, conjunctive, additive or discretionary. These categories as observed by [Str99] reflect how members efforts are combined to obtain the group product, see also [Lev01]. In Laughlin’s typology [Lau80], see also related work with colleagues: Davis, Laughlin and Komorita [DLK76], tasks are distinguished as those belonging to cooperating groups and those that belong to competing groups – mixed-motive
Chapter 3. The RIM Framework

tasks. Tasks that belong to cooperative groups are further distinguished as intellective tasks and decision-making tasks.

1. Intellective tasks have a correct solution, i.e., the solution can be measured and evaluated in terms of its correctness. These tasks require group members to find a correct solution.

2. Decision-making tasks do not have a correct solution, i.e., an objective measure of correctness is not readily available and the preference and/or priorities among alternatives is a matter of individual subjective assessment. These task require group members to align their preferences and reconcile their differences so as to reach an agreement and obtain a group position.

McGrath’s Group Task Circumplex

Despite the effort spent by the authors in developing task typologies, it is observed by Straus [Str99] that none of the typologies has been rigorously tested in an empirical research. One exception is the McGrath’s Group Task Circumplex Model [McG84] which is traceable from Steiner’s [Ste72], Hackman and Morris’ [HM75, HM78], Laughlin’s [Lau80] and Davis’ [Dav80] task typologies. It has been widely used in a number of studies, see for example [CJV90, Dal93, DG87, HMO93, Str99]. McGrath’s Task Circumplex is shown in Figure 3.1.

The horizontal axis reflects the degree to which the task entails conceptual versus behaviour performance requirements and two categories: choose and execute are at the extremes of this axis. The vertical axis reflects the degree to which the task is cooperative or conflictual and generate and negotiate are the two categories at the extremes of this axis. Mennecke and Wheeler [MW93a, MW93b] observe that these axes are built on the task as behavior description framework of Hackman [Hac69]. McGrath proposes that most group tasks can be put along these axes and into the categories above which represent four basic processes: generate, choose, negotiate and execute arranged in four quadrants. The descriptions of McGrath’s task categories for each of the four processes are given in Table 3.2.

McGrath’s Task Circumplex model, notwithstanding its success, has been found to have some limitations, especially those concerned with naturally occurring groups which are embedded within larger social units (communities, organizations, etc..) [McG91]. It also lacks a provision for a means to objectively measure the degree to which tasks in each quadrant of the circumplex differ both from tasks within the same category and also in other categories [MW93a] and it concentrates more on task characteristics or task/group outputs than on the socio-emotional issues associated with processing a group’s task [MW93b]. Despite these limitations, its basic tenets have been found to hold even for ad-hoc, laboratory-based or experimental groups that work under some controlled conditions, see for example [Str94]. All the task typologies discussed thus far, look at the task and its underlying impact on the outcome, behaviour and socio-emotional feelings of group participants. One other factor that has a bearing on group performance and effectiveness is task complexity. A number of researchers have attempted to develop frameworks for this component. One framework that has tried to integrate most of the prominent task complexity frameworks is that of Harvey [HC01]. This framework integrates Wood’s framework [Woo86], Campbell’s framework [Cam88, Cam91] and Byström and
3.3. Structuring the Modeling Process

Järvelin’s framework [BJ95]. This framework identifies three components upon which task complexity is based:

i. **Scope** – which measures the breadth, extent, range, reach and general size of the task. It is a function of sub-tasks, outcomes (products), outcome characteristics, conflicting outcome characteristics, and information that is processed.

ii. **Structurability** – measures how well-defined the sequence and relationships between sub-tasks are. It is determined by analyzability, alternatives and coordination.

iii. **Uncertainty** – measures complexity based on the degree of predictability or the confidence associated with a task. It is measured using internal confidence, external confidence and random events.

### 3.3.2 Collaborative Modeling: What Task Type?

To determine what nature and type a task collaborative modeling is, we need to look back at the concepts discussed from the task typologies. One observation which we have already argued for in Chapter 2 is that collaborative modeling is a communicative process
Table 3.2: Descriptions of McGrath task types [McG84].

<table>
<thead>
<tr>
<th>QUADRANT 1</th>
<th>GENERATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1</td>
<td>Planning Tasks: Generating Plans; Key notion: Action-oriented plan</td>
</tr>
<tr>
<td>Type 2</td>
<td>Creativity Tasks: Generating Ideas; Key notion: Creativity</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>QUADRANT 2</th>
<th>CHOOSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 3</td>
<td>Intellective Tasks: Solving problems with correct answer; Key notion: Correct answer</td>
</tr>
<tr>
<td>Type 4</td>
<td>Decision-making Tasks: Dealing with tasks for which the preferred or agreed upon answer is the correct one; Key notion: Preferred answer</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>QUADRANT 3</th>
<th>NEGOTIATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 5</td>
<td>Cognitive-Conflict Tasks: Resolving conflicts of view points; Key notion: Resolving policy conflicts</td>
</tr>
<tr>
<td>Type 6</td>
<td>Mixed Motive Tasks: Resolving conflicts of motive conflicts; key notion: Resolving pay-off conflicts</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>QUADRANT 4</th>
<th>EXECUTE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 7</td>
<td>Contests/Battles: Resolving conflicts of power; competing for victory; Key notion: Winning</td>
</tr>
<tr>
<td>Type 8</td>
<td>Performances: psycho-motor tasks performed against objective standards; Key notion: Excelling</td>
</tr>
</tbody>
</table>

that involves argumentation, negotiation and decision-making. The task that modelers are concerned with, is expected to engage them in a communicative process. A number of key observations can be gleaned from McGrath’s Circumplex in Figure 3.1 and Table 3.2 which can help us to rightly put the collaborative modeling task on the appropriate axis in view of the communicative process. Generating tasks, as observed in the McGrath’s Task Circumplex, require groups to devise strategies they will use to carry out the task. Within this category, group members may be involved in either planning tasks which require them to plan how to achieve their goals or creativity tasks where they create new ideas and new approaches or strategies to solve the problem. When modelers are given a problem to solve, they have to first deliberate about the problem before they actually settle down to solving it. During this phase they are generating ideas about either strategies they intend to use to solve the modeling task or rules to govern the modeling process and goals to strive for. Therefore, collaborating modeling involves task types as defined in the first quadrant of McGrath’s Task Circumplex.

Within the choice category of the McGrath’s Task Circumplex, group members may be involved in either intellective tasks that require them to choose a process to decide about issues with correct solutions or they may be required to choose between problems in a number of multiple ways - decision-making tasks. Here we see that collaborative modeling being sort of a wicked problem lacks a straightforward correct solution since modelers simply have to agree on an “acceptable” solution which is as a result of the agreement or consensus from the majority of the group members. Therefore, modelers are less involved in intellective tasks. However, they are almost always involved in decision-making tasks. In negotiation category, group members must resolve differences of opinions among them regarding their preferences, priorities, decisions or goals – cognitive-conflict tasks or group members may be required to resolve competitive dis-
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3.4. The Rules, Interactions and Models

putes, i.e., resolve conflicts of interests among them – mixed-motive tasks. Again here we note that group members are more concerned with cognitive–conflict tasks than with mixed motive-tasks. Negotiation is one of the fundamental communicative processes that modelers are often engaged in and collaborative modeling is known to be a negotiation process [Rit08a, Rit07].

In executing tasks, groups members compete against each other and they may engage in resolving conflicts of power – contests/battles/competitive tasks or they may engage in executing performance tasks – performances/psychomotor tasks. This is one of the tasks that we less expect to feature for collaborating modeling since as already argued, collaborative modeling is taken to be a cooperative and collaborative modeling game with a win-win solution. We do not expect to see modelers involved in sort of contests, battles or competitions of whatever sort. Therefore, collaborative modeling does to feature in this category.

3.3.3 Planned Pro-active and Ad-hoc Reactive Rule Setting

Taking collaborative modeling as a game enables us to look at the strategy that modelers employ to solve the modeling task before them. The strategy is guided by the rules and goals set in, or for, the modeling game. Modelers often plan what they are supposed to do without the help of a facilitator. We call this planned pro-active rule setting strategy. This strategy involves the following phases: (1) – choosing the main approach, (2) – sub-division of work, and, (3) – choosing the language [SHP09a, Sse09]. Within the ad-hoc reactive rule setting strategy modelers are less concerned about a structured approach and once given a modeling task, they simply start straight away to solve the problem in sort of an ad hoc manner. The rules and goals are set as they go along and we call this ad-hoc rule setting strategy. Unlike the planned pro-active rule setting strategy, the rules set in the ad-hoc rule setting are not as structured as those set in the planned pro-active rule setting. This strategy involves the following phases: (1) – exploring the modeling process, (2) – assigning the roles, and, (3) – modeling the sub-process [SHP09a, Sse09]. We note that each of this strategies satisfies Hackman’s task definition and can be mapped to McGrath’s Group Task Circumplex in quadrant 1, 2 and 3 especially, tasks 1, 2, 4 and 5. This is the situation in non-facilitated modeling sessions. Structuring of the modeling process is discussed further in section 8.2.1, see Figure 8.4.

3.4 The Rules, Interactions and Models

The RIM framework that we present for the analysis of collaborative modeling processes, is a three-tier – tier in the sense of division according to category – framework that examines the communicative acts (interactions) in a modeling session, the rules/goals set, and the models produced as a result of the interaction and collaboration which is, as argued already, a sort of modeling game. Exploiting the task types as defined in the McGrath’s Circumplex, we identify rules and goal setting to be a task that occurs within the first quadrant and it is a type 1 and type 2 task since setting the rules and goals involves planning and generation of ideas among the modelers. Modelers’ interaction is a communicative process and involves negotiations and decision-making tasks about either the rules to apply or goals set to realize the end-product which is the model. Within this communicative process they agree on the strategy to use to solve the modeling problem and what constitutes quality for the different modeling artifacts. Within the RIM framework,
these tasks can be mapped onto tasks 4 and 5 in quadrant 2. Thus, task types within McGrath’s Circumplex can be observed in terms of rules or goals and interactions during a collaborative modeling effort within the RIM framework.

The different players in a collaborative modeling effort work under a set of rules and goals with the interactions playing a key role in aligning the rules and goals to the realization of the products (models). This begs the question: What is the interplay between the triage of rules/goals, interactions and models that brings out proper alignment? This can be answered if we can track each conversational move or speech act identifying the explicit or implicit rules and goals associated with such communicative acts and conversational propositions that give birth to model statements. This calls for tracking not only the conversations in the collaborative modeling game and the rules and/or goals, but also the interactions and model propositions. Tracking means time-stamping each of the communicative acts. Time stamping is explained in section 6.2. In the next sections we look at the rules/goals, interactions and models.

3.4.1 Rules and Goals: Types and Topics

Treating modeling by communication in an interactive and collaborative environment as a game, requires identification of the rules under which the modeling game is played including goals driving and motivating the players (modelers) and the whole modeling game. All this is done to attain a required level of quality for both the process (process of modeling) and the models themselves. We view goals as a key type of rule (“goal rules”) [SHP09a]: from a gaming perspective, the goals are rules setting states to strive for. The rules should ideally guarantee process and model quality, but they also reflect existing conventions for (inter-) action in modeling and conversation. The Semiotic Quality (SEQUAL) framework of Krogstie et al. [KSJ06], is one of the robust frameworks for attaining product-oriented quality. Since our framework is process-oriented, we apply the Quality of Modeling (QoMo) framework of van Bommel et al., [BHP07] to translate the various quality aspects of the process of modeling via goals of modeling. It is not our intention, however, to re-discuss the SEQUAL or the QoMo frameworks since the details are already given in Chapter 2. The rules, as already pointed out, are time-stamped to help us track the associated interactions and the products produced.

These rules could be set for the players during the planning phase, (see type 1 task in McGrath’s Circumplex [McG84]) or they can be set during the execution of the modeling game by the modelers themselves when they redefine the collaborative modeling task. We call the first category rules set for the modeling game and the second category rules set in the modeling game. These rules can further be classified as either explicit or implicit rules. The combined distinctions form a simple $2 \times 2$ matrix, see [SHP09d, Sse09]. It should be noted that the rules and goals for collaborating modeling satisfy Hackman’s [Hac69] task definition, especially if we look at components (ii) and (iii) of his task definition. Rules have the following properties: time of activation, content and number of interaction it was activated in, time of activation or de-activation, content in which a rule is activated or de-activated and the id.(number) of the interaction it was deactivated in, type of rule, and model-proposition which is a model formation proposition that is either implicitly or explicitly agreed to. These elements which are explained in [SHP10b, SHP09d] are given in Table 3.3.
3.4 The Rules, Interactions and Models

<table>
<thead>
<tr>
<th>Table 3.3: Explanation for elements of a rule.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
</tr>
<tr>
<td>Content</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Interaction</td>
</tr>
<tr>
<td>ModelProposition</td>
</tr>
<tr>
<td>Goal</td>
</tr>
</tbody>
</table>

3.4.2 Interactions: Types and Topics

Communication between the modelers is studied and analyzed using an interaction-log. The interaction-log consists of time-stamped interactions that include the modelers’ conversational statements (speech acts or conversational moves). These come from the communicative process that involves: negotiations, argumentations, (dis)agreements, propositions, comments, consensus, etc. It is is a unifying format that describes the evolution of the sequence of events in the interactive and collaborative modeling environment. The sequence of events is described by the different types of interactions at any given time, t.

<table>
<thead>
<tr>
<th>Table 3.4: Explanation for elements of an interaction.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Element</strong></td>
</tr>
<tr>
<td>InteractionNr</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>Topic</td>
</tr>
<tr>
<td>Actor</td>
</tr>
<tr>
<td>Speech-act</td>
</tr>
<tr>
<td>ModelProposition</td>
</tr>
<tr>
<td>Rule</td>
</tr>
</tbody>
</table>

When studying and analyzing the interactions, we identify the: actor (player) who initiates a specific interaction, topic under discussion, content generated by the interaction and goal worked towards. These elements which are explained in more detail in [SHP10b, SHP09d] are given in Table 3.4. The interaction consisting of negotiations, propositions, argumentations, agreements and leading to consensus may be looked at as knowledge sharing and knowledge refinement [HPW05a] and can be traced to McGrath’s Group Task Circumplex [McG84], mainly types 2, 4 and 5.

3.4.3 Models: Explicit and Implicit Model Actions

Models (intermediary products and end-products) are the end-results of the interaction between the modelers. Each of the modelers in an interactive and collaborative modeling environment is assumed to have their own mental models according to their perception of the domain or universe of discourse (UoD). By engaging in the different types of conversational moves and dialogue games, these mental models are modified, refined and shaped into concrete conceptions. These conceptions result in formal models and meta-models.
which become shared mental models [BW03] of the domain, for all the modelers, see Figure 3.2. This is as a result of the agreements and consensus reached after a series of communicative engagements, mainly, argumentations and negotiations.

![Figure 3.2: Perceptions, conceptions and mental-models.](image)

Since the interactions that give birth to the products are time-stamped, it is reasonable to time-stamp the products as well. This helps us know, at any given time $t$, the type of conversational move perspective that led to the production of the model. Models, when viewed from the communicative process, “are generated lists of propositions (statements) derived from the entire conversation up to some time $t$, and subject to selection criteria determining which proposals make it to the common (shared) model” [SHP09d, p.60].

<table>
<thead>
<tr>
<th>Element</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule</td>
<td>Guidelines that direct the selection of a model-proposition.</td>
</tr>
<tr>
<td>Time</td>
<td>Time at which a model-proposition is (de-)activated.</td>
</tr>
<tr>
<td>SelectionCriteria</td>
<td>A set of evaluation criteria used to select a model-proposition.</td>
</tr>
<tr>
<td>Interaction</td>
<td>Interaction from which a model-proposition is generated.</td>
</tr>
</tbody>
</table>

In collaborative modeling, a model proposition is either explicitly agreed with or implicitly not disagreed with [SHP10b]. We identify the following for a model proposition: a rule that directs the selection of a model-proposition, time at which a model-proposition is activated or de-activated, selection-criteria which is a set of evaluation criteria used to select a model-proposition, interaction from which a model-proposition is generated. These elements which are explained in [SHP10b, SHP09d] are given in Table 3.5.

### 3.5 Rules, Interactions and Models: The Relationships

In the preceding sections, we have described the components of the rules and/or goal, interactions and model propositions which can help us study and analyse the communicative process during collaborative modeling. For proper understanding, these were discussed
3.5. Rules, Interactions and Models: The Relationships

as if they were isolated elements. We, however, have already argued that there is an inter-
play between the rules and/or goals, interactions and models. This interplay is not clear
yet and needs to be established. In the following sections, we look at this interplay and
tie-up what has been discussed so far in a conceptual framework which we call a rules-
interactions-models framework. To establish this interplay between the rules and/goals,
interactions and models, one needs to look back at the element descriptions of the these
components in Tables 3.3 – 3.5. It is clear that there are elements with component names
(rule, interaction, model-proposition) defined in one table which appear in another ta-
ble. These are the elements that provide the interplay or the link relationship between the
rules/goals, interactions and models. This means that changes in the interaction-log, result
in changes in the products produced and vice versa. Likewise, rules/goals of modeling
lead to intermediary products and end-products and vice versa. This interplay is shown in
Figure 3.3, and is discussed in [SHP10b].

![RIM framework relationships between rules, interactions and models.](image)

The relationships can be studied along the cyclic paths: $I \rightarrow M \rightarrow I$, $R \rightarrow M \rightarrow R$ and
$R \rightarrow I \rightarrow R$, in Figure 3.3. They are explained in Table 3.6.

<table>
<thead>
<tr>
<th>Path</th>
<th>Interplay</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I \rightarrow M \rightarrow I$</td>
<td>The interactions lead to the generation of models and generated (intermediate) models drive further interaction.</td>
</tr>
<tr>
<td>$R \rightarrow M \rightarrow R$</td>
<td>Some rules/goals of modeling apply to (intermediate) models and these models may lead to the setting of new rules/goals.</td>
</tr>
<tr>
<td>$R \rightarrow I \rightarrow R$</td>
<td>Rules guide and restrict interactions and some interactions may change the rules of play.</td>
</tr>
</tbody>
</table>
3.5.1 The RIM Framework

In this section we tie-up all the concepts discussed thus far into a conceptual model which we refer to as a RIM framework. This framework for analysis is based on previous theoretical work on the act of modeling [PHB06], but pushes for operationalization of the theory in the form of qualitative analysis of (transcripts of) actual modeling sessions. The conceptual model is depicted in Figure 3.4.

Although the concepts about rules, interactions and models are clear, there are two key fundamental things that need clarification before the framework can be effectively and efficiently used to study and analyse the modeling processes. These include: i) time-stamping the interactions, and, ii) analyzing and categorizing the interactions.

**Time-stamping the Interactions**

The interaction-log in the RIM framework is sort of a repository for all the communicative acts that occur during a collaborative modeling session. This repository is constructed by either audio recording or video recording the conversational moves between and among the modelers in a modeling session. Segments of these conversational moves are time-stamped when a replay of the audio or video recording is done. Alternatively, a logged “chat box” conversation can be used, automating the recording of the interaction as well as time-stamping. This, in essence, enables us to extract all the conversations by each participant at any given time, $t$. It should be noted that time-stamping of the rules/goals and model propositions is implicitly done via the interactions since they are contextually identified as rules/goals or model-propositions from the interactions through the process of classification and categorization. This is discussed further in section 6.2.1.
3.5. Rules, Interactions and Models: The Relationships

Analyzing and Categorizing the Interactions

To analyze, classify and categorize the speech acts into macro-interactions, grounded theory (GT) methodology of Glasser and Strauss [GS67] may be used, see also [BC07, Chr07]. It should be noted that in GT the researcher is concerned with: 1) what is happening, and, 2) what the main theme or problem for which the participants are concerned with is and how they are trying to do it. Secondly, GT develops a theory inductively from a large set of data without any preconceptions, discourages literature review to prevent preconceptions, and stable concepts and patterns emerge from the data by constant comparison and eventually the theory that is grounded in data emerges. Although question 1 is somehow related to our research, especially if one tries to open the seal off the black-box of collaborative modeling, question 2 is not as the problem being solved in collaborative modeling will always be clear – self-assigned or given by the experimenter – see Hackman’s [Hac69] task definition. We do not, however, dispute the observation that the theory should be grounded in data, although we believe that the theory can still emerge from the data using other analytical techniques than GT.

Our analysis of the communicative process is, therefore, based on the observation by Winograd and Flores [WF86] that speech-acts are individual statements in the whole conversation and cannot be analyzed outside the whole conversation in which they occur. This means that both macro-conversational and micro-conversational structures within the conversations must be identified. The language-action perspective (LAP) [Gol03] is, therefore, a candidate in analyzing the whole conversation in which the speech-acts (at the micro-level) are just components of macro conversational structures. We, therefore, base our analysis of the communicative process in the RIM framework on LAP to identify the conversational interactions that occur in a collaborative modeling process. We, in essence, apply a discourse analysis technique to analyse and categorize the interactions, see for example [Sse09] and section 6.2.2.

3.5.2 Analyzing Collaborative Modeling with the RIM Framework

In this section we show how the RIM framework can be used at the hand of a few illustrations. The illustrations are based on the modeling session and coding scheme described in [SHP09d] and examples given in [SHP10b]. It should be noted that the elements for each of the components (rules, interactions and models) in the RIM framework described in Tables 3.3 – 3.5 are followed when coding and categorizing the interactions, rules and model propositions. It is not hard to see how the micro speech acts (the dialogues or conversational moves) in the dialogue games give rise to macro interaction categories classified using the Walton and Krabbe typology [WK95]. Analyzing the data from such a well-structured process helps us to pin-point to the types and categories of these rules and goals, the interaction types and it enables us to see how the modeling session unfolds and progresses. It should be noted that the intention of these illustrations is not to discuss the types and topics shown for the rules and interactions but rather to show how the RIM framework can be used to time-stamp, analyse and categorize the speech acts. Details of the types and topics are discussed in Chapters 6 and 8 as well as the coding scheme used in the discourse analysis of the communicative acts or conversational moves.
Example 1. Interaction analysis given in Table 3.7 is based on the following excerpt of conversations that took place during a modeling session.

<table>
<thead>
<tr>
<th>Time</th>
<th>Actor</th>
<th>Speech Act</th>
</tr>
</thead>
<tbody>
<tr>
<td>02:00</td>
<td>M1</td>
<td>So, where does Ordering start?</td>
</tr>
<tr>
<td>02:03</td>
<td>M2</td>
<td>First we have to decide who takes part in it. So we can set that on top of the diagram?</td>
</tr>
<tr>
<td>02:10</td>
<td>M1</td>
<td>There are numbers, so that’s easy, so probably the purchasing officer is involved?</td>
</tr>
<tr>
<td>02:18</td>
<td>M2</td>
<td>Eh ... I guess so.</td>
</tr>
<tr>
<td>02:21</td>
<td>M1</td>
<td>So he needs ordering one second ... “draws 2”.</td>
</tr>
</tbody>
</table>

**Table 3.7: Extracted elements of interaction from the coded meta-data.**

<table>
<thead>
<tr>
<th>Int. #</th>
<th>Int. Name</th>
<th>Top. #</th>
<th>Top. Name</th>
<th>Speech Act Type/Category</th>
<th>Rsp. to</th>
<th>Time</th>
<th>Actor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>INFORMATION SEEKING</td>
<td>1</td>
<td>SET CONTENT</td>
<td>QUESTION</td>
<td></td>
<td>02:00</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[Where does ordering start?]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>DECISION MAKING</td>
<td>2a</td>
<td>SET CONTENT</td>
<td>PROPOSITION</td>
<td></td>
<td>02:03</td>
<td>M2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2b</td>
<td>SET GRAMMAR GOAL</td>
<td>SET GRAMMAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>QUESTION</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[Can we set who takes part in Ordering on top of the diagram?]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>INQUIRY</td>
<td>3a</td>
<td>SET GRAMMAR GOAL</td>
<td>PROPOSITION-QUESTION</td>
<td>2b</td>
<td>02:10</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3b</td>
<td>SET CONTENT</td>
<td>PROPOSITION</td>
<td>2a</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[Purchasing Officer is involved in Ordering]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>NEGOTIATION</td>
<td>4</td>
<td>SET CONTENT</td>
<td>AGREEMENT WITH</td>
<td>3b</td>
<td>02:18</td>
<td>M2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[Eh... I guess so]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>DELIBERATION</td>
<td>5</td>
<td>SET CONTENT</td>
<td>DRAWING</td>
<td></td>
<td>02:21</td>
<td>M1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>[So he needs ordering one second ... “draws 2”, i.e., number 2 (purchasing officer) on top of first swim lane]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**KEY: Int.: Interaction  Top.: Topic  Rsp.: Response.**

Example 2. Rule analysis in Table 3.8 is based on the following excerpt of modeling session conversations.

<table>
<thead>
<tr>
<th>Time</th>
<th>Actor</th>
<th>Speech Act</th>
</tr>
</thead>
<tbody>
<tr>
<td>01:25</td>
<td>M1</td>
<td>Let’s create 5 swim lane diagrams.</td>
</tr>
<tr>
<td>01:30</td>
<td>M2</td>
<td>Yes, isn’t that what I just proposed?</td>
</tr>
<tr>
<td>08:43</td>
<td>M1</td>
<td>Sequences are started with the START symbol ...</td>
</tr>
<tr>
<td>08:45</td>
<td>M2</td>
<td>Yes ...</td>
</tr>
<tr>
<td>08:48</td>
<td>M2</td>
<td>Use blocks to indicate activities.</td>
</tr>
<tr>
<td>15:18</td>
<td>M1</td>
<td>So no decision diamonds in UML activity diagrams?</td>
</tr>
<tr>
<td>15:19</td>
<td>M2</td>
<td>No; well; maybe.</td>
</tr>
</tbody>
</table>
### Table 3.8: Extracted elements of a rule from the coded meta-data.

<table>
<thead>
<tr>
<th>Rule</th>
<th>Int. Name(_A)</th>
<th>Content(_A)</th>
<th>Time(_A)</th>
<th>Int. Name(_D)</th>
<th>Content(_D)</th>
<th>Time(_D)</th>
<th>M.P</th>
</tr>
</thead>
<tbody>
<tr>
<td>VALIDATION</td>
<td>DELIBERATION</td>
<td>All participants should agree on the model. [Proposed and activated in the Assignment.]</td>
<td>All</td>
<td>DELIBERATION</td>
<td>De-activated when all or the majority have agreed on the model, i.e. reached consensus.</td>
<td>End</td>
<td></td>
</tr>
<tr>
<td>GRAMMAR</td>
<td>INFORMATION</td>
<td>Sequences are started with the START symbol ... - [148] CLARIFICATION</td>
<td>08:43</td>
<td>INFORMATION</td>
<td>Yes... [149] AGREEMENT WITH 148</td>
<td>08:45</td>
<td>A.C</td>
</tr>
<tr>
<td>GRAMMAR</td>
<td>NEGOTIATION</td>
<td>Use blocks to indicate activities - [151] PROPOSITION</td>
<td>08:48</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>GRAMMAR</td>
<td>INQUIRY</td>
<td>So no decision diamonds in UML activity diagrams? [248] QUESTION</td>
<td>15:18</td>
<td>INQUIRY</td>
<td>No; well; maybe- [249] ANSWER 248</td>
<td>15:19</td>
<td></td>
</tr>
</tbody>
</table>

**KEY:** Int.: Interaction A.C.: Activation Content M.P.: Model Proposition [A/D]: Activated/De-activated

### Example 3.
Model proposition analysis in Table 3.9 is based on the following excerpt.

<table>
<thead>
<tr>
<th>Time</th>
<th>Actor</th>
<th>Speech Act</th>
</tr>
</thead>
<tbody>
<tr>
<td>14:41</td>
<td>M1</td>
<td><em>If there is no place, he can’t order or there is no availability.</em></td>
</tr>
<tr>
<td>14:45</td>
<td>M2</td>
<td><em>Yeah, true...</em></td>
</tr>
<tr>
<td>14:50</td>
<td>M2</td>
<td><em>You cannot do decision diamonds in UML activity diagrams.</em></td>
</tr>
<tr>
<td>14:57</td>
<td>M2</td>
<td><em>You can only have splits and joins of some sort, not the decisions as such.</em></td>
</tr>
<tr>
<td>16:46</td>
<td>M1</td>
<td><em>We can also say that if the form isn’t filled in well then it is rejected but...</em></td>
</tr>
<tr>
<td>16:55</td>
<td>M2</td>
<td><em>Yeah ...</em></td>
</tr>
<tr>
<td>17:07</td>
<td>M1</td>
<td><em>No-route and terminal point from &quot;accept&quot; in swim lane 7, with &quot;no order&quot; ...</em></td>
</tr>
<tr>
<td>17:14</td>
<td>M2</td>
<td><em>OK..., Yes</em></td>
</tr>
</tbody>
</table>

**Observations - Link to Task Types.** It should be noted that the task types as already argued in section 3.4, are evident from the communicative interactions of the modelers given in Examples 1 – 3. The communicative dialogues or exchanges, including the different propositions, agreements or disagreements, acceptances or rejections that are clearly demonstrated within the examples, point to either planning and generation of ideas among and between the modelers or creative tasks that lead to model proposition statements from which the models are generated. Rules and goals, although not explicitly stated as such, can be discerned, contextually, from the speech acts which are generated within either planning or idea generation (task 1 and 2 within quadrant 1) and during the decision-making and negotiation tasks (tasks 4 and 5 within quadrant 2).
Table 3.9: Extracted elements of a model proposition from the coded meta-data.

<table>
<thead>
<tr>
<th>Model Proposition</th>
<th>Time</th>
<th>Rule Name</th>
<th>Int. Name</th>
<th>Selection Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>If there is no place, he cannot order or there is no availability.</td>
<td>14:41</td>
<td>14:45</td>
<td>CREATION</td>
<td>NEGOTIATION</td>
</tr>
<tr>
<td>Yeah, true...</td>
<td></td>
<td></td>
<td></td>
<td>Explicitly agreed with.</td>
</tr>
<tr>
<td>You cannot do decision diamonds in UML activity diagrams.</td>
<td>14:50</td>
<td>-</td>
<td>GRAMMAR</td>
<td>PERSUASION</td>
</tr>
<tr>
<td>You can only have splits and joins of some sort, not the decisions as such.</td>
<td>14:57</td>
<td>-</td>
<td></td>
<td>Not explicitly disagreed with.</td>
</tr>
<tr>
<td>We can also say that if the form isn’t filled in well then it is rejected but...</td>
<td>16:46</td>
<td>16:55</td>
<td>CREATION</td>
<td>NEGOTIATION</td>
</tr>
<tr>
<td>Yeah...</td>
<td></td>
<td></td>
<td></td>
<td>Explicitly agreed with.</td>
</tr>
<tr>
<td>No-route and terminal point from “accept” in swim lane 7, with “no order” ...</td>
<td>17:07</td>
<td>17:14</td>
<td>GRAMMAR</td>
<td>NEGOTIATION</td>
</tr>
<tr>
<td>OK..., Yes</td>
<td></td>
<td></td>
<td></td>
<td>Explicitly agreed with.</td>
</tr>
</tbody>
</table>

**KEY: Act.: Activated  De-act.: De-activated  Int.: Interaction**

### 3.6 Concluding Remarks

In this chapter we have looked at how viewing collaborative modeling as a game can help us study and analyse the modeling process in view of the rules enacted, goals strived for and the model propositions that come out of the agreements between the models. We have argued for this metaphorical view and shown how system design and development can be viewed as a game design using game design theory. To analyse how the modelers structure the modeling process without the help of a facilitator, we have argued for the need to know the type and nature of collaborative modeling tasks. In this regard, Hackman’s task definition was found to provide the required ingredients for classifying collaborative modeling tasks. The chapter has also looked at number of typologies and we positioned the collaborative modeling task within McGrath’s Group Task Circumplex quadrants and task types with respect to the communicative process. It has been observed that the communicative process in which the modelers are engaged including argumentation, negotiation and decision-making can be mapped to the task types within this Circumplex.

In this chapter, it has been observed that the modeling process is driven by a triage of the following things: the rules, interactions and models. Interactions have been singled out as being at the center of the entire collaborating process. We have identified the elements of the rules, interaction, and model propositions which help in the studying and analysis of the modeling process. The chapter has also established a relationship between the rules, interactions and models and we have shown how we can loop back from each of the above categories. This looping back is what enables us to identify flaws in the modeling process by determining what has gone wrong so that we can eventually correct it. Using a few illustrations we have been able to show how the framework can be used for the analysis of the modeling process. In the next chapter we look at how the quality can be established and measured for the different modeling artifacts used in, and produced during, the modeling process.
4 The COME Framework

No single quality framework will be able to serve all purposes ... multiple quality frameworks will be needed ...

– Daniel L. Moody, 2005

4.1 Overview

This chapter introduces the “Collaborative Modeling Evaluation (COME)” framework that can be used to evaluate the different modeling artifacts used in, and produced during, a collaborative modeling process. A conceptual model on which COME is based is introduced with three steps followed in the evaluation. We show how quality dimensions or factors associated with each modeling artifact are generated, selected and scored (rated, ranked and/or weighted). A Multi-criteria Decision Analysis (MCDA) approach is introduced that can be used to facilitate the decision-making process in which the modelers reconcile their subjectivity, biases, priorities and preferences. One MCDA approach that is used in this regard is the Analytic Hierarchy Process (AHP). We show how collaborative modelers can assign weights to the quality dimensions of the modeling artifacts using AHP and how group decisions, aggregation of individual priorities and judgements can be done with AHP. Within the COME framework, a “Collaborative Modeling Process Quality (CMPQ) construct for assessing the quality of collaborative modeling is developed. This construct integrates concepts from the Theory of Reasoned Action/Planned Behaviour (TRA/TPB), Technology Acceptance Model (TAM) and Method Evaluation Model (MEM) to measure modelers’ Perceived Quality of the Modeling Language (PQML) and Perceived Quality of End-Products – models – (PQEP), Perceived Usefulness of the Modeling Procedure – (PUMP) and Perceived Ease of Use of the Medium (EOUM). This chapter also presents two research instruments that can be used to assess the quality of the different modeling artifacts, modelers’ perceived quality and satisfaction and the psychological and behavioural factors that can impact the overall quality. An example illustrating how the COME frameworks works and how it can be used is also introduced. The chapter concludes with some key remarks about the concepts used in the COME framework. One key observation about the COME framework is its ability to not only help the modelers assign and score the quality dimensions used in the evaluation of the modeling artifacts, but also to help reduce the subjectivity, bias associated with personal preferences and priorities which are inherent within the modelers’ mental models [RAMS94] and their previous experiences, knowledge and skills.

This chapter is an extended version of the following publications: [SHP13, SHP09b].
Chapter 4. The COME Framework

4.2 The COME Framework

In collaborative modeling, a number of factors come into play and need to be analyzed and evaluated if we are to effectively and efficiently measure and assess modeling process quality [SRD03]. First, different stakeholders with different skills, expertise and knowledge are brought together in a problem-solving (modeling) activity. Second, a number of modeling artifacts are used in, and produced during, the modeling process. The quality of the complete process is also influenced by how well the artifacts fit together. All this impacts on the success of the collaborative modeling effort and on the quality of the modeling process – especially its effectiveness and efficiency [SHP10a]. Although the quality of each of these may be established separately, the quality of the entire modeling process is an aggregation of the quality of all these modeling artifacts. The efficiency and effectiveness of any collaborative modeling process has to be measured by analyzing the performance of the participants with respect to their collaboration and interaction: communication, negotiation, consensus, group-decision-making, etc. As discussed in Chapter 3, collaboration is normally goal-oriented and rule-based. The modelers have to work under explicit or implicit rules towards achieving certain goals. Their over-riding concern is to produce a model that represents a specified universe of discourse (UoD). This model or the end-product is often assessed for quality, in isolation, and, independent of other factors that may impact on the overall quality. There is, therefore, a need to look at the modeling process in its entirety and evaluate all artifacts used and produced during the collaborative modeling process.

While the goal remains evaluation of the modeling processes, the evaluation framework presented in this chapter is driven by an insight of trying to incorporate the social dynamics of the modeling group (interactions, goals and rules), in addition to the syntactic, semantic and pragmatic quality measures in the evaluation of the modeling process. We believe considering all the facets of the modeling process and all the artifacts used in, and produced during, the modeling process will help us better understand this process and its evaluation. Although a number of quality frameworks have been developed for analyzing and/or evaluating some of the artifacts that we look at, e.g., conceptual models (including under our broad definition: IS models – software process models, business process models, enterprise models, etc.) [CGP +05, MR07, PN05, Rec05a, RSS01, Sch99, WF05]; modeling methods (including software design processes, modeling procedures and techniques) [Clo07, HR00, GPR +06, GRCP03, GW03, GW04, SR98b, ST05, SW07]; modeling languages [LK06, Rec05b, RRK07, SAJ +02]; support-tools or media [DOLV94, FH01, FH98b, RSPG08, VVV07], to our best knowledge, there are very few methods and frameworks for performing a comprehensive evaluation of the collaborative modeling process itself.

In Chapter 2 a number of quality frameworks were discussed, notably, SEQUAL, QoMo, GoM and the Moody-Shanks framework. The SEQUAL framework [KSJ06], as argued, is a versatile framework that is strongly rooted in existing theory – semiotic theory, and can thus “claim theoretic validity” [Rit10c]. It can be used to evaluate not only the models, but also the modeling language. It can be used to determine the quality with respect to new knowledge acquisition, knowledge transfer, learning and level of agreement. It does not, however, bring out firmly and explicitly the quality of the modeling procedure and support-tool, which have an impact on the overall quality of the
4.2. The COME Framework

modeling process. Moreover, it does not state how the dimensions can be measured despite giving a number of dimensions [Rit10c]. The QoMo framework [BHP07], which extends the SEQUAL framework by incorporating the rules and goals of modeling as a way of describing the processes for modeling, the modeling activities, knowledge of the modelers, domain modeled, modeling languages and agreement between the modelers in the evaluation framework, still lacks an empirical study and empirical evaluation. The COME framework, presented here, is part of the effort to empirically apply and validate some of the concepts in QoMo, see also [SHP10b, SHP09d]. GoM, a generic approach, [Ros98, RSS01, SR98a] lacks a sound theoretical methodology and provides limited empirical proof [Rec06]. The Moody-Shanks quality framework concentrates mainly on one modeling artifact – the model. The work by Rittgen [Rit07] made some initial attempt to study and analyze the modeling process and developed the collaborative modeling architecture (COMA) tool [Rit08a] to facilitate collaboration and some limited evaluation (of the models).

![The conceptual model of the COME framework](Image)

**Figure 4.1:** The conceptual model of the COME framework [SHP13].

The COME evaluation framework follows and extends the approach suggested by Pfeiffer and Niehaves [PN05] to evaluate the different artifacts used in, and produced during, the modeling process. Their approach follows a design science approach [HMPR04] to identifying the different IS research artifacts and evaluating them. Because their framework employs the philosophical notions of structuralism, it still focuses mainly on the inner structure of the models and the evaluation of their quality. Although our approach extends their framework by evaluating a wider range of modeling artifacts involved in the modeling process, it fundamentally differs from theirs in the way it scores the quality dimensions of the artifacts and the method used to evaluate the artifacts. In our case, we
apply principles and concepts from the “Analytic Hierarchy Process (AHP)” [Saa80] to measure and evaluate the modeling process artifacts. AHP is, essentially, a method for making complex decisions on the basis of subjective opinions by multiple stakeholders. In our case, the process renders the score for an individual modeling session which can then be compared with a similarly calculated score for another session. Given that variables between the sessions are sufficiently controlled, this enables well-founded judgement about which method works best. The advantages of our evaluation framework and the AHP approach lie in advanced management of subjectivity, aggregation of individual priorities, and preferences of the stakeholders about the quality of the modeling artifacts into group priorities and preferences. Also, the AHP helps the stakeholders reach consensus about their preferences and priorities. The conceptual model of the collaborative evaluation framework, which is adapted from [SHP13], see also [Sse09], is shown in Figure 4.1. Within this model we have three main steps:

1) selecting the modeling artifact(s) to evaluate.
2) choosing the evaluation method to apply in the evaluation of the modeling artifact(s).
3) choosing an evaluation and validation approach to evaluate and validate the evaluation methods and modeling artifacts.

Selecting the Modeling Artifact(s). This step involves determining and selecting the modeling artifact whose quality is to be measured and/or assessed during a collaborative modeling session. The four artifacts, which are briefly described in the subsequent sections, include the following: 1) modeling language (ML) which refers to the meta-language that provides concepts (constructs) in which modelers define the problem and the solution; 2) modeling procedure (MP) which details the processes, techniques, strategies or approaches (methods) of how the problem is defined and how the solution is reached; 3) end-products (EP) which are the final outcomes (models) of the communicative process that typically use the modeling language concepts and a modeling procedure to represent real world entities in the problem domain and solution domain; 4) support-tool (ST) – (medium) which refers to either an electronic or non-electronic group support system that aids the communicative process, generation of the outcomes and/or evaluation of the outcomes. It should be noted that these modeling artifacts and their quality dimensions may be generated from the existing literature, e.g. from SEQUAL, GoM, Moody-Shanks frameworks, etc. The forward direction (right arrow) of the double-headed arrow between step 1 and step 2 means “determine the quality dimensions in step 2 of the identified modeling artifacts in step 1”. Likewise, the backward arrow (left arrow) of the same double-headed arrow means “apply the identified quality dimensions in step 2 to evaluate the modeling artifacts in step 1”.

Choosing the Evaluation Method. In step 2 we choose the method to evaluate the modeling artifacts. Within this step three activities take place. These activities are indicated by the following sub-steps: (1) generating quality dimensions (criteria, factors) which are the characteristics or features of the modeling artifacts upon which quality assessment will be done. These may come, and/or are generated, from those existing in the literature (e.g.
from SEQUAL, GoM, Moody-Shanks frameworks, etc.), (2) assessing and selecting the dimensions to use (may involve narrowing the scope and grouping the dimensions), and, (3) rating, weighting and/or ranking the dimensions using an evaluation method. Table 4.1 shows how the dimensions are generated from a literature survey. Due to Miller’s [Mil56] observation about our cognitive limitations for information processing which is limited to that magical number seven plus or minus two, see also [SO03], the generated dimensions are grouped into cognitively manageable categories for the evaluation instrument. It should be noted that from this point onwards, the grouped dimensions will be used for all our evaluations and they are reported in, and adapted from [SHP09b, SHP10a].

Table 4.1: Generation and selection of modeling artifact dimensions (a) and (b).

(a) ML and MP generated dimensions and groupings.

<table>
<thead>
<tr>
<th>Artifact</th>
<th>Quality Dimensions</th>
<th>Source</th>
<th>Quality Dimensions Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling Language (ML)</td>
<td>construct deficit, construct overload, construct redundancy, construct excess; expressive power, directness, systematics; syntax, semantic &amp; pragmatic clarity; modeling primitive adequacy</td>
<td>LK06, LSS94, Kro01a, KSJ06, NK05, SAU+02, SP07, WW93</td>
<td>Understandability, Clarity, Syntax correctness, Conceptual minimalism</td>
</tr>
<tr>
<td>Modeling Procedure (MP)</td>
<td>efficiency; effectiveness; ease of application, in-out-description adequacy, process &amp; relation description adequacy, method compatibility, interaction &amp; collaboration adequacy, communication &amp; negotiation adequacy; rule &amp; goal commitment, shared understanding</td>
<td>BRU00, BT84, DKBV09, GW03, HDKC06, KSJ06, MSK02, Rec06, Rei03, RKV08, SP07, SR97b, SW07</td>
<td>Efficiency, Effectiveness, Satisfaction, Commitment &amp; Shared Understanding</td>
</tr>
</tbody>
</table>

(b) EP and ST generated dimensions and groupings.

<table>
<thead>
<tr>
<th>Artifact</th>
<th>Quality Dimensions</th>
<th>Source</th>
<th>Quality Dimensions Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>End-Product (EP)</td>
<td>correctness, completeness, propriety, clarity, consistency, orthogonality, generality, syntax adherence adequacy, semantics adequacy, pragmatics adequacy; user-comprehensibility; Modifiability, re-usability, flexibility; user satisfaction.</td>
<td>KSJ06, LSS94, PN05, PSR04, Re03, R5S01, SP07, SR98a, SR03</td>
<td>Product Quality, Understandability, Modifiability &amp; Maintainability, Satisfaction</td>
</tr>
<tr>
<td>Support Tool – Medium (ST)</td>
<td>functionality, performance &amp; reliability; efficiency, effectiveness; satisfaction; synchronicity, negotiation/argumentation adequacy, commenting/proposition adequacy, planning/ agenda setting adequacy, immediacy feedback, concurrency (multiple addressability, parallelism), multiple cues, degree of personalization, language variety, personal focus, ease-of-use, interactivity, symbol variety, persistence, rehersability (edit-ability, reprocess-ability)</td>
<td>ALW+97, DLB8, DL84, DLT87, DOLV94, DV99, DV5M98, ESM98, FH98b, Goo87, Gru88, HN96, JV93, Koe98, KSJ06, LLL80, MSK02, RB96, Ric92, Ric87, SP07, Spr91, Swa87</td>
<td>Functionality, Usability, Satisfaction &amp; Enjoyment, Collaboration &amp; Communication Facilitation</td>
</tr>
</tbody>
</table>

A multi-criteria decision analysis (MCDA) method, see section 2.3.3, can be used for sub-step (2) and sub-step (3) as well as determining a measurable and quantifiable quality of the dimensions. This is explained in the AHP approach described later in this chapter. Our choice for the AHP is prompted by its ability to reduce the subjectivity or bias associated with the individual judgments when computing and aggregating the individual and group priorities. Sub-steps 2 and 3, as indicated by the internal (uni-directional) arrows in step 2, involve either a re-assessment or a re-generation of the quality dimensions. The
rated, weighted and/or ranked dimensions are used to evaluate the modeling artifact(s) as shown by the double-headed arrow between steps 1 and 2. The forward direction (right arrow) of the double-headed arrow between step 2 and step 3 means “apply the evaluation method in step 2 in the evaluation and validation approach in step 3”. Likewise, the backward arrow (left arrow) of the same double-headed arrow means “validate using step 3, the evaluation method in step 2”.

**Selecting Evaluation and Validation Approach.** This step involves selecting an evaluation and validation approach for the evaluation method and the modeling artifacts. This means that the evaluation method in step 2 is also evaluated to determine its appropriateness for evaluating the dimensions and the modeling artifacts and it is then validated with an appropriate approach. The work of Siau and Rossi [SR98b] is an excellent survey of the literature about evaluation approaches for modeling methods. These approaches, although given for the evaluation of IS methods, can easily be tailored to the evaluation of the evaluation method used, and we are concerned here with the application of only empirical approaches, as opposed to non-empirical approaches, see Siau [SW07] for the categorization of these approaches. Since we are looking at the evaluation process within the whole communicative process, we follow the discursive, participant/IT-based approach. In this approach, different persons with their subjective experiences are brought together with a goal of engaging in a dialogue to reach a “more objective view and valuation of some facts” [WF05, p.11]. Questionnaires or statistical analysis techniques can be applied. In the current chapter, we explore in detail concepts involved in steps 1 and 2 while step 3 will be looked at in Chapters 6 and 7 where the discursive, participant/IT-based evaluation and validation approach is applied. It should be noted that the evaluation of the modeling artifacts through the quality dimensions and the validation of the evaluation method using any selected evaluation and validation approach is cyclic. This is indicated by the outer arrows around the three boxes of the three steps.

**4.3 The Modeling Artifacts**

This section looks at the four modeling artifacts whose quality can help us determine the overall quality of a collaborative modeling process. While a number of frameworks have been proposed for evaluating and measuring model quality, there are no universally agreed on standards and some of the frameworks are not readily applicable and acceptable in practice [Moo05]. This has, therefore, led to ad-hoc evaluation of conceptual models using subjective opinions, beliefs, experience and common sense. Due to this state of affairs, Moody et al. [Moo05] proposed a methodology that can be used to structure and develop model quality frameworks and how such frameworks can be validated so as to receive wide acceptance in practice. Product quality and process quality which were first distinguished in [MSD98] are explained below.

- **Product Quality.** In the context of conceptual modeling, product quality refers to the quality of the produced models, i.e, the end-products or outcomes. The focus is on identifying defects on the characteristics of the models with the goal of correcting them.

- **Process Quality.** Process quality is concerned with the quality of the procedure or method (strategy or technique) that leads to the generation of the models. Unlike product
4.3. The Modeling Artifacts

quality, process quality aims at defect prevention rather than defect correction.

Therefore, in addition to product quality, modelers should be satisfied with both the process that generates the products and the outcome [Rei03]. They should be satisfied with the syntactic, semantic, pragmatic, empirical and physical quality of both the modeling language and the model. Despite this distinction between product quality and process quality, there has been no substantial research on process quality. As noted in Chapter 2, most of the approaches and/or frameworks have mainly concentrated on model quality evaluation, apart from the QoMo framework which made initial attempts to look at process quality. QoMo, unfortunately, has not yet been empirically tested as a viable evaluation framework for the modeling process.

4.3.1 Modeling Language

Many conceptual models, which are abstract representations of real world domains, are a collection of linked graphic symbols of an underlying modeling language. A set of constructs and rules referred to as the *modeling grammar* is given in [WW93] as a basis for studying, understanding and analyzing modeling languages. The notion of constructs is based on Bunge’s ontology and forms the theoretical backbone of Information Systems (IS) constructs [WW90]. To help in the evaluation of modeling languages, Gemino and Wand [GW04] distinguish between a set of specific model statements (*scripts*) from constructs and rules (*grammar*) which are used to produce the models. This distinction helps us to determine whether the comparison and evaluation should be with respect to the scripts (model propositions) – in this case tying it to a single-modeled domain – or with respect to the grammars and therefore compare the ability of the grammar to model any domain. The generic nature of the grammar is what should be advocated for and the evaluation should be with respect to the grammar. Modelers should evaluate the modeling language’s understandability, clarity, syntax correctness with respect to its grammar.

In [LK06], for example, an evaluation of seven well-established conceptual Business Process Modeling Languages (BPMLs) is given. These are: Activity Diagram (AD), Business Process Definition Model (BPDM), Business Process Modeling Notation (BPMN), Event-driven Process Chains (EPC), Integrated Definition 3 (IDEF 3), Petri Nets and Role Activity Diagram (RAD). To evaluate and compare these BPMLs, an evaluation framework based on Curtis et al.’s framework [CKO92] is developed. By analyzing these BPMLs along the behavioral, functional, informational and organizational perspectives, a basis for evaluation and comparison is established. The developed framework uses the concept of a *meta-model* to develop the evaluation mechanism. The importance of a meta-model is emphasized in [PN05]. It removes the subjectivity of the person involved in the evaluation. In addition, it removes the ambiguity of the syntax and semantics of the constructs. The same concept of using a meta-model to compare modeling languages is explored in [SAJ+02] using representatives of activity-oriented, state-oriented and communication-oriented modeling languages: EPC, UML State Diagram and Business Modeling Language (BML). The framework uses theoretical concepts of the modeling languages rooted in the grammars to evaluate and compare them. The comparison concepts are: concept definitions, concepts relationships and correspondences of the concepts between the languages.

It is, however, noted in [LK06] that the comparison normally shifts from the meta-
model to notational elements and concepts – since majority of the BPMLs lack meta-models. This raises a question whether the meta-model is adequate in determining the quality of any modeling language. To evaluate the model for quality, one needs to first look at the adequacy (expressive power, completeness, correctness, etc.,) of the modeling language. Additionally, the evaluation of the adequacy of the modeling language should also take the perspective of the participant. She should be able to understand the concepts in the language, the concepts should be easy to learn and remember, the language should have a set of signs and symbols for producing the model and it should have well-defined rules for combining signs and symbols. We follow the generic quality framework in [NK05] to assess the quality of the modeling language. In view of this, we define the modeling language quality construct, PQML, as given below. Quality dimensions for the PQML construct are defined in Table 4.2.

The Perceived Quality of the Modeling Language (PQML) is the user’s affective attitude towards a modeling language in providing a meta language that provides concepts in which modelers define the problem, express and communicate the solution.

Table 4.2: PQML construct quality dimensions.

<table>
<thead>
<tr>
<th>Quality Criterion</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understandability</td>
<td>Understandability refers to how adequate the model represents concepts you recognize in view of your or someone else’s domain knowledge.</td>
</tr>
<tr>
<td>Clarity</td>
<td>Clarity of the modeling language refers to how easily you learn and remember the concepts and notations of the modeling language through the signs, symbols, and textual expressions of the modeling language.</td>
</tr>
<tr>
<td>Syntax correctness</td>
<td>Syntax correctness refers to correct use of the modeling language's syntax as specified in the underlying meta-model. It is checking whether the model is consistent and complete against a meta-model it is based on.</td>
</tr>
<tr>
<td>Conceptual minimalism</td>
<td>Conceptual minimalism refers to the existence of primitive (basic) signs and symbols for representing data concepts of the domain as separate objects and assembling the objects to form composite abstractions. Conceptual minimalism relates to the simplicity of the modeling language.</td>
</tr>
</tbody>
</table>

4.3.2 Modeling Procedure

Any performed task is driven by set-goals [LL90]. A goal is a result that a stakeholder strives to achieve and its awareness is accompanied by a set of perceived goal attainments [BVR03]. This means that stakeholders in any collaborative modeling effort strive to achieve some set goals. To achieve these goals, there may be a well-defined procedure in which they formulate and define the problem and agree on how the solution will be reached. To evaluate and measure the quality of the modeling procedure, one needs to assess whether the group goal is achieved. The most prominent measure for this is effectiveness. In [DKBV09], this is viewed as “... the extent to which a result contributes to the establishment of a goal set for the collaboration process” (p. 3).

Other quality constructs include, e.g. the amount of time to reach the solution and to attain the goals and objectives, time to negotiate, etc. Stakeholders should also be satisfied with the negotiation, the decision and decision-making process [PSR04], the communication process and the goals and objectives set and how they are achieved through the
modeling procedure. Stakeholders’ commitment to supporting the goals and objectives, the collective decisions and their contribution to shared understanding is another measure of the success of a collaborative effort. In view of this discussion, we define the modeling procedure quality construct, PUMP, and its quality dimensions are defined in Table 4.3.

Perceived Usefulness of the Modeling Procedure (PUMP) is the user’s affective attitude towards the usefulness of the procedure used to detail the processes of how the problem is defined and how the solution is reached.

Table 4.3: PUMP construct quality dimensions.

<table>
<thead>
<tr>
<th>Quality Criterion</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Efficiency</td>
<td>Efficiency of the modeling procedure refers to the resources, e.g., time, required for reaching the solution and attaining the modeling goals and objectives; the time needed to negotiate, reach agreement and consensus.</td>
</tr>
<tr>
<td>Effectiveness</td>
<td>Modeling procedure effectiveness refers to how the modeling procedure enables the modelers in using communication and negotiation to get the expected outcome and thus attain their set goals. It also includes the facilitation and the way the modeling process is carried out and/or conducted, and the decision-making process.</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>Satisfaction of the modeling procedure refers to the modelers’ positive feeling about the achievement of the intended result using the modeling procedure. Intended results may include intermediary or end-results. Satisfaction can concern the way modelers communicated, negotiated, reached agreement and how they made modeling decisions.</td>
</tr>
<tr>
<td>Commitment &amp; Shared Understanding</td>
<td>Commitment and shared understanding refer to the modeler’s stake and promise to support the goals and objectives of the modeling process, the responsibility to abide by the modeling rules and group decisions and his/her readiness to contribute to the group’s shared understanding.</td>
</tr>
</tbody>
</table>

4.3.3 End-Products

The end-products are the results or outcomes of a collaborative modeling process. The modeling language is used to generate the products, end-products are the models formed. Quality constructs for measuring and assessing the quality of the modeling process outcomes include product quality which may include the complexity, abstractness, clarity, correctness, completeness, consistency and understandability of the products, see for example [DOV00]. In case of models, they should be modifiable and maintainable, i.e. they should allow to be easily changed and re-used. We use the general framework defined in [Kro01a, KSJ06] for the assessment of quality of models. The definition of the end-products quality construct, PQEP, in the context of this research is given next. Its quality dimensions are defined in Table 4.4.

The Perceived Quality of the End-Products (PQEP) (models) is the user’s affective attitude towards the outcome (including intermediary and final models) of a modeling process.

4.3.4 Support-tool: The Medium

The support-tool or the medium is the means that supports and facilitates the collaborative modeling process. This can range from a simple white-board [RKV09] to a Group Support System (GSS) [DOLV94]. To evaluate such a support-tool, a number of qual-
### Table 4.4: PQEP construct quality dimensions.

<table>
<thead>
<tr>
<th>Quality Criterion</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Quality</td>
<td>Product quality refers to the accuracy of the model in depicting all the identified aspects, adequate representation of the domain concepts in the products, abstractedness, clarity and correctness.</td>
</tr>
<tr>
<td>Understandability</td>
<td>Understandability of the products refers to the degree to which the modelers comprehend the language concepts represented in the products, e.g., its syntax, semantics, etc., the relationship between the different concepts which are depicted by the products, and the ease with which the modelers can explain the concepts in the products even to those who never participated in the modeling process.</td>
</tr>
<tr>
<td>Modifiability and Maintainability</td>
<td>Modifiability and maintainability of the products refer to ease of changing the products to accommodate new changes and the degree to which the products can be kept up-to-date, and how easily they can be re-used in the re-engineering and re-structuring of the enterprise processes.</td>
</tr>
<tr>
<td>Satisfaction</td>
<td>Product satisfaction of the modelers refers to a positive feeling about the product’s quality. This could include satisfaction with respect to the product’s correctness, completeness, accuracy, consistency, clarity, understandability and/or its complexity.</td>
</tr>
</tbody>
</table>

Modeling Products

The Perceived Ease of Use of the Medium (EOUM) (or Ease of Use of the Support-Tool (EOUST)) is the user’s affective attitude towards a technology-based Group Support System (GSS) that supports the collaborative modeling process.

### Table 4.5: EOUM construct quality dimensions.

<table>
<thead>
<tr>
<th>Quality Criterion</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Functionality</td>
<td>Tool functionality refers to the different functions that a tool has which support activities of the modeling process. It also refers to how the support tool executes the modeling activities and how reliable it is in executing those activities.</td>
</tr>
<tr>
<td>Usability</td>
<td>Usability of a tool support refers to its effectiveness and efficiency to achieve specified goals in particular environments. It is a set of attributes which bear on the effort needed for use and on the individual assessment of such use by a stated or implied set of users. Where efficiency relates to the level of effectiveness achieved to the expenditure of resources whereas effectiveness refers to the goals or sub-goals of using the support tool to the accuracy and completeness with which these goals can be achieved.</td>
</tr>
<tr>
<td>Satisfaction &amp; Enjoyment</td>
<td>Satisfaction refers to perceived usability of the support tool by its users and the acceptability of the support tool to the people who use it and to other people affected by its use. It also refers to the degree of fun and enjoyment by the modelers in using the tool. Measures of satisfaction may relate to specific aspects of the system or may be measures of satisfaction with the overall support system.</td>
</tr>
<tr>
<td>Collaboration &amp; Communication Facilitation</td>
<td>Collaboration and communication facilitation refers to the degree to which the support system helps modelers to collaboratively achieve the set goals and objectives. It also refers to the ability of the support system to aid the communication process and decision making process to reach agreement and consensus.</td>
</tr>
</tbody>
</table>


4.4 The Analytic Hierarchy Process

This section looks at an MCDA method that we use in sub-steps (2) and (3) of step 2 in Figure 4.1 – selecting the evaluation method – of the COME framework. It is used to assign quality scores to the modeling artifacts, to rank and weigh the artifacts and finally evaluate the artifacts and determine which of them meet the modelers’ quality goals. This evaluation method can be used during the group decision-making and/or negotiation process to reconcile the modelers’ subjective opinions, views, priorities and judgements [SHP09b]. The MCDA that we select is the “Analytic Hierarchy Process (AHP)” developed by Saaty [Saa80]. AHP is a complex multi-criteria approach for aiding decision-making. It is a flexible tool for dealing with both qualitative and quantitative multi-criteria decision problems [Saa08b]. It integrates different evaluative measures into an overall score for ranking, evaluating and selecting alternatives. The main feature of AHP is that it is based on pairwise comparisons and has a rich mathematical foundation. It should be pointed out from the outset that the alternatives, in this research, could refer to quality dimensions when selection is to be performed, modeling artifacts when the evaluation and selection is to be done with respect to the quality dimensions, or collaborative modeling approaches when more than one modeling approach is used during a modeling session. Evaluation and selection in this case is with respect to the modeling artifacts and the best modeling approach is selected after the synthesizing step, see section 4.4.3.

![Figure 4.2: The analytic hierarchy process (AHP) steps, adapted from [NC05].](image)

In [Ho08, VK06] a literature review of a number of applications of AHP is given. The applications include: Social, Personal, Manufacturing, Education, Management, Government, Industry, Business, Logistics, Health-care, Environment, Marketing, Agriculture, Military, etc. Specific types of problems where AHP is applied include, though are not limited to: evaluation, selection, location/allocation, assignment, etc. In addition, AHP can be integrated with other tools such as Linear Programming (with it variants: Mixed...
& Integer Programming, etc.), Quality Function Development (QFD), Goal Programming (GP), Genetic Analysis (GA), Development Envelopment Analysis (DEA), Analytic Network Process (ANP), Analytic Neural Networks (ANN), and in Strengths, Weaknesses, Opportunities and Threats (SWOT) analysis. The Analytic Hierarchy Process consists of mainly three main steps: structural decomposition, comparative judgement, and synthesizing. Each step is broken into a number of sub-steps which are summarized in Figure 4.2, see for example [Ho08, LACC08, NC05].

4.4.1 Structural Decomposition
The decomposition step has, basically, two sub-steps as explained below.

**Problem Identification.** This step involves identifying the unstructured problem to solve. It could be an evaluation, selection, or a location/allocation problem. Problem identification means also identifying the characteristics or features of the problem which can be used in decision-making. These could be the criteria, sub-criteria, attributes and/or alternatives. By weighting the different quality attributes, sub-criteria and criteria for each artifact with respect to the overall goal, modelers are able to assign and determine their priorities and preferences.

**Hierarchy Construction.** This step involves decomposing the problem into a hierarchical structure with distinctive levels. The structure can be obtained using “decision-tree like diagrams”. As noted in [Saa90], a hierarchy is not the same as a traditional decision tree, and it need not be complete for one element to function as criterion or attribute for all those on the lower level. The topmost level, in the hierarchy, is the goal level followed by the criteria level, which is also followed by the sub-criteria, sub-sub-criteria and attributes levels (if any) down to the lowest level which consists of alternatives. Figure 4.3 is an example of a template of a hierarchical structure that can be used to decompose a problem into a goal, criteria, sub-criteria up to alternatives, each on a different level of the hierarchy.

**Figure 4.3:** An example of an AHP hierarchical structure.
4.4.2 Comparative Judgement

The comparative judgement step has three sub-steps: pairwise comparison, relative weight estimation and consistency check.

**Pairwise Comparison.** The comparative judgement step, where judgement is an expression of an opinion [Saa08a], is aimed at establishing (local) priorities at each level and requires comparing, pairwise, each criterion, sub-criterion, etc., in the low hierarchy levels to determine the priority of each. Comparison, which is an expression of intensity about the dominance (strength or intensity) of one element over the other helps to determine the priority of preference of one element over the other. To achieve this, we compose comparative matrices at each level. As an illustration, in Figure 4.3, to carry out a comparison of criteria $C_{2,1}$ and $C_{2,2}$ with respect to the goal $G_1$, we compute an $n \times n$ matrix for level 2 where $n = 2$ in this case. Similarly, to obtain a comparative judgement for sub-criteria $SUB_{3,1}$ and $SUB_{3,2}$ on level 3 with respect to criterion $C_{2,1}$ on level 2, we compute $n \times n$ matrices for each where $n = 2$ again. This is repeated for sub-criteria $SUB_{3,3}$ and $SUB_{3,4}$ with respect to $C_{2,2}$ et cetera, up to the lowest level of the criteria, sub-criteria or attributes. Therefore, if we have $n$ evaluation criteria (sub-criteria or attributes) we will have to carry out a total of $n(n - 1)/2$ pairwise comparisons. It should be noted that Figure 4.3 is simply a form or template that can be filled with a concrete goal, criteria, sub-criteria and alternatives as shown in Figure 4.5, section 4.7.

• **Comparison Scale**

In the comparison step, each of the elements is assigned and ranked using a nine (1 – 9) point scale, see the fundamental scale – Appendix C, Table 1, in a questionnaire-like instrument (see Figure 4.4) in order to determine their relative importance to each other. A fully developed and validated AHP instrument is given in Appendix A. Note that we use the term element generically to refer to either a criterion, sub-criterion or an alternative.

<table>
<thead>
<tr>
<th>Element</th>
<th>Element A’s Scale</th>
<th>Element B’s Scale</th>
<th>Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>A_1</td>
<td>o o o o o o o o o</td>
<td>o o o o o o o o o</td>
<td>B_1</td>
</tr>
<tr>
<td>A_2</td>
<td>o o o o o o o o o</td>
<td>o o o o o o o o o</td>
<td>B_2</td>
</tr>
<tr>
<td></td>
<td>. . . . . . . . .</td>
<td>. . . . . . . . .</td>
<td>. .</td>
</tr>
<tr>
<td>A_n</td>
<td>o o o o o o o o o</td>
<td>o o o o o o o o o</td>
<td>B_n</td>
</tr>
</tbody>
</table>

*Figure 4.4: An example of an AHP evaluation instrument.*

Note also that the scores given by the modelers using the fundamental scale on an evaluation instrument such as that shown in Figure 4.4 are the real weights given to the different
elements (criteria, sub-criteria, attributes and alternatives). These scores are still shrouded in subjectivity and bias. We describe next the ideal case that, if attained, reduces or eliminates the subjectivity and bias.

- **Forming a Pairwise Comparison Matrix**

  The outcome of the comparative judgement step is a pairwise comparison matrix the entries of which are the comparison values between the \(i^{th}\) row and the \(j^{th}\) column indicating the relative importance of one criterion over another. This comparison value gives the importance of the row’s criterion relative to the column’s criterion.

  **The Real Case.** The real case when forming a comparison matrix, represents a situation where the actual (quantitative) judgements or evaluations of the judges (modelers) are captured from the pairwise comparisons using the fundamental scale and an evaluation instrument such as that shown in Figure 4.4. Let \(A_1, A_2, \ldots, A_n\) be the elements (criteria, sub-criteria, etc.) to be pairwise compared to determine the relative dominance of one element over the other. Also, let \(A = (a_{ij}), i, j \in \{1, \ldots, n\}\) be an \(n \times n\) comparative (judgement) matrix and let \(a_{ij}\) be its entries. Saaty [SO03] observes that the entries \(a_{ij}\) are defined by the following rules:

- **Rule 1.** If \(a_{ij} = a\), then \(a_{ji} = 1/a, a \neq 0\)
- **Rule 2.** If \(A_i\) is judged to be of equal relative intensity to \(A_j\), then \(a_{ij} = 1, a_{ji} = 1\); and in particular \(a_{ii} = 1\) for all \(i\).

  Matrix \(A\) then has the following form:

  \[
  A = \begin{bmatrix}
  A_1 & A_2 & \ldots & A_n \\
  A_1 & 1 & a_{12} & \ldots & a_{1n} \\
  A_2 & 1/a_{12} & 1 & \ldots & a_{2n} \\
  \ddots & \ddots & \ddots & \ddots & \ddots \\
  A_n & 1/a_{1n} & 1/a_{2n} & \ldots & 1
  \end{bmatrix}
  \]

  After recording the quantified judgements of the pairwise compared elements as entries in the matrix \(A\), the remaining problem is to assign to the elements \(A_1, A_2, \ldots, A_n\) a set of numerical weights \(w_1, w_2, \ldots, w_n\) that “would reflect the recorded judgments” [Saa90, SO03]. This problem necessitates transforming the originally and vaguely formulated problem to a precise mathematical problem working under the assumption of an ideal (exact) case and progressively moving away from the ideal case to a general problem where the stringent conditions of the ideal case are somewhat relaxed. The dilemma faced, however, is determining how the weights \(w_i, i \in \{1, \ldots, n\}\) should be related to the entries \(a_{ij}\) of matrix \(A\) while at the same time allowing the weights to reflect the judges’ quantified judgements [SO03]. We describe next this relationship between the entries \(a_{ij}\) and the weights \(w_i, i, j \in \{1, \ldots, n\}\).

  **Ideal (Exact) Case.** The ideal case arises when the judgements by the judges (modelers) are a result of a precise (physical) measurement or evaluation. Before giving the relationship between the the entries \(a_{ij}\) and the weights \(w_i, i, j \in \{1, \ldots, n\}\), we quote an elegant example that Saaty uses to establish this relationship in an ideal case.
Say the judge or judges are given stones $A_1, A_2, \ldots, A_n$, and a precision scale. To compare $A_1$ with $A_2$, they put $A_1$ on a scale and read off its weight – say, $w_1 = 305$ grams. They weigh $A_2$ and find $w_2 = 244$ grams. They divide $w_1$ by $w_2$, and get 1.25. They pronounce their judgement, “$A_1$ is 1.25 times as heavy as $A_2$ and record it as $a_{12} = 1.25$” [SO03, p.236].

It is not hard to see how this example straightforwardly, establishes the relationship between the weights $w_i$, and the matrix entries $a_{ij}$, $i, j \in \{1, \ldots, n\}$. This relationship, in the ideal case, is formally stated thus:

$$a_{ij} = w_i / w_j, \quad \text{or} \quad w_i = a_{ij} w_j \quad 1 \leq i, j \leq n . \quad (4.1)$$

Hence matrix $A$ becomes:

$$A = \begin{bmatrix}
A_1 & A_2 & \ldots & A_n \\
A_1 & 1 & w_1 / w_2 & \ldots & w_1 / w_n \\
A_2 & w_2 / w_1 & 1 & \ldots & w_2 / w_n \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
A_n & w_n / w_1 & w_n / w_2 & \ldots & 1
\end{bmatrix}$$

It is noted in [SO03] that having such stringent relations as given in Equation 4.1 is unrealistic for a general case. This is due to the insolvability of the problem, when the matrix entries $a_{ij}$ are given, for determining the (priority) vector $w$, whose entries are the weights $w_1, w_2, \ldots, w_n$. The purpose of the pairwise comparison is to construct the pairwise (judgement) $A$ which is eventually used to determine the (priority) vector, $w$, with weights $w_1, w_2, \ldots, w_n$ which represent the expert’s relative opinion/judgement for the criteria, sub-criteria or attributes, i.e.,

$$w = (w_1, w_2, \ldots, w_n)^T \quad (4.2)$$

where $w_i > 0$, $\sum_{i=1}^n w_i = 1$. We show later in this section some methods for determining the (priority) vector, $w$. Before looking at these methods, we look at some definitions concerning matrix $A$ from the concepts discussed thus far.

The matrix $A = (a_{ij})$, where $a_{ij} = w_i / w_j$, for $i, j \in \{1, \ldots, n\}$, has all its entries positive and is called a reciprocal matrix since it satisfies the property [Saa90]:

$$a_{ji} = 1 / a_{ij} . \quad (4.3)$$

Matrix $A$ is said to be consistent if the following condition holds:

$$a_{jk} = a_{ik} / a_{ij}, \quad i, j, k \in \{1, \ldots, n\} . \quad (4.4)$$

The judgements given by the modelers are put in a comparative (judgement) matrix, using Equation 4.1, and the reciprocal condition in Equation 4.3. The criteria, sub-criteria, etc.,
are put along and on top of the matrix.

**Relative Weights Estimation: Eigenvector Method.** There are a number of methods for computing the (priority) vector of the relative weights and aggregating the individual and group judgements or priorities. The most popular aggregation methods are Aggregation of Individual Judgements (AIJ) and Aggregation of Individual Priorities (AIP) [EM07], see sections 4.5.1 and 4.5.2 for further elaboration. For prioritization, the right Eigenvector Method (EGVM) and the Row Geometric Mean Method (RGMM) are the most popular. We prefer to use the EGVM to show how the relative weights are computed because of its simplicity and transparency. The RGMM is explained in section 4.5. Within the EGVM, for a realistic (general) case, the weights, rather than being obtained from Equation 4.1, are obtained from [SO03]:

\[
    w_i = \frac{1}{n} \sum_{j=1}^{n} a_{ij} w_j \quad \text{or} \quad nw_i = \sum_{j=1}^{n} a_{ij} w_j, \quad i \in \{1, \ldots, n\}. \quad (4.5)
\]

That is, \( w_i \) is equal to the average of \((a_{i1} w_1, a_{i2} w_2, \ldots, a_{in} w_n)\). The relative weights of all the attributes are thus computed from the eigenvalue problem of the form:

\[
    A w = \lambda w \quad \text{or} \quad (A - \lambda I) w = 0. \quad (4.6)
\]

which is a system of homogeneous linear equations and \( I \) is the identity or unit matrix. This system has a non-trivial solution if and only if the determinant of \( A \) vanishes, i.e.,

\[
    \det(\lambda I - A) = |\lambda I - A| = 0. \quad (4.7)
\]

It should be noted that in the ideal case \( \lambda = n \) is an eigenvalue of \( A \). Thus Equation 4.6 can be expanded as:

\[
    A_1 \quad A_2 \quad \ldots \quad A_n
\]

\[
    A_1 \begin{bmatrix}
    1 & w_1/w_2 & \ldots & w_1/w_n \\
    w_2/w_1 & 1 & \ldots & w_2/w_n \\
    \vdots & \vdots & \ddots & \vdots \\
    w_n/w_1 & w_n/w_2 & \ldots & 1
    \end{bmatrix}
    \begin{bmatrix}
    w_1 \\
    w_2 \\
    \vdots \\
    w_n
    \end{bmatrix}
    = n \begin{bmatrix}
    w_1 \\
    w_2 \\
    \vdots \\
    w_n
    \end{bmatrix}
\]

It is noted in [Saa91] that the matrix entries \( a_{ij} \) in Eq. 4.6 are always known. The weights, \( w_i \) are not known since we often lack an exact scale to give the precise values of \( w_i/w_j \). In this case, matrix \( A \) is approximated by its reciprocal (perturbation) matrix \( A' \) and the weights, \( w_i \), can thus be computed from:

\[
    A' w = \lambda_{\text{max}} w \quad \text{or} \quad (\lambda_{\text{max}} I - A') w = 0. \quad (4.8)
\]

where \( \lambda_{\text{max}} \) is the largest eigenvalue of \( A \), called the principal eigenvalue of \( A' \) in Equation 4.6 and \( w = (w_1, w_2, \ldots, w_n)^T \). The importance of this largest eigenvalue is its use in controlling the inconsistency and subjectivity in the evaluators’ judgements. Equation
4.4 The Analytic Hierarchy Process

4.8 is a system of homogeneous linear equations having a non-trivial solution if and only if the determinant of \( A' \) vanishes, i.e.,

\[
\det(\lambda_{\text{max}} I - A') = |\lambda_{\text{max}} I - A'| = 0.
\]  

\( (4.9) \)

- Normalization

Normalization is a process that shows the relative importance of the criteria when compared with respect to each other. If \( R_i \) is the row-sum for the \( i^{\text{th}} \) row, \( i = 1, 2, \ldots, n \), and \( T_R \) is the total of all row-sums of matrix \( A \) then we have:

\[
R_i = \sum_{j=1}^{n} \frac{w_i}{w_j}, \quad i \in \{1, \ldots, n\}, \quad T_R = \sum_{i=1}^{n} R_i. \tag{4.10}
\]

Therefore, the normalized entries, \( w_i' \), of the principal eigenvector (local priorities), \( w' = (w_1', w_2', \ldots, w_n')^T \), are given by:

\[
w_i' = R_i / T_R. \tag{4.11}
\]

where \( w_i' > 0 \) and \( \sum_{i=1}^{n} w_i' = 1 \), which is a solution to Equation 4.6. The principal eigenvector (vector of priorities), \( w = (w_1, w_2, \ldots, w_n)^T \) is given by Equation 4.8.

Consistency Check. To check whether matrix judgements (decisions) are consistent, we need to check the consistency of the comparative matrices at each level of the hierarchy. This is done via the Consistency Index (C.I) and the Consistency Ratio (C.R), calculated by:

\[
C.I = (\lambda_{\text{max}} - n) / (n - 1), \quad \text{and} \quad C.R = C.I / R.I. \tag{4.12}
\]

where, as noted in [LACC08, Saa90], R.I is a Random Index (the average consistency index) calculated as an average of a randomly generated pairwise matrix of the same order and is often obtained from a table of random indices, see for example [SO03, Saa08a] and Appendix C, Table 2. It is noted, in [Saa94, Saa08a] that the acceptable upper threshold for C.R is:

\[
C.R \leq \begin{cases} 
0.05, & n = 3 \\
0.08, & n = 4 \\
0.10, & n > 4.
\end{cases} \tag{4.13}
\]

Therefore, if C.R is less than or equal to the given upper bound, matrix \( A \) is of sufficient consistency and the judgement/decision is acceptable.

4.4.3 Synthesizing

Synthesizing: Overall Rating and Ranking. This step consists of determining overall rating and ranking of alternatives whose priorities may be given as normalized or idealized priorities. It determines the overall priority (preference) rating of the alternatives by aggregating the relative weights of the criteria. Before, we have shown that the comparison step has to be done for every criterion. During the synthesizing step, all weights from the comparison step are combined into one overall weight. The synthesizing step has the following sub-steps [Saa08a]:
i Synthesis of the weight of each criterion with respect to the goal.

ii Synthesis of the comparisons to get the (local) priority of alternatives with respect to each criterion.

iii Multiplication of the local priorities of each alternative by the local priorities of each criterion and summing up the local priority products to obtain the overall (global) priority for each alternative.

Let \( w'_{ik} \) be the local priority for the \( k^{th} \) alternative, \( A_k \), for \( k \in \{1, 2, ..., m\} \), with respect to the \( i^{th} \) criterion, \( C_i \). Let \( w'_i \) be the local priority of \( C_i \) with respect to the goal, G. Then the global priority, \( w'_{A_k} \), of alternative \( A_k \) with respect to all local priorities of the criteria is given by:

\[
w'_{A_k} = \sum_{i=1}^{n} w'_{ik} w'_i.
\] (4.14)

where \( w'_{A_k} > 0 \), and \( \sum_{k=1}^{m} w'_{A_k} = 1 \). Table 4.6 is an aid to the computations by Equation 4.14.

**Table 4.6: Computation of global priorities.**

<table>
<thead>
<tr>
<th>Altern.</th>
<th>Criteria local priorities w.r.t. goal</th>
<th>Alternative Global Priority</th>
</tr>
</thead>
<tbody>
<tr>
<td>( A_1 )</td>
<td>( w'<em>{11} ) ( w'</em>{21} ) ( w'<em>{i1} ) ..... ( w'</em>{n1} )</td>
<td>( w'_{A_1} )</td>
</tr>
<tr>
<td>( A_2 )</td>
<td>( w'<em>{12} ) ( w'</em>{22} ) ( w'<em>{i2} ) ..... ( w'</em>{n2} )</td>
<td>( w'_{A_2} )</td>
</tr>
<tr>
<td>( \ldots )</td>
<td>( \ldots ) ( \ldots ) ( \ldots ) ..... ( \ldots )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( A_k )</td>
<td>( w'<em>{1k} ) ( w'</em>{2k} ) ( w'<em>{ik} ) ..... ( w'</em>{nk} )</td>
<td>( w'_{A_k} )</td>
</tr>
<tr>
<td>( \ldots )</td>
<td>( \ldots ) ( \ldots ) ( \ldots ) ..... ( \ldots )</td>
<td>( \ldots )</td>
</tr>
<tr>
<td>( A_m )</td>
<td>( w'<em>{1m} ) ( w'</em>{2m} ) ( w'<em>{nm} ) ..... ( w'</em>{nm} )</td>
<td>( w'_{A_m} )</td>
</tr>
</tbody>
</table>

Idealized Priorities. An alternative way of expressing overall (global) priorities for alternatives is to use an idealized form [Saa08b]. Priorities for the ideal mode are obtained by dividing each priority by the largest one. According to Saaty [Saa08b], the goal of having idealized priorities is to make one of the elements (criterion, sub-criterion, alternative) the ideal one so that others can get their proportionate values. This has the advantage that the different elements can be rated using numerical or verbal ratings. Let \( w''_{Ak} \) be the idealized overall priority for alternative \( k \), \( k \in \{1, 2, ..., m\} \). Then

\[
w''_{Ak} = w'_{Ak} / \max\{w'_{Ak}\}, \quad k \in \{1, 2, ..., m\}.
\] (4.15)
Verbal Ratings and Rating Categories. As noted in [Saa08b] there are situations when it is desirable to use verbal ratings for alternatives on each covering criterion. To do this, we establish rating categories for each covering criterion. Examples of rating categories and verbal ratings are: Excellent, Very Good, Good, Average, Below Average, Poor; High, Medium, Low; Strongly Agree, Agree, Not Sure, Disagree, Strongly Disagree. The categories are then prioritized using the usual pairwise comparison for preference. The alternatives are then evaluated by selecting the most fit rating category for each criterion and the idealized priorities are obtained using the process of normalization, i.e., by use of Equation 4.15.

4.5 Negotiations and Group Decisions with AHP

To employ AHP in a multi-actor decision-making process, there are two important issues that need to be addressed [Saa08a]: how to combine the individual judgements in a group into a group’s judgement and how to construct a group preference from the individual preferences. In order to answer the above questions, there is need to determine [FP98]: 1) whether the group acts together as a “unit” or acts as “separate individuals”, 2) which aggregation procedure (mathematical or otherwise) may be used to combine the individual judgements, and, 3) how to obtain and incorporate individual weights in the aggregation if they are not equally weighted. In the next sections, we describe two aggregation methods for analytic hierarchy process group decision-making (AHP-GDM) based on the above principles, see also [EM07, RG94]. These principles were applied to collaborative modeling evaluation and group decision-making in [SHP09c].

4.5.1 Aggregation of Individual Judgements

Under the Aggregation of Individual Judgements (AIJ) technique, the group normally becomes the “new individual” rather than a collection of independent individuals [FP98]. Individual actors in a bid to embrace the new individual – the group – give up their individual preferences (interests, goals, objectives, etc.) for the group. Following the procedure suggested in [EM07], we show how group priorities can be got. Let \( A_i, i \in \{1, \ldots, m\} \), be the \( m \) alternatives to be evaluated and upon which the selection decisions are to be based, and let \( r \) be the number of decision makers, and let \( k, 1 \leq k \leq r \), be the \( k \)-th decision maker. Let the pairwise comparison (judgement) matrix for the \( k \)-th decision maker be given by \( A[k] = (a_{ij}^k), i, j \in \{1, \ldots, n\} \) and let \( w[k] = (w_1^k, w_2^k, \ldots, w_n^k) \) be its corresponding priority vector \( (w_i^k > 0, \sum_{i=1}^n w_i^k = 1) \). If \( \beta_k \) is the weight of the \( k \)-th decision maker in contributing to the group decision, where \( \sum_{k=1}^r \beta_k = 1, \beta_k \geq 0 \), then the group pairwise (judgement) matrix is given by:

\[
A[G] = \left( a_{ij}^{[G]} \right), \, i, j \in \{1, \ldots, n\} \quad (4.16)
\]

where \( a_{ij}^{[G]} = \prod_{k=1}^r \left( a_{ij}^k \right)^{\beta_k}, \, i, j \in \{1, \ldots, n\} \), which is obtained by aggregating the individual priorities using the Weighted Geometric Mean Method (WGMM) [FP98, RG94] with the following corresponding group vector obtained by using the Row Geometric Mean Method (RGMM) [AM03, EAM04, EM07], in this case,

\[
w[G] = \left( w_i^{[G]} \right), \, i \in \{1, \ldots, n\} \quad (4.17)
\]
where $w_i^{[G]} = \left( \prod_{j=1}^{n} a_{ij}^{[G]} \right)^{1/n}$, $i, j \in \{1, ..., n\}$, with $a_{ij}^{[G]}$ given by Equation 4.16. Note that in Equations 4.16 and 4.17, the Weighted Geometric Mean Method (WGMM) is first used to obtain the group judgement matrix $A^{[G]}$ from the $k$-th decision maker’s matrix, $A^{[k]}, k \in \{1, ..., r\}$. Then using any prioritization techniques: Eigenvector Method (EGVM) [Saa80] or Row Geometric Mean Method (RGMM), the group priorities, $w^{[G]}$, are computed, see [EAM04, MJPL05].

Remark 1. If the decision makers have the same weight, which is a special case, then $\beta_k = 1/r$.

### 4.5.2 Aggregation of Individual Priorities

In the Aggregation of Individual Priorities (AIP) procedure, unlike the Aggregation of Individual Judgements (AIJ) procedure, individuals act in their own right with different value systems resulting in individual alternative priorities [FP98]. To aggregate the individual priorities into group priorities, we can use either the Weighted Geometric Mean Method (WGMM) or the Weighted Arithmetic Mean Method (WAMM). Let $w^{[k]} = (w_1^{[k]}, w_2^{[k]}, ..., w_n^{[k]})$, where $w_i^{[k]} > 0, \sum_{i=1}^{n} w_i^{[k]} = 1$, be the priority (weight) vector of the $k$-th individual actor (decision maker). Then the group’s aggregated priority vector, $w_i^{[G]}, i \in \{1, ..., n\}$ for the alternatives, using WGMM, is given by:

$$w_i^{[G]} = \prod_{k=1}^{r} \left( w_i^{[k]} \right)^{\beta_k}, i \in \{1, ..., n\}$$  \hspace{1cm} (4.18)

where $w_i^{[k]} = \left( \prod_{j=1}^{n} a_{ij}^{[k]} \right)^{1/n}, i \in \{1, ..., n\}$. The group priority vector is finally assembled as:

$$w^{[G]} = \left( w_i^{[G]} \right), i \in \{1, ..., n\}$$  \hspace{1cm} (4.19)

Equations 4.18 and 4.19, reveal that the individual decision maker’s priorities, $w^{[k]}, k \in \{1, ..., r\}$, in the AIP technique, are first computed from their corresponding pairwise matrices, $A^{[k]}, k \in \{1, ..., r\}$, using any prioritization procedure (RGMM or EGVM). Group priorities, $w^{[G]}$ are then obtained from these individual priorities using the WGMM, see for example [EAM04, MJPL05].

Theorem 1. If WGMM is used as the aggregation method and RGMM is used as the prioritization technique, then $w_i^{[G]}(AIJ) = w_i^{[G]}(AIP)$

Proof. [EAM04] □.

### 4.5.3 Consistency of Judgements in AHP-GDM

As already observed, when individual modelers’ decisions are involved, we can check whether their judgements are consistent using Equation 4.12 with the corresponding upper threshold values given in Equation 4.13. This is the case when the eigenvalue method (EGVM) is used as a prioritization technique. However, when the Row Geometric Mean
4.5. Negotiations and Group Decisions with AHP

Method (RGMM) is used as the prioritization technique, we compute the group consistency using the Geometric Consistency Index (GCI) [AM03] which is given by Equation 4.20:

\[
GCI = \frac{2}{(n-1)(n-2)} \sum_{i<j} \log^2 (e_{ij}) \quad i, j \in \{1, \ldots, n\}
\]  

(4.20)

where \( e_{ij} = a_{ij} w_j / w_i \), \( i, j \in \{1, \ldots, n\} \).

**Remark 2.** The condition \( i < j \) requires that only the elements above the principal diagonal in the pairwise comparative matrix \( A = (a_{ij}), i, j \in \{1, \ldots, n\} \) are used in the computations.

Because of subjectivity and inconsistency, there are may be errors associated with any \( k \)-th decision maker, \( k \in \{1, \ldots, r\} \), when comparing alternatives \( A_i \) and \( A_j \). In this case the geometric consistency index of the \( k \)-th decision maker, \( GCI^{[k]} \), and the group, \( GCI^{[G]} \), are, respectively, given by:

\[
GCI^{[k]} = \frac{2}{(n-1)(n-2)} \sum_{i<j} (\epsilon^{[k]}_{ij})^2 \quad i, j \in \{1, \ldots, n\}
\]  

(4.21)

where \( \epsilon^{[k]}_{ij} = \log (e^{[k]}_{ij}) \), \( i, j \in \{1, \ldots, n\} \).

\[
GCI^{[G]} = \frac{2}{(n-1)(n-2)} \sum_{i<j} (\epsilon^{[G]}_{ij})^2 \quad i, j \in \{1, \ldots, n\}
\]  

(4.22)

where \( \epsilon^{[G]}_{ij} = \log (e^{[G]}_{ij}) = \sum_{k=1}^{r} \beta_k \epsilon^{[k]}_{ij} \), \( i, j \in \{1, \ldots, n\} \).

**Theorem 2.** If WGMM is used as the aggregation method and RGMM is used as the prioritization procedure and GCI is used as the measure for inconsistency, then \( GCI^{[G]} \leq \max_{k \in \{1, \ldots, r\}} \{ GCI^{[k]} \} \).

**Proof.** (see [EAM04]) □.

Aguarón and Moreno-Jiménez [AM03] established a relationship between the Geometric Consistency Index (GCI) and Saaty’s Consistency Index (CI) and Consistency Ratio (CR). In [EAM04, EM07, Xu00] it is noted that when the WGMM is used as the aggregation method and the decision makers have an acceptable level of inconsistency, then so has the group irrespective of the prioritization procedure (EGVM or RGMM) used.

**Corollary 1.** If the individual decision makers’ judgements are of acceptable inconsistency, so are those of the group, i.e.,

\[
\text{If} \quad GCI^{[k]} \leq \tau, \quad k \in \{1, \ldots, r\}, \text{then} \quad GCI^{[G]} \leq \tau
\]  

(4.23)
where \( \tau \) is the threshold of the acceptable inconsistency. In [AM03] the thresholds for GCI corresponding to those of Saaty’s CI are given as:

\[
GCI \leq \begin{cases} 
0.031, & n = 3 \\
0.035, & n = 4 \\
0.037, & n > 4.
\end{cases}
\] (4.24)

4.6 Measuring Attitudes, Beliefs and Intentions

In Chapter 2, while discussing the Theory of Reasoned Action (TRA) [FA75] and Theory of Planned Behaviour (TPB) [Ajz85], it was noted that the different views, opinions, priorities and preferences, etc., that bring the subjectivity and biases in the evaluations, are brought about by the modelers’ attitudes, beliefs, intentions and behaviour towards the artifacts’ quality. The overall quality measure is thus affected by these psychological and behavioural factors. These are better captured through the modelers’ affective attitude towards the modeling artifacts’ quality. This is the reason we defined the the PQML, PUMP, PQEP and EOUM constructs in terms of this affective attitude, see sections 4.3.1 – 4.3.4. This affective attitude is better measured and assessed through the perceptions of the modelers, and in this regard, Davis’ TAM model concepts [Dav86] and and Moody’s MEM model concepts [Moo01] – perceived usefulness, ease of use and attitude towards using or intention to use – see sections 2.5.3 and 2.5.4 – can be used in a quality construct to measure and assess the impact of these psychological and behavioural factors. The Collaborative Modeling Process Quality Assessment (CMPQ) construct – which is a causal model for assessing the quality of the modeling artifacts based on these affective attitudes was developed in [SHP10a], see Chapter 6 – Figure 6.6. Appendix B – Part A – provides an instrument for measuring and assessing the PQML, PUMP, PQEP, and EOUM using the CMPQ construct.

4.7 Application of the COME Framework

In this section, we demonstrate, at the hand of a few examples, how concepts within the COME framework can be applied to collaborative modeling evaluation using the AHP evaluation method. The examples we use are adapted from [SHP09b]. It should be noted that the aim here is to demonstrate how the concepts can be applied – thus we apply mainly step 2 in the conceptual model of the COME framework, depicted in Figure 4.1 since this is where the actual evaluation takes place. Step 1 is straight-forward since it involves a literature search to identify the modeling artifacts with their corresponding dimensions. Table 4.1 shows the selected dimensions that were obtained from a literature search. Step 3, which involves the discursive evaluation and validation approach involving participants/IT experts, is presented in Chapters 6 and 7. We start with the steps within the three phases of AHP: structural decomposition, comparative analysis and synthesizing shown in Figure 4.2.

**Problem Identification.** The problem to be tackled in collaborative modeling is a modeling process evaluation and selection of the best collaborative modeling approach (CMA) that meets the modelers’ quality goals with respect to the modeling artifacts. The different quality dimensions (attributes, sub-criteria and criteria) for each artifact – Tables 4.2–4.5 – and the overall goal, which is the evaluation of the modeling process using the artifacts,
are identified.

**Hierarchy Construction.** For the identified problem, we decompose the modeling process evaluation problem as shown in Figure 4.5. This is, in essence, the “structural decomposition” of the identified problem.
Pairwise Comparison – Comparison Scale. Pairwise comparison requires us to answer the question: “Of the two elements, which one is more important with respect to a higher level criterion and what is the strength of its dominance?” [Saa08a, Saa08b]. To answer this, we ask judges – collaborative modelers – to compare, pairwise, the elements at each level in the AHP hierarchy given in Figure 4.5. This is aided by using, for example, a collaboration and decision support software tool for example, ExpertChoice [EC11] or D-Sight [DS11]. Figure 4.6 shows how the relative importance of elements is determined by comparing them, pairwise, with respect to their parent element using the ExpertChoice Tool.

**Figure 4.6: Expert Choice questionnaire form.**

In this case, the elements are two criteria: modeling language and modeling procedure on level \( l_{i+1} \), \( 1 \leq i \leq n \), which are pairwise compared with respect to their parent criterion: Modeling Process Evaluation on level \( l_i \), \( 1 \leq i \leq n \), see Figure 4.3 for the levels. A judgement (relative scale on the fundamental scale – Appendix C, Table 1), e.g., 9, is given in the left half of the questionnaire meaning that “modeling language is extremely more important than modeling products” in measuring or assessing modeling process quality. When constructing the pairwise comparison matrix, a reciprocal, \( \frac{1}{9} \), will be entered below the main diagonal at the intersection of the modeling language row and modeling products column, see Table 4.7(a). A reciprocal, \( \frac{1}{9} \), means that “modeling
products is extremely more important than modeling language”.

Pairwise Comparison – Forming a Comparative Matrix. Table 4.7 is an example of a comparative matrix which, pairwise, compares the relative importance of the general criteria ($C_1 – C_4$) – modeling language, modeling procedure, end-product and support tool – with respect to the goal (G) – modeling process evaluation. When an element is compared to itself, we give it a relative scale of 1 (equal importance) and this explains these values on the principal diagonal of the comparative matrix. The reciprocal property in Equation 4.3 requires that if an element (criterion comparative judgement intensity), say, 9, is entered in the first row, third column, i.e., $a_{13} = 9$, its reciprocal is entered in third row, first column, i.e., $a_{31} = 1/9$. In Table 4.7, two forms of the comparative matrices are given: matrix and tabular. The tabular form facilitates inclusion of other computed values, e.g., priorities, principal eigenvalue ($\lambda_{max}$), consistency ratio (C.R) and consistency index (C.I).

**Table 4.7: Comparative matrix of general criteria $C_1 – C_4$ w.r.t. goal G (a) and (b).**

(a) Matrix form.

<table>
<thead>
<tr>
<th>Modeling Language</th>
<th>Modeling Procedure</th>
<th>Modeling Products</th>
<th>Medium (Support Sys.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling Language</td>
<td>1</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>Modeling Procedure</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Modeling Products</td>
<td>1/9</td>
<td>1/4</td>
<td>1</td>
</tr>
<tr>
<td>Medium (Support Sys.)</td>
<td>1/4</td>
<td>1/4</td>
<td>1/2</td>
</tr>
</tbody>
</table>

(b) Tabular form.

<table>
<thead>
<tr>
<th>Modeling Language</th>
<th>Modeling Procedure</th>
<th>Modeling Products</th>
<th>Medium (Support Sys.)</th>
<th>Priorities vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling Language</td>
<td>1</td>
<td>9</td>
<td>4</td>
<td>0.469</td>
</tr>
<tr>
<td>Modeling Procedure</td>
<td>1</td>
<td>4</td>
<td>4</td>
<td>0.093</td>
</tr>
<tr>
<td>Modeling Products</td>
<td>1/9</td>
<td>1</td>
<td>2</td>
<td>0.079</td>
</tr>
<tr>
<td>Medium (Support Sys.)</td>
<td>1/4</td>
<td>1/2</td>
<td>1</td>
<td>0.041</td>
</tr>
</tbody>
</table>

$\lambda_{max} = 4.220$  C.I = 0.073  C.R = 0.082

Relative Weight Estimation – Eigenvector Method. For this illustration, we use the secondary criteria ($S_5 – S_8$): efficiency, effectiveness, satisfaction, commitment and shared understanding, and we compute their relative weights with respect to their parent criterion which is, in this case, the modeling procedure using the eigenvector method, see Equation 4.6. The results for relative weight estimation, using this method, are given in Table 4.8. The priorities given in this table are normalized as can easily be checked by Equation 4.11. From this table, efficiency has the highest priority, followed by effectiveness and communication and shared understanding, whereas satisfaction has the least priority. This means that while determining the quality of the modeling process with respect to the modeling procedure, modelers’ priority and preference is on the efficiency and effectiveness
Chapter 4. The COME Framework

of the modeling procedure.

Table 4.8: Comparative matrix of subcriteria $S_5 - S_8$ w.r.t. subcriterion $C_2$.

\[
\begin{array}{cccccc}
\text{Efficiency} & \text{Effectiveness} & \text{Satisfaction} & \text{Communication} & \text{Priorities} \\
1 & 2 & 6 & 3 & 0.464 \\
\frac{1}{3} & 1 & 5 & 6 & 0.368 \\
\frac{1}{6} & \frac{1}{5} & 1 & 1 & 0.077 \\
\frac{1}{3} & \frac{1}{6} & 1 & 1 & 0.092 \\
\end{array}
\]

\[\lambda_{\text{max}} = 4.174 \quad C.I = 0.058 \quad C.R = 0.065\]

Consistency Check. To check for consistency, we use Equation 4.9 and Equation 4.12 to compute the principal eigenvalue ($\lambda_{\text{max}}$), consistency index (C.I) and the consistency ratio (C.R). The random index (R.I) for a $4x4$ matrix (the order $n = 4$ in our case) is 0.89, see Appendix C, Table 2. These values are given at the bottom of the comparative matrix table. The comparative matrix in Table 4.8 is of order $n = 4$. Equation 4.13 confirms consistency.

Synthesizing – Overall Rating and Ranking. We synthesize the priorities of alternatives, which are the modeling approaches: CMA1 – computer-mediated communication (CMC) modeling sessions (using a GSS tool, e.g., COMA), CMA2 – face-to-face (FTF) modeling sessions (with or without a facilitator) or CMA3 – modeling sessions that employ a simple tool such as a white-board or a flip-chart (CMA3) as follows. We make use of the local priorities of the these alternatives with respect to each criterion and compute the composite or the global priorities using Equation 4.14. As pointed out before, Table 4.6 is used to facilitate the ensuing computations for global priorities. Synthesized results, are shown in Table 4.9.

Table 4.9: Synthesized results for alternatives with respect to goal.

<table>
<thead>
<tr>
<th>Modeling Language</th>
<th>Modeling Procedure</th>
<th>Products</th>
<th>Medium</th>
<th>Priorities (Normalized)</th>
<th>(Idealized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMA 1</td>
<td>0.705</td>
<td>0.637</td>
<td>0.573</td>
<td>0.667</td>
<td>1.000</td>
</tr>
<tr>
<td>CMA2</td>
<td>0.181</td>
<td>0.274</td>
<td>0.330</td>
<td>0.230</td>
<td>0.345</td>
</tr>
<tr>
<td>CMA3</td>
<td>0.141</td>
<td>0.089</td>
<td>0.098</td>
<td>0.112</td>
<td>0.116</td>
</tr>
</tbody>
</table>

Interpretation of these results shows that the CMA1 approach is judged a better approach than either CMA2 or CMA3. This is what is preferred by the modelers. An alternative interpretation is that CMA2 is 34.5% as good as the CMA1 while CMA3 is 17.4% as good as CMA1.

4.8 Concluding Remarks

This chapter has introduced the COME framework which can be used to evaluate the modeling artifacts used in, and produced during, a collaborative modeling session. The
conceptual model on which the COME framework is based has introduced three steps which can be followed in the evaluation of the modeling artifacts and evaluation and validation of the evaluation method. Four modeling artifacts, namely the modeling language, modeling procedure, end-products and support tool, have been identified together with their corresponding quality dimensions with sub-steps within the evaluation method to generate and score (rate, rank, weigh) them. One MCDA approach that can be used in this regard is the AHP method. AHP, as has been shown, can be used to compare pairwise not only the quality dimensions but also the modeling artifacts. It has been argued that using the AHP approach, modelers can reconcile their priorities and preferences thus reducing on the subjectivity and biases associated with the different views about the quality of the artifacts. To capture the attitudes, beliefs, intentions and behaviour of the modelers within the evaluation, a collaborative modeling quality construct has been introduced. This construct uses concepts from Davis’ Technology Acceptance Model (TAM) and Moody’s Method Evaluation Model (MEM), which are based on the Theory of Reasoned Action (TRA)/Theory of Planned Behaviour (TPB). We have given an example to illustrate how the COME framework works and how it can be used to evaluate the different modeling artifacts and select the dimensions or modeling approaches that meet modelers’ quality goals. Since the scoring of the modeling artifacts and agreement/consensus about these quality scores can be done by the modelers using the discursive approach, this in a way provides a communicative and interactive link to the RIM framework. This link is exploited in the next chapter.
5 RIM and COME: The Meta-model

The whole is better than the sum of its parts – Gestalt Principle.
– Wertheimer, Köhler & Koffka

5.1 Overview

This chapter presents a meta-model that unifies the RIM and COME frameworks. The meta-model serves two main purposes. First, it helps us to establish a link between the RIM framework and the COME framework using one of the tiers in the RIM framework – the interaction tier. Using this link, we are able to track flaws in the RIM framework using heuristics developed in the COME framework with a view of correcting them. Second, the meta-model serves as a template or blueprint that can help in the design of a support-tool that can be used in the analysis and evaluation of modeling processes. The meta-model is developed incrementally from the deep and detailed structures of RIM and COME concepts. The detailed analysis of these concepts help us identify the interrelationships between the different concepts, the implicit and/or explicit constraints, and rules that govern them. We use a fact-oriented methodology – the Object-Role Modeling (ORM) methodology – to analyse the deep structures of the concepts in both frameworks. Reasons are given as to why this approach is preferred to other modeling methods. Detailed ORM verbalizations are given to serve as communication channel for technical and non-technical personnel and to explicitly bring out the interrelationships between the concepts, their underlying constraints and rules. The chapter is ended with concluding remarks about the meta-model.

5.2 Why a Meta-model?

The first question that needs an answer is: why bother to integrate the two frameworks and what is the significance of having such an integration in view of the analysis and evaluation of the modeling processes? To adequately answer this question, one needs to reflect once again on the two frameworks: RIM and COME as discussed in the previous two chapters in light of their different concepts whose (inter-) relationships can be captured in a meta-model. The main concepts in the modeling process, based on the concept of meta-modeling, can best be depicted as shown in Figure 5.1

As can be seen in the figure, the different levels of abstraction portray an object-type-instance relationship where a given model $M_1$ is created using (modeling) language $L_1$ and $M_2$ is the meta-model of the object modeled by $M_1$. While there are a number of authors who have researched, and employed, the technique of meta-modeling and its application in a number of fields, e.g., method engineering [JMJ09], software engineering

This chapter is an extended version of the following publications: [SHP10b, SHP10c].
5.2.1 Meta-models and Meta-modeling

A meta-model, according to Oei et al., “is a set of basic concepts which are related to each other, the so-called concept structure and a set of constraints determining the set of possible application models and the set of possible transitions between application models” [OHFB92, p.2]. Nissen et al. define meta-models to be “models about models ... which are abstract representations of an existing or desired real world and their interrelationships” [NJJ+96, p.38]. From these two definitions the following can be discerned about a meta-model. A meta-model provides: 1) a set of concepts (concept structure), 2) a set of (inter-) relationships, and, 3) a set of constraints. Building on these observations, and re-calling the concepts defined about the RIM and COME framework in the previous chapters, it is not hard to see why a meta-modeling approach is the appropriate technique to provide a mechanism for unifying and defining the concepts in both frameworks, providing a formal notation for the concepts, constraints and their underlying relationships. By taking a meta-modeling approach, we realize the following by exploiting some of the

Figure 5.1: Abstraction levels in meta-modeling [Hol00].
5.2. Why a Meta-model?

properties of a meta-model, see also [BSPJ06]:

1. A **meta-model can serve as a template or blueprint for deriving the actual analysis and evaluation structures.**

2. **It can serve as a conceptual language for communicating the analysis and evaluation concepts between and among the different stakeholders in a modeling session.**

3. **The meta-model can serve as an appropriate technique for the construction of a support-tool that incorporates analysis and evaluation concepts.**

4. **The meta-model can offer the means to track the flaws in the RIM framework using heuristics developed in the COME framework.**

5.2.2 The Concepts

As pointed out in Chapter 3, the RIM framework is a versatile framework that, if properly and appropriately applied, can help us analyse the different communicative activities (negotiations, decision-making, argumentation, etc.) with the view of trying to understand what takes place during the modeling process and how modelers do whatever they do. Due to the fact that modeling is done as a group activity and the fact that modelers have different levels of knowledge, skills and competencies as exhibited by their mental models, there is need to analyse the communicative process to reveal and unwrap the different actions that may point to the procedure that modelers use to solve any given problem. To agree on a certain direction to follow, modelers will have evaluated the different courses of action still through the communicative and negotiation dialogues. This has to be done by evaluating the different proposals, reconciling their priorities and preferences so that agreement and possibly some form of consensus is reached. The concepts, thus, mainly come from the communicative process guided and directed by the rules and goals. The meta-model, formally, establishes these concepts, the constraints that exist between them, and their relationships.

As seen in Chapter 4, the evaluation is extended to the modeling artifacts used in, and produced during, the modeling process. Weighting and scoring the artifact dimensions, evaluating and selecting the artifact or the selecting the modeling method/approach that meets the quality goals, aggregating the modelers’ priorities or aggregating their preferences requires a robust evaluation framework. The COME framework provides a platform to do this. Integrating the two frameworks: the RIM and the COME framework provides a holistic approach that helps us to not only study, analyse and understand what takes place during a modeling session and how modelers do their thing, but also helps us to pin-point at those phases, events, circumstances or actions in the communication process that are likely to have led to low quality evaluations. Tracking such flaws from the COME to RIM and applying quality heuristics to RIM from COME helps modelers attain the required level of quality, improve their shared understanding and provides a model in which analysis and evaluation concepts are defined and applied. Concepts within the COME framework are both analytic and evaluative in nature.

5.2.3 Developing the Meta-model Using ORM

Although most of the meta-models in literature are developed using the Object Modeling Group’s (OMG) de-facto software development standard language – the Unified Modeling
Language (UML) [BRJ98], we prefer to use Terry Halpin’s [Hal01, Hal89] Object Role Modeling (ORM) Language. Object Role Modeling standard version 2 (ORM2) [HM08, Hal05], implemented in the Natural ORM Architect (NORMA) tool [NOR11], has the following features over other modeling languages that make it a candidate to develop a meta-model for the RIM and COME frameworks, see for example [Hal05, TK07].

- **ORM is a fact-oriented approach for modeling.**

- **Facts and rules in the domain or Universe of Discourse (UoD) can readily be verbalized using a language understandable by non-technical people.**

- **All facts in ORM are treated as relationships unlike Entity-Relationship (ER) modeling and UML.**

- **Facts are not grouped into structures (e.g., attribute-based entity types, classes, relation schemes, XML schemas) thus facilitating semantic stability and enhancing natural verbalizations in a native language.**

- **ORM being fact-oriented, its graphical notation is far more expressive than other graphical notations.**

- **Representation of all explicit and implicit constraints is permitted in ORM.**

- **Being design and implementation independent, ORM enhances the inter-operability among tools since the same model can be used for different purposes.**

The meta-model that integrates the two frameworks and which we present in this chapter, is discussed in [SHP10b, SHP10c]. This meta-model can be used for not only the analysis and evaluation of a collaborative modeling process and the associated modeling artifacts but also for tracking and tracing the modeling flaws from the evaluation framework to the analysis framework and heuristics can then be used to further analyse and correct these flaws. As argued in [SHP10b], the meta-model links the modeling artifacts and the evaluation framework to the Rules, Interactions and Models (RIM) framework through the interactions which are governed by rules. In Chapter 3, the interactions, rules and models were seen to be both frame for, and result of, the communicative process which is, as observed by Rittgen [Rit07], a negotiation process. Negotiation, which is part of the whole argumentative and communicative process, plays a key role in any collaborative group effort. It is through negotiation that modelers reach agreement and possibly consensus after reconciling their different priorities, preferences, biases in their mental models.

Negotiation dialogue has been widely studied, see for example [Pru81, Rai82, RZ94]. Although it pervades a number of areas and disciplines, two areas in computing, in general, and information systems in particular, have received tremendous coverage with wide ranging practical applications. These include Artificial Intelligence (AI) where Multi-Agent Systems (MAS) is one of the most widely studied and applied area of negotiation dialogues, see for example [AP04, MEPA03, PJ96, PSJ98], and electronic commerce [LLLL92, SD01, SL95]. Negotiation dialogues, as pointed out in Walton and Krabbe typology [WK95, WRM05], see section 2.3.1, start from a position of conflict and the goal is to establish some consensus or compromise for all the parties involved. Through
Collaborative Modeling Analysis

In this section, we look at details of the structure of RIM framework components (rules, interactions and model propositions). In the RIM framework discussed in Chapter 3 we looked at the surface structure of these concepts. We now take a stride and look at a deeper and more fine-grained structure of these concepts so that the analysis of collaborative modeling sessions using the communicative dialogues can efficiently and effectively be done with theoretically sound concepts. Each of the discussed structures reveals the relationships and linkages of the central concept (rule, interaction, model proposition or a modeling artifact to be evaluated) with its associated elements as defined in section 3.4, Tables 3.3 – 3.5. We reveal the structure of these components and the relationships of their elements through “ORM verbalizations”.

5.3.1 Rule Model – The Structure

Figure 5.2 gives the structure of the rule and its associated elements. These elements are defined in Table 3.3 in section 3.4.1. A number of observations are worth mentioning here from the rule model. At the center of this model is the rule which is identified by a name. As argued in chapter 3 about the relationship between a rule and the goal – where it was argued that a goal is a special type of a rule which modelers strive for – we see that the model brings out this relationship indicating that each goal is a sub-type of a rule. A rule, which is either explicitly or implicitly stated, is activated and de-activated by content. It is possible that more than one rule is activated by the same content and the same rule is activated by the same content, activated and de-activated at time $t$ and activated and de-activated within the modelers’ interactive and communicative dialogues. Rules guide the model propositions which are a result of the communicative dialogues between and among the modelers. As seen while discussing the RIM framework, some model propositions may lead to generation of new rules. Using ORM methodology, we give a few verbalizations about the rule model shown in Figure 5.2.

- Each Rule is explicit or is implicit.
- Each Goal is an instance of a Rule
- Rule is (de-)activated at Time.
It is possible that more than one Rule is (de-)activated at the same Time and that the same Rule is (de-)activated at more than one Time.

In each population of Rule is (de-)activated at Time, each Rule, Time combination occurs at most once. This association with Rule, Time provides the preferred identification scheme for RuleIsActivatedAt-Time.

Each Rule is activated at some Time. No Rule is activated at and is de-activated at the same Time.

\textbf{Rule is (de-)activated in Interaction.}

It is possible that more than one Rule is (de-)activated in the same Interaction and that the same Rule is (de-)activated in more than one Interaction.

In each population of Rule is (de-)activated in Interaction, each Rule, Interaction combination occurs at most once. This association with Rule, Interaction provides the preferred identification scheme for RuleIs(De)ActivatedInInteraction.

If some Rule is activated in some Interaction then that Rule is de-activated in some Interaction.

\textbf{Rule is (de-)activated by Content.}

It is possible that more than one Rule is (de-)activated by the same Content and that the same Rule is (de-)activated by more than one Content.

In each population of Rule is (de-)activated by Content, each Rule, Content combination occurs at most once. This association with Rule, Content provides the preferred identification scheme for RuleIs(De)ActivatedByContent.

If some Rule is activated by some Content then that Rule is de-activated by some Content.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{model_for_the_rule_structure.png}
\caption{Model for the rule structure.}
\end{figure}
5.3. Collaborative Modeling Analysis

- **Rule guides ModelProposition.**
  
  For each ModelProposition, at most one Rule guides that ModelProposition.

  It is possible that the same Rule guides more than one ModelProposition.

### 5.3.2 Interaction Model – The Structure

Figure 5.3 gives the ORM model of the interaction and its structure. These components are defined in Table 3.4 in section 3.4.2. Central to this model is the interaction which can be looked at as an exchange of speech acts or communication dialogues which could either be some form of group decision-making where, as seen already, modelers (actors) reconcile their different opinions, bias, priorities or preferences and reach some sort of compromise or consensus or could be some form of negotiation where modelers under an argumentative process involving proposals and counter-proposals, acceptances or rejections of those (counter) proposals, agreements or disagreements with the (counter) proposals, withdraws, supports, etc., eventually reach some compromise. Relating this to the RIM framework in Chapter 3 – Figure 3.4, it is not hard to see the link between the interactions in this model, the rules and model propositions. As seen in the RIM framework, some rules guide the interactions and interactions may lead to generation of more rules. Some interactions generate model propositions and some model propositions may lead to further interactions.

![Model for the interaction structure.](image)

- **Interaction contains exchange of SpeechAct.**

  Each Interaction is some GroupDecisionMaking or is some GroupNegotiation.

  Each GroupNegotiation is an instance of Interaction.

  Each GroupDecisionMaking is an instance of Interaction.
Interaction has Actor.
It is possible that more than one Interaction has the same Actor and that the same Interaction has more than one Actor.
In each population of Interaction has Actor, each Interaction, Actor combination occurs at most once.
This association with Interaction, Actor provides the preferred identification scheme for Interaction-HasActor. Each Interaction has some Actor.

Interaction begins/ends at Time.
Each Interaction begins/ends at at most one Time.
For each Time, at most one Interaction begins/ends at that Time.
If some Interaction begins at some Time then that Interaction ends at some Time.

Interaction has Topic.
Each Interaction has exactly one Topic.
It is possible that more than one Interaction has the same Topic.

Topic responds to Topic.
Each Topic responds to at most one Topic.
It is possible that more than one Topic responds to the same Topic.

Topic has TopicNr.
It is possible that more than one Topic has the same TopicNr and that the same Topic has more than one TopicNr.
In each population of Topic has TopicNr, each Topic, TopicNr combination occurs at most once.
This association with Topic, TopicNr provides the preferred identification scheme for TopicHasTopicNr. Each Topic has some TopicNr.

Interaction has InteractionNr.
It is possible that more than one Interaction has the same InteractionNr and that the same Interaction has more than one InteractionNr.
In each population of Interaction has InteractionNr, each InteractionNr, Interaction combination occurs at most once.
This association with InteractionNr, Interaction provides the preferred identification scheme for InteractionHasInteractionNr.
Each Interaction has some InteractionNr.

Interaction contains exchange of SpeechAct.
Each Interaction contains exchange of exactly one SpeechAct.
It is possible that more than one Interaction contains exchange of the same SpeechAct.

SpeechAct has Category.
Each SpeechAct has exactly one Category.
It is possible that more than one SpeechAct has the same Category.

Interaction generates ModelProposition.
It is possible that more than one Interaction generates the same ModelProposition and that the same Interaction generates more than one ModelProposition.
In each population of Interaction generates ModelProposition, each Interaction, ModelProposition combination occurs at most once.
This association with Interaction, ModelProposition provides the preferred identification scheme for InteractionGeneratesModelProposition.

Interaction is guided by Rule.
It is possible that more than one Interaction is guided by the same Rule and that the same Interaction is guided by more than one Rule.
In each population of Interaction is guided by Rule, each Interaction, Rule combination occurs at most once.
This association with Interaction, Rule provides the preferred identification scheme for InteractionIsGuidedByRule.
Each Interaction is guided by some Rule.
5.3. Collaborative Modeling Analysis

5.3.3 Model Propositional Model – The Structure

Figure 5.4 gives the structure of the model proposition and its corresponding structure which is derived from the definitions given in Table 3.5. A model proposition is guided by a rule and is activated or de-activated at time \( t \). It is generated from an interaction and is selected by some selection criteria.

![Diagram of model proposition structure](image)

**Figure 5.4:** Model for the model proposition structure.

- **ModelProposition** is guided by **Rule**.
  Each **ModelProposition** is guided by at most one **Rule**.
  It is possible that more than one **ModelProposition** is guided by the same **Rule**.

- **ModelProposition** is (de-)activated at **Time**
  It is possible that more than one **ModelProposition** is (de-)activated at the same **Time** and that the same **ModelProposition** is (de-)activated at more than one **Time**.
  In each population of **ModelProposition** is (de-)activated at **Time**, each **ModelProposition**. **Time** combination occurs at most once.
  This association with **ModelProposition**, **Time** provides the preferred identification scheme form **ModelPropositionIsActivatedAtTime**.
  If some **ModelProposition** is activated at some **Time** then that **ModelProposition** is de-activated at some **Time**.

- **ModelProposition** is generated from **Interaction**.
  It is possible that more than one **ModelProposition** is generated from the same **Interaction** and that the same **ModelProposition** is generated from more than one **Interaction**.
  In each population of **ModelProposition** is generated from **Interaction**, each **ModelProposition**, **Interaction** combination occurs at most once.
  This association with **ModelProposition**, **Interaction** provides the preferred identification scheme for **ModelPropositionIsGeneratedFromInteraction**.
  Each **ModelProposition** is generated from some **Interaction**.
ModelProposition is selected by SelectionCriteria.

It is possible that more than one ModelProposition is selected by the same SelectionCriteria and that the same ModelProposition is selected by more than one SelectionCriteria.

In each population of ModelProposition is selected by SelectionCriteria, each ModelProposition, SelectionCriteria combination occurs at most once.

This association with ModelProposition, SelectionCriteria provides the preferred identification scheme for ModelPropositionIsSelectedBySelectionCriteria.

Each ModelProposition is selected by some SelectionCriteria.

5.4 Collaborative Modeling Evaluation

In this section the ORM model for the evaluation of the modeling artifact is given.

5.4.1 The Modeling Artifact – The Structure

The structure of the modeling artifact evaluation model is given in Figure 5.5 and its associated concepts are defined in Table 5.1.

![Figure 5.5: Model for modeling artifact evaluation structure.](image)

Each modeling artifact has a number of quality criteria (dimensions or factors) through which the quality is assessed and measured. Modelers assess and evaluate these quality criteria by giving them quality scores (from a quality research instrument, questionnaire, etc.,). These scores may be assigned to the quality criteria individually or collectively as a group, where in this case modelers have to agree on the final score after overcoming their differences in priorities and preferences. The quality scores are used to compute the (indicative) quality values upon which decision may be made about the quality of a particular modeling criterion or artifact with respect to others. The quality value, which is a measure of quality, is finally used to select only those quality dimensions or modeling artifacts that meet the modelers’ quality goals. The modeling artifact’s quality may be established through the quality scores and quality values. This quality is established during the communicative interactions between the modelers. The evaluation may be done using either a multi-criteria decision analysis (MCDA) approach such as AHP, MAUT/MAVT, ELECTRE, or PROMETHEE methods (of type synthesizing, outranking, interactive) or
Table 5.1: Explanation for elements of a modeling artifact.

<table>
<thead>
<tr>
<th>Element</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality</td>
<td>Degree of excellence or deficiency-free state.</td>
</tr>
<tr>
<td>QualityCriterion</td>
<td>A modeling artifact feature to measure quality.</td>
</tr>
<tr>
<td>QualityScore</td>
<td>A value given to a criterion as a measure of its quality. It may be an individual or group score.</td>
</tr>
<tr>
<td>PriorityValue</td>
<td>Aggregated quality scores to determine priority values. Group negotiation/decision-making to agree on quality scores.</td>
</tr>
<tr>
<td>Interaction</td>
<td>A set of guidelines that direct the interactions.</td>
</tr>
<tr>
<td>Rule</td>
<td>A multi-criteria decision analysis approach used for the evaluation. It is of a certain type</td>
</tr>
<tr>
<td>MCDA</td>
<td>Any other evaluation method that can be used to weigh, rate and rank the quality dimensions and modeling artifacts.</td>
</tr>
</tbody>
</table>

✠ ModelingArtifact has QualityCriterion.

- It is possible that more than one ModelingArtifact has the same QualityCriterion and that the same ModelingArtifact has more than one QualityCriterion.
- In each population of ModelingArtifact has QualityCriterion, each ModelingArtifact, QualityCriterion combination occurs at most once.
- This association with ModelingArtifact, QualityCriterion provides the preferred identification scheme for ModelingArtifactHasQualityCriterion.
- Each ModelingArtifact has some QualityCriterion.

✠ QualityCriterion is given QualityScore.

- It is possible that more than one QualityCriterion is given the same QualityScore and that the same QualityCriterion is given more than one QualityScore.
- In each population of QualityCriterion is given QualityScore, each QualityCriterion, QualityScore combination occurs at most once.
- This association with QualityCriterion, QualityScore provides the preferred identification scheme for QualityCriterionIsGivenQualityScore.
- Each QualityCriterion is given some QualityScore.

✠ For each QualityScore, exactly one of the following holds:

| QualityScore is some GroupQScore, i.e., Each GroupQScore is an instance of QualityScore.; |
| QualityScore is some IndividualQScore, i.e., Each IndividualQScore is an instance of QualityScore. |

✠ QualityScore is used in PriorityValue.

- It is possible that more than one QualityScore is used in the same PriorityValue and that the same QualityScore is used in more than one PriorityValue.
- In each population of QualityScore is used in PriorityValue, each QualityScore, PriorityValue combination occurs at most once.
- This association with QualityScore, PriorityValue provides the preferred identification scheme for QualityScoreIsUsedInPriorityValue.
- Each QualityScore is used in some PriorityValue.

✠ PriorityValue is a measure of Quality. Each PriorityValue is a measure of exactly one Quality.

- It is possible that more than one PriorityValue is a measure of the same Quality.
ModelingArtifact is of Quality. Each ModelingArtifact is of exactly one Quality.

- It is possible that more than one ModelingArtifact is of the same Quality.
- It is possible that more than one ModelingArtifact is evaluated in the same Interaction and that the same ModelingArtifact is evaluated in more than one Interaction.
- In each population of ModelingArtifact is evaluated in Interaction, each ModelingArtifact, Interaction combination occurs at most once.
- This association with ModelingArtifact, Interaction provides the preferred identification scheme for ModelingArtifactIsEvaluatedInInteraction.

ModelingArtifactIsEvaluatedInInteraction using MCDA.

- Each ModelingArtifactIsEvaluatedInInteraction using at most one MCDA.
- It is possible that more than one ModelingArtifactIsEvaluatedInInteraction using the same MCDA.
- Each MCDA is of exactly one Type.
- It is possible that more than one MCDA is of the same Type.
- The possible values of Type are ‘weighting’, ‘outranking’, ‘interactive’.

5.4.2 The Role of the Interactions

Analyzing the model structures for the different components of the RIM framework and the COME framework, it is not hard to see the role played by the interaction component. The interaction is at the center of all these models, an indication that it plays a crucial role in unifying the RIM elements and the COME elements. This is not surprising since the entire modeling session is driven by the modelers’ communicative dialogues including negotiations, argumentations, (group) decision-making, etc. It is through the same communication channel that they evaluate the different modeling artifacts used in, and produced during, a collaborative effort. In section 3.5, this central role was indirectly mentioned through the back and forth relationships between the rules, interactions and models without explicitly identifying them. Building on this observation, we exploit the central role played by the interaction to derive a meta-model that can be used to not only analyse what takes place during a modeling session, but also to evaluate the quality of the different modeling artifacts. This meta model is given in the next section.

5.5 The Meta-model

In this section, we tie together all the concepts discussed thus far into a meta-model. As seen in the preceding sections the analysis concepts are detached from the evaluation concepts. Yet we have already argued that the communicative process that leads to the interactions is seen during the development of the models and also during the evaluation of the modeling artifacts used in, and produced during, the collaborative effort. Looking back at the analysis and evaluation ORM models, it is not hard to see the role played by the interaction. This is one of the elements that is defined for each and every component of the analysis and evaluation framework. Building on this observation, we give the meta-model that integrates both the analysis and evaluation frameworks. This meta-model is given in Figure 5.6

5.6 Concluding Remarks

This chapter has presented a meta-model that integrates the two frameworks: RIM and COME for, respectively, analyzing and evaluating the quality of the modeling processes.
Using the ORM methodology, we have analyzed the depth and breadth of the structure of meta-model main components which are the rules, interactions, model propositions and modeling artifacts, and established relationships and links between the different elements of these components. Looking at such a detailed structure enables us to identify the main drivers of both the analysis framework and the evaluation framework. We have identified the interaction component as a link-pin between the RIM and COME framework. The main goal of establishing this link between the RIM and the COME framework is two-fold. First, it allows us to track, forth and backwards, the flaws in the RIM framework and use heuristics within the COME framework to pin-point these flaws through low evaluation scores. Secondly, using heuristics in the COME framework, we can correct the detected flaws in the RIM framework by allowing collaborative modelers to revisit their judgements about the modeling artifacts used in, and produced during, the modeling session. This is the main strength of the meta-model. The chapter has also looked at the formalizations of the main concepts within the meta-model. This formalization using the ORM methodology strengthens the theoretical validity of the concepts and consolidates their theoretical relevance and practical applicability. In the next two chapters we look at some of the modeling sessions that were used to develop, study and validate the main concepts of the frameworks and the meta-model.
PART III

Meta-model Validation
This part of the books deals with collaborative modeling activities done to validate the frameworks and the meta-model.

**Chapter 6**

Chapter 6 gives results, findings and observations from two controlled experiments that we carried out to validate our frameworks and meta-model. The chapter starts with an overview in Section 6.1 and we introduce the research instruments and data analysis methods used in Section 6.2. Details of the research instruments are given in Section 6.2.1 while the data coding and analysis details are given in Section 6.2.2. The first set of exploratory and explanatory modeling experiments is described in Section 6.3 with those conducted in the Netherlands described in Section 6.3.1 while those conducted in Uganda are explained in Section 6.3.2. Controlled explanatory modeling experiments are described in Section 6.4. The experimental design, preparation and execution are described in Section 6.4.1. Data analysis procedures and the results are described in Section 6.4.2. This chapter is ended with some concluding remarks about the modeling sessions, the results and about our findings and observations in Section 6.5.

**Chapter 7**

Chapter 7 gives results from two validation experiments with IT experts and our findings and observations about these results. We start with an overview in Section 7.1. The first validation experiment is described in Section 7.2 while the modeling session design, preparation and execution is described in Section 7.2.1. Section 7.2.2 describes the data analysis procedures and the results. Our second validation experiment with IT experts is described in Section 7.3. Section 7.3.1 describes the research design, preparation and execution. In Section 7.3.2 we describe the data analysis procedures and the results. This chapter is ended with some concluding remarks, in Section 7.4, about the results, findings and observations from both modeling experiments.
6 Meta-model Validation: Controlled

The first ninety percent of the task takes ten percent of the time, and the last ten percent takes the other ninety percent!

– Ninety-ninety rule of project schedules

6.1 Overview

This chapter starts by discussing the research instruments that were developed and later used in most of the modeling sessions (exploratory, explanatory and confirmatory) for the analysis and evaluation of the modeling processes. It goes on to discuss the first exploratory modeling sessions that were carried out and insights gained from them which were further developed, improved upon and consolidated in subsequent (explanatory and confirmatory) modeling sessions both in this chapter and in the next chapter. Since most of the modeling sessions were carried out in a facilitated set-up environment (in computing labs or other specially prepared rooms), we prefer to call these modeling sessions: “controlled modeling experiments”. Controlled is used in the sense that one part of the meta-model is studied in “depth” (intensely) in one set of modeling experiments while the other part, although there, is studied in “breadth” and vice-versa in another set of experiments. This, however, does not create a disconnect between the analytic part of the meta-model (RIM) and the evaluative part (COME) since we are always aware of the existence of the other part. Taking this approach enables us to study and analyse critically the components and elements existing in either the RIM or the COME part of the meta-model. We introduce the data coding schemes, data gathering and analysis methods that were used in the analysis and evaluation of collaborative modeling processes. The chapter further discusses the explanatory modeling sessions that were carried out after the exploratory modeling sessions. An a-priori model that was used to study the interrelationships between the modeling artifacts is introduced. The chapter concludes with some remarks about the research instruments, data gathering and analysis methods, exploratory and explanatory modeling sessions carried out, and the a-priori model and insights gained about the RIM and COME frameworks and the meta-model.

The previous three chapters have presented frameworks and a meta-model that are derived from our conceptual model which was presented in section 1.2, Figure 1.1. Although we have presented a number of examples, illustrations and demonstrations to clarify the concepts in these frameworks and the meta-model, we are yet to show the required scientific rigour and relevance which should be demonstrated for the frameworks and the meta-model. This is one of the two chapters in which we take a stride to demonstrate the rigour and relevance of the developed constructs. Bearing in mind that we are following the design science approach [HMPR04, Hev07], there is a need to show both the rigour

This chapter is an extended version of the following publications: [SHP09a, SHP10a].
of the research approach and strategy taken and relevance of the designed constructs, methods, etc., by showing their applicability to practice.

6.2 Research Instruments and Data Analysis Methods

In this section we look at the research instruments that were used to collect the data for both the analysis and evaluation of the modeling processes and the methods that were used to analyse the data collected thereof. One could say this is a “one-stop center” for the description of the methods that were used for data collection and analysis. We prefer to describe them once rather than repeating them for each of the exploratory, explanatory and confirmatory modeling experiments that were carried out since the same methods were used. We do, however, point out any additional factors and/or constructs to which attention was paid in each modeling experiment and any other methods that were employed for data collection or analysis.

6.2.1 Research Instruments

One of the noted challenges in Information Systems research is related to lack of theoretical rigour in the development of measurement scales that should be used to capture the underlying explanatory concepts of the developed theoretical models or frameworks [DBW89, KZ87, MB91]. To overcome this challenge, there is a need to design and use rigorous and theoretically sound research instruments [Str89]. For this purpose, a number of guidelines have been developed to overcome the challenge of measurement and scale construction and the validation of the developed research instruments, see for example [DeV03, DXT94, RR07, SBG04]. Using these guidelines, we used “the-already-validated” research instruments and also designed some to measure the underlying theoretical concepts in the meta-model, i.e. for the analytic part of the meta-model (RIM framework) and the evaluative part (COME framework). These instruments ranged from electronic/technological tools (for the-already-validated ones) to new researcher-designed instruments. These are explained next.

♦ Electronic Research Instruments – RIM. Electronic research instruments were the major source of data for the analytic part of the meta-model (RIM framework). These electronic research instruments were purposely used as primary sources of data by recording the modeling sessions and, in some cases, used as evaluation instruments. As pointed out already in section 2.3, the whole collaborative effort is grounded in the communicative process. To identify the different facets of this communication, from the communicative dialogues and the different speech acts, there is need to record, digitally, this exchange between the different participants in the modeling session, see for example Figure 6.1. Visual and audio recording provides one of the major sources of data that is analyzed not only in getting the different facets of the communicative process but also knowing what takes place during collaborative modeling and how modelers do whatever they do. In essence, the recording of the modeling sessions helps us study and analyse the modeling process or the act of modeling from the communicative perspective.

Although it would be adequate to record the audio (sound) only, there are times when participants speak with “body language” resulting in what Sackler [Sac98] calls “the unspoken message” – shaking one’s head (in approval or disapproval, disbelief), frowning (showing displeasure or discontentment), etc. Explicit agreement about the proposals may
be detected by words such as “OK”, “Yes”, “Yeah”, “Agree”, etc., while explicit disagree-
ment may be detected by words such as, “No”, “Impossible”, “Can’t be”, “I disagree”,
ext. Implicit agreement or disagreement is harder to detect than its explicit counterpart.
Thus, having a visual recording that captures the body language helps to identify those
moments when the modelers either implicitly agreed or implicitly disagreed. This no-
tion was briefly introduced in section 3.4.3 as implicit and explicit model actions. Audio
as well as visual recording may bring out other factors such as power and leadership
struggles due to the different roles that modelers implicitly or explicitly play or assign
to themselves during the course of modeling. Such roles and activities, if recorded, can
point to the patterns that teams use to organize their work [Rit10a] which is eventually
used to determine how modelers structure the modeling process in the absence of a facil-
itator [SHP09d].

Interaction Log and Time-stamping. While discussing the RIM framework, an interaction-
log which acts as the repository of all the communicative speech acts was introduced in
section 3.5.1. These speech acts are supposed to be time-stamped for easy and subsequent
reference. Therefore, the recording instrument or the Digital Replay System (DRS), see
for example Figure 6.1, should have the capability of timing the audio and visual record-
ings. For most of the modeling sessions, we used an electronic cam-corder (video camera)
and a good digital audio recording instrument with good sound quality.
Electronic Research Instruments – COME. For the evaluation of the modeling artifacts we used three types of research instruments for the evaluative part of the meta-model (COME framework):

1. electronic research instrument (AHP-based)
2. researcher-designed research instrument (AHP-based)
3. researcher-designed extended research instrument

The electronic AHP-based research instrument, see section 4.7 – Figure 4.6 was used mainly to extend the communicative process from the analysis part of the modeling session into the evaluation part so that modelers can accomplish the collaborative evaluation of the modeling artifacts, thus exploiting the interaction link between the RIM and COME frameworks in the meta-model, see section 5.4.2. As argued already, modelers possess different priorities and preferences within their mental models due to their diverse backgrounds, a fact that brings about conflicting interests [Rit10a]. By engaging in a negotiation process which leads to some form of consensus, they are able to reconcile their differences in opinion and bias. The electronic AHP-based research instrument helps them to undertake this communicative dialogue where they eventually reach consensus by agreeing on the final score (weight) to give to a quality dimension of a modeling artifact. The main advantage of using the electronic AHP-based research instrument is that the subjectivity, measured by the Consistency Ratio (C.R.), see section 4.4.2 – Equation 4.13, is kept in check by the modelers as the weights are assigned to the different quality dimensions. This helps modelers to change their earlier positions through a negotiation process to bring it down below the appropriate threshold.

User-designed Research Instruments – COME. Two research instruments were designed by the researcher for the evaluation of the modeling artifacts. One is an AHP-based research instrument and the other is an extended researcher-designed research instrument, which is basically a “psychometric instrument” [DeV03, Nun78] that brings on board psychological (attitude, perception, intention, etc.) as well as behavioural factors from the Theory of Reasoned Action (TRA) and Theory of Planned Behaviour (TPB) discussed in sections 2.5 and 4.6. These two instruments are described next.

Researcher-designed AHP-based Instrument. The researcher-designed AHP-based research instrument served the following purpose. It was used as an “pre-survey” research instrument where the modelers’ initial (biased) opinions and ideas were captured before they engaged in a collaborative and communicative process. Getting the individual evaluation scores (weights) given to the quality dimensions of the modeling artifacts which indicate the priorities and preferences about the quality of each of these dimensions enables their aggregation so that a group priority can be computed. Since the modelers act in their own individual capacities while assigning the scores, these individual quality priorities and preferences are then aggregated using the Aggregation of Individual Priorities (AIP) technique discussed in section 4.5.2. This instrument is given in Appendix A.

Researcher-designed Extended Instrument. The second researcher-designed instrument, which we refer to as the “extended research instrument” was adapted and extended from
two research instruments existing in the literature. The first research instrument that was extended is given in [SHP10a], see Appendix B – Part A. The extension was to mainly incorporate concepts about evaluation of the modeling artifacts from: the (revised) SEQUAL framework (see section 2.4.1), the Quality of Modeling (QoMo) framework (see section 2.4.2) and some concepts from Guidelines of Modeling (GoM) framework (see section 2.4.3). We also adapted the research instrument given in [HMR97, Mat91] to incorporate psychological and behavioural factors that are measured by the Theory of Reasoned Action (TRA) (see section 2.5.1) and the Theory of Planned Behaviour (TPB) (see section 2.5.2) in our extended research instrument. Incorporation of TRA/TPB concepts in the research instrument helps us to operationalize the evaluation of “perceived-ness”, “use” and “ease-of-use” of the modeling artifacts. This, in a way, brings on board the Technology Acceptance Model (TAM) concepts (see section 2.5.3) in the evaluation and Moody’s Method Evaluation Model (MEM) concepts for evaluating the effectiveness and efficiency of the modeling session (see section 2.5.4). The extended research instrument is given in Appendix B – (parts A, B and C).

In constructing the researcher-designed instruments we followed the approach suggested for measurement and scale development, see for example, [Dav89, MB91, RR07, Str89]. The stages of this approach are summarized in Figure 6.2. The first stage, item creation, creates pools of candidate items for each relevant concept. Scale development, which consists of two sub-stages: item identification and substrata identification, is used to group the identified items into meaning and separate categories where construct, convergent and discriminant validity [GSB00, Str89] can be displayed [MB91, RR07]. It should be noted that item creation and identification is part of the COME framework methodology as discussed in section 4.2 – step 2: selecting the modeling artifacts and their quality dimensions, and step 3: choosing the evaluation method (sub-step 2). The quality dimensions were identified and grouped into the quality categories shown in Figure 4.1 during the initial exploratory modeling experiments. It should also be noted that the psychological and behavioural factors in the researcher-designed instrument in Appendix B (Part C) are based on the created quality dimensions since these capture the attitude, perception and intention of the modelers about the quality or use of the modeling artifacts. This instrument was tested for validity and reliability. Validity and reliability tests of the research instrument are reported in [SHP10a].

Unstructured, Non-Participant Observation and Interviews. The methods described above were the major sources of data. We, however, in addition to those methods and research instruments, used unstructured observation methods, see for example [Bry08], to record as much detail as possible what was going on in the modeling sessions. We
used a non-participant variant of the unstructured observation method which requires that
the “observer” (modeling session facilitator or another person) assigned this role simply
observes but does not directly take part in what is going on. In addition to the observation
approach, we interviewed the participants in the modeling sessions after the debriefing
phase at the end of every session. These two approaches simply supplemented the above
data collection methods but were not meant to be the primary source of data. This explains
why they were unstructured.

### 6.2.2 Data Coding and Analysis Methods

We used two methods – content analysis [Bry08, ch.18] and discourse/conversational
analysis [Gol03] – to code, categorize and analyze the electronically recorded data for
the analytic part of the meta-model. This was essentially done to identify and isolate
those macro and micro communicative dialogues and speech acts using the RIM frame-
work. For the evaluative part of the meta-model which is the COME framework, we
used the AHP approach and second generation statistical methods – Structural Equa-
tion Modeling (SEM) [Byr01a, Byr01b, Chi98, GSB00, RM06] and Factor Analysis
[AH08, Bro06, KM78] to analyse the data.

♦ **Data Coding and Categorization Methods – RIM.** Codes serve the purpose of la-
beling, separating, compiling and organizing data [Bry08, Fri11]. We used the content
analysis method to analyse, code and categorize the unstructured transcripts from the
electronic (audio and visual) media. Content analysis [Bry08, ch.18], see also [Ber52,
ch.12], is an approach for the analysis of documents and texts (visual, audio, printed,
etc.,) “that seeks to quantify content in terms of predefined categories in a systematic and
replicable manner” [Bry08, p.274]. It should be noted that, although the definition of
content analysis emphasizes the quantitative nature of the analysis (which may include
counting or determining frequencies of occurrences of certain words in the speech acts),
it is a qualitative data analysis approach. We did employ, therefore, *qualitative content
analysis* during the categorization of the identified communicative dialogues and speech
acts to construct meaning to the macro and micro conversational statements that lead to
the interactions in the RIM framework. This type of qualitative content analysis led to
categorization of interactions into the different types of arguments, propositions, negotia-
tions and decision-making statements. One of the qualitative content analysis approaches
that we employed is “discourse (conversation) analysis” given in [Gol03] which is used to
analyze the communicative dialogues for the Language Action Perspective (LAP). We fur-
ther used a combination of *focused coding* – a coding scheme of Grounded Theory (GT)
[GS67] – to break down, examine, compare, conceptualize and categorize the transcribed
data into macro and micro conversational dialogues and speech acts, and *pattern coding*
which is “a way of grouping summaries into smaller number of overarching themes or
constructs” [MH84].

The coding scheme helps to group communicative dialogues and speech acts into
the different categories of the interactions in the RIM framework. Transcription of the
recorded data is a laborious and tedious process, use of a software tool (package) is often
required. Among the Computer Assisted Qualitative Data AnalysisS (CAQDAS) tools
that are widely used for helping in the transcription and coding of the recorded data (text,
video, audio, image, geo-data or maps, etc.) using the content analysis coding techniques
are the MAXQDA [MAX11], NVivo [NVi11] and Atlas.ti [ATL11] tools. For our modeling session transcriptions we used Atlas.ti 6.2 to analyse and code our data for the analytic part (RIM) of the meta-model, see Figure 6.3. This choice is based on the following:

Atlas.ti, like NVivo, offers functionality for text files independently of audio/video files and offers functionality to code the audio/video directly without a need for a transcript. MAXQDA lacks the second functionality. In addition, as observed by Friese [Fri11], one does not have to use Glasser and Strauss’s Grounded Theory (GT) [GS67] when using Atlas.ti despite the coding techniques reflecting ideas and terminology from GT. Some of the ideas (concepts) and terminology that we used from GT which are available in Atlas.ti include: code (CO) and memo (ME).

Why Content Analysis and not Grounded Theory. The question that comes to mind when one claims to have used qualitative content analysis to analyze the unstructured transcripts is: why not use the classical grounded theory to analyze, code and categorize the transcribed data? We agree that grounded theory [GS67], see also [Chr07], is a versatile technique for collecting, analyzing, coding and categorizing data into themes and concepts that eventually lead to the theory which is grounded in the data. Our preference of (qualitative) content analysis to GT stems from the fact that whereas in GT the concepts or themes are coded as the data is collected and the researcher never has any idea which
concepts or themes are likely to emerge from the data (no preconception on part of the researcher) [BC07], for content analysis preconceptions are inevitable.

The researcher applying content analysis to analyze the collaborative communicative dialogues may have some preconceptions about the exchanges, such as propositions, argumentations, negotiations and decision-making taking place within the modeling session. Moreover, most of the categorizes in content analysis emerge after data analysis whereas in GT they may emerge during data collection and they dictate the way data are further collected. In this case “data are treated as potential indicators of concepts and the indicators are constantly compared” [Bry08, p.542]. Although we used “focused coding” to break down, examine, compare, conceptualize and categorize the transcribed data into macro and micro conversational dialogues and speech acts categorizes – a concept similar to open coding in GT, we did not apply directly the other coding schemes (axial and selective coding) as required for the GT method. For our case focused coding and pattern coding were enough to generate these categories.

Transcribing, Coding and Categorizing with Atlas.ti. To code the recorded data with Atlas.ti requires, first, saving the transcript in either a rich text format (RTF) or an excel compatible comma separated values (CSV) format and then importing it into one the CAQDAS tools being used. A pre-analysis phase that involved transcribing the audio data into text was used. We saved the transcribed data in Excel CSV format which was then imported into the Atlas.ti tool. Apart from helping us study the unspoken messages (body language), visual data played a lesser significant role in the transcriptions than audio data. Thus, visual data was not directly transcribed into Atlas.ti. This can be explained by our interest in the communicative dialogues and speech acts. In addition to codes (CO) and memos (ME), we used quotes (QU) (or quotations), code families (CF) and memo families (MF) to categorize the communicative and speech acts into smaller (micro) and bigger (macro) categories. Figures 6.4 shows an example of categorizing a communicative dialogue (CD) or speech act (SA) into micro categories (propose, ask) using the Atlas.ti
coding system.

**CD/SA:** OK, We have to model...Process...Where shall we start?

**CO:** Propose, Ask.

**QU:** Comment: Setting Creation Goal.

**ME:** Proposition, Setting the Agenda, Seeking Consensus, Consulting.

Figure 6.5 shows how the micro categories can be combined into a macro category (*Negotiation*) using the code family (CF) coding system and network view of Atlas.ti. Negotiation as observed in section 2.3.2, starts from a position of conflict and numerous communicative exchanges (propositions, acceptances, rejections, arguments, etc.) take place within this communication category.

It should be noted that it is this kind of analysis and categorization that leads to the concepts of the RIM framework. As can be gleaned from Figures 6.4 and 6.5, creation goal is part of the rule and goal component in the RIM whereas the micro and macro categories from the communication dialogues or speech acts (from the code families) are part of the interaction component of the RIM framework.

**Data Analysis Methods – COME.** In our modeling sessions, data that was used for the evaluation of the quality of the modeling artifacts came from two sources: electronic and non-electronic AHP-based research instruments and the researcher-designed extended research instrument. Analysis of these data was done using two types of techniques. For the AHP-based data (both electronic and non-electronic), the AHP methodology [Saa80] was used to analyse the data, see section 4.4. This involved mainly the aggregation of the scores (weights) indicating the modelers’ priorities and preferences using the methods described in section 4.5. To analyse data captured by the the researcher-designed extended research instrument we used, as pointed out already, the classical statistical meth-
ods, mainly factor analysis and second generation statistical methods, including Structural Equation Modeling (SEM). These methods are briefly illustrated in the section 6.3.2 where we give results from the explanatory modeling sessions.

6.3 Exploratory and Explanatory Modeling Sessions

To test the concepts of the frameworks and to test both their theoretical and practical relevance, we carried out a number of modeling sessions. These included the exploratory (pre-test and pilot) and explanatory controlled modeling sessions involving, first, both undergraduate and graduate university students in The Netherlands and in Uganda, and, second, IT professionals in the field. Modeling sessions with IT experts are described in Chapter 7. For the exploratory modeling sessions, the terrain we were treading was rather unknown in the beginning – from the perspective of the “act of modeling or modeling process” [PHB06] and what takes place in there – a fact that makes the problem being looked at to be more of a “wicked problem” [Con07, RW73] or “messy problem” [Ven99] (which indeed is) rather than a “tame problem” [Con01]. There was, therefore, a need to explore the concepts in a number of pilot modeling sessions. This gave us also a chance to pre-test and pilot test the research instruments which were eventually enhanced using the insights gained from the exploratory modeling sessions. In this section we explore some of these modeling sessions and the results that were obtained.

6.3.1 Exploratory and Explanatory Modeling Experiments – NL

Most of the theoretical concepts discussed for the RIM and COME frameworks were developed, defined and refined through a number of exploratory and (partial) explanatory modeling session experiments. We describe below participant selection, nature of the modeling experiments, experimental design, preparation and execution.

♦ Participants and Nature of Modeling Experiment. These modeling session experiments involved, initially, undergraduate students who were offering either a degree in computer science or information systems at the Institute of Computing and Information Sciences (iCIS) in the Faculty of Science at Radboud University Nijmegen (RUN) – The Netherlands (NL), and later graduate students were used in the modeling experiments. Despite the majority of the participants in the collaborative modeling experiments being from a computing background, it was not a strict requirement that one needed to have had some experience with modeling, although those who already had such skills were not excluded. By “experience with modeling”, we mean knowledge about, or skills with, a modeling language, modeling procedure, end-product (model) or a support-tool – the four modeling artifacts discussed in section 4.3 which are at the center of the RIM and COME frameworks and the meta-model. Relaxing such a requirement serves three purposes:

(i) bringing on-board participants with different skills and competencies and thus study how these, through their mental models, play out during the communicative and analytic phase (RIM) and communicative and evaluative (COME) phase and how they influence the priorities and preferences of the participants (see for example [FW05]).

(ii) studying how the different skills and competencies possessed help modelers assign roles, organize and structure the modeling process activities (see for example
6.3. Exploratory and Explanatory Modeling Sessions

(iii) studying whether the “seniority” brought about by the knowledge and/skills possessed influences the way agreement or disagreement, negotiation, group decision-making and/or consensus is attained (see for example [DH88, Pri90, Rit11]).

All the modeling experiments were synchronous, collocated sessions that employed either Face-to-Face (FTF) communication or Computer-Mediated Communication (CMC). These two modes offered us an environment to compare the degree of effectiveness and efficiency of the modeling session with respect to the effects and influences of the medium (support-tool). Although Group Support Systems (GSS)/Group Decision Support Systems (GDSS) [DOLV94, DOV00, GDSV01, NJDV+91, YA01] have long been studied and recognized to influence group activities, their impact in collaborative modeling has just gained momentum, see for example [RHI11, Rit10b, Rit10d, Rit10e]. Having a comparative study of FTF and CMC in both exploratory, explanatory and confirmatory modeling experiments helped us identify the dimensions of such a tool that could impact on the quality of the collaborative modeling processes.

♦ Experiment Design, Preparation and Execution. Most of the modeling cases that were worked on by the participants in the exploratory and partially explanatory modeling experiments were designed in the form of collaborative modeling games (CMG) [Hop08, HWR09, Sch09, SHP09a, Wil08]. This gaming metaphorical view of collaborative modeling as discussed in section 3.2, helped us study the process of modeling using the analytic (RIM) part of the meta-model using the triage of rules and goals, interactions and models. Each of the collaborative modeling game-cases consisted of a detailed description of a problem to be solved together with instructions to be followed but without prescription of the modeling method or modeling language to use. This was the case where Face-to-Face (FTF) communication was used and brown-paper models were to be developed on a white-board or another digital tool that allows model drawing was to be used, see for example [SHP09d]. For the modeling cases that required Computer-Mediated Communication (CMC), participants were first taken through the inner workings of the tool to use and then afterwards, they were let to carry on with the actual problem solving. The CMGs were designed with a task complexity that required modelers to solve the problem using McGrath’s task circumplex [McG84], see section 3.3.1 – 3.3.2 and Figure 3.1, by executing the following phases:

(i) production and presentation of ideas
(ii) discussion and evaluation of issues
(iii) solving the problem

Note that the modelers were neither aware of these phase nor did the instructions reveal the order of these phases. Our overriding goal was to see how far they could go in structuring the modeling process to as close a process that contains those phases. It should also be noted that embedded within these three phases are the communication and evaluation which we study through the analytic (RIM) part and evaluative (COME) part of the meta-model. Descriptions of the modeling cases were given to the participants in
“modeling labs” – rooms that were specially arranged by the researcher in which to have the modeling experiments. The modeling experiments had the following phases:

1. **briefing phase** – where the modelers were briefed about the purpose or objectives of the modeling experiment. The modeling case and instructions were also given;

2. **pre-survey instrument fill-out phase** – where the modelers’ prior and unbiased experiences were captured;

3. **actual modeling and evaluation phase** – where the modelers engaged in the actual collaborative production of the models and evaluation of the artifacts, and in which unstructured observation occurred;

4. **post-survey research instrument fill-out phase** – where the modelers’ post-modeling experiences were captured; and

5. **debriefing phase** – which was a wrap phase and in which unstructured interviewing occurred.

The researcher-designed AHP-based instrument was used in the pre-surveys, the electronic AHP-based instrument was used in the actual evaluation during the communicative process while the researcher-designed extended research instrument was used as a post-survey instrument. In addition to the modelers, the modeling session had a modeling session facilitator whose role was more of clarifying if and/or when called upon than chauffeuring or driving the modeling session. The role of unstructured observation was played by another non-participant person whose role was to record as much as possible what was taking place. Recording and timing of the modeling sessions was done for phase 3 since this was the one that involved the McGrath’s task circumplex task types.

### 6.3.2 Exploratory and Explanatory Modeling Experiments – UG

The second set of exploratory and partial explanatory experiments were carried out in Uganda. Unlike the exploratory and explanatory modeling experiments carried out in The Netherlands which concentrated more on concepts in the RIM framework, modeling experiments in Uganda concentrated more on the COME framework concepts. Using these modeling experiments we were able to develop a *Collaborative Modeling Process Quality (CMPQ)* construct that can be used to measure the quality of the modeling artifacts through the quality constructs discussed in sections 4.3.1 – 4.3.4, namely, Perceived Quality of the Modeling Language (PQML), Perceived Usefulness of the Modeling Procedure (PUMP), Perceived Quality of the End Products (PQEP), Perceived Ease of Use of the Medium (EOUM) or the Ease of Use of the Support-tool (EOUST), see also [SHP10a].

◊ **Participants and Nature of Modeling Experiment.** Participants in the modeling experiments were third-year undergraduate students in the Department of Computer Science, in the Faculty of Science at Kyambogo University (KYU) undertaking a Bachelor of Information Technology and Computing (BITC) degree course. The students’ task was to: 1) identify the different processes, associated activities and objects; 2) develop the conceptual model using COMA’s UML editor; and, 3) assess the quality of the whole collaborative modeling process by filling-out the given questionnaire immediately after
the modeling session. Task 1 is associated with the modeling procedure whose quality is assessed via the PUMP construct. Task 2 is concerned with the end-products (conceptual model), the modeling language (UML) and the medium or support-tool (COMA) whose quality is measured, respectively, via the PQEP, PQML and EOUM constructs. Task 3 is concerned with assessing the quality of the whole collaborative modeling process via the CMPQ construct by filling-out the given questionnaire.

**Experiment Design, Preparation and Execution.** The modeling experiment was conducted after an introductory course in information and system modeling using UML. A simple UML editor, embedded within the Collaborative Modeling Architecture (COMA) tool [Rit08a], was used. A total of 107 students participated in the modeling experiment. They were divided into 6 groups with an average of 17 participants and 3 or 4 participants per computer terminal. The modeling experiments were conducted on two days, each day having three groups. Each experiment lasted for not more than 70 minutes.

The **CMPQ Construct.** The construct was developed basing on the following assumptions or propositions.

### Figure 6.6: Causality relationships between the modeling artifacts.

- **P1:** Modelers assessing the modeling process will always assess highly the modeling procedure for higher quality values of the modeling language.
- **P2:** Modelers will always assess highly the quality of the products (models) if the modeling language is highly rated.
- **P3:** Modelers will always rate highly the modeling procedure if they have highly rated the quality of the medium or support system.
- **P4:** Modelers will always rate highly the products (models) if the (medium) support system is rated to be of high quality.
- **P5:** Modelers will always assess the quality of the products (models) highly if they have highly rated the modeling procedure.

These assumptions, in a way, establish cause-effect relationships between the different CMPQ constructs (PQML, PUMP, PQEP and EOUM) and two sets of variables: exogenous or independent variables (I.V.) and endogenous or dependent variables (D.V.).
The exogenous variables include the PQML and EOUM constructs while the endogenous variables in the model include PUMP and PQEP. Due to the assumption of high quality assessments, it is presumed that all effects are positive. Figure 6.6 depicts the causality relationships between the four CMPQ constructs. To study these causality relationships between the different constructs we further developed a structural and measurement model in Figure 6.7 using Structural Equation Modeling (SEM) [Byr01a, GSB00, RM06] where the exogenous constructs are represented by the symbol $\xi$ and endogenous are represented by $\eta$ while the actual scores or measures of the quality dimensions (see Tables 4.2 – 4.5) given by the modelers are, respectively, represented by $X$ and $Y$. The quality dimension scores are given codes, e.g., $ML_1, ML_2, \ldots, ML_n$ for the modeling language (ML); $ST_1, ST_2, \ldots, ST_n$ for the support-tool (medium), etc., see Appendix B – Part A.

Definitions of the terms used in the structural and measurement model are given in Appendix D. The structural and measurement model can be analyzed using, first, Exploratory Factor Analysis (EFA) [KM78], and, second, Confirmatory Factor Analysis (CFA) [AH08, Bro06, DXT94], see also [Fie09, 17]. To this end, we developed two models, an a-priori proposed conceptual and theoretical model (Model 1) and a competing model (Model 2), that included the four identified constructs: PQML, PUMP, PQEP and EOUM as first order factors in the first model and CMPQ as a second-order factor in the second model onto which the four factors in model 1 load. These models, which are also discussed in [SHP10a], are presented in Figure 6.8. The second model acts as a competing model for the first model and is intended to corroborate the four factors in the first model [TSS08].
6.3. Exploratory and Explanatory Modeling Sessions

![Diagram of CFA models: Conceptual model and competing model.](image)

♦ Content Validation of the Instrument. The initial measurement instrument had a total of 54 quality dimensions synthesized from the literature using steps 2 and 3 of the COME framework in Figure 4.1: 10 for PQML, 10 for PUMP, 15 for PQEP and 19 for EOUM. These mainly came from concepts from the SEQUAL, QoMo and GoM frameworks. We tested the researcher-designed instrument for content validity. Content validity [Str89, GSB00] is established through literature reviews and/or expert panels or judges and measures the degree to which the selected items in the research instrument represent the content pool to which the research instrument will be generalized [SBG04]. To achieve this, a panel of three content experts is considered adequate for content validation [Lyn86]. In light of this recommendation, three experts were asked for their judgement about the adequacy and representation of the constructs and their quality dimensions for the CMPQ construct, see also the item identification step in Figure 6.2.

A 5-point rating scale (with 1 = highly appropriate and 5 = highly inappropriate) was used to rate the appropriateness of the quality dimensions. The mean value of each of the dimensions ranged between 1.10 and 4.33. This means that some of the quality dimensions were inappropriate. The qualitative judgement of the experts indicated that the numbers above were too many for any construct and many were found to overlap. It was recommended to refine, merge and group many of these quality constructs. The original dimensions and their refined and merged groupings are shown in Table 4.1. The groupings form a set of sixteen quality dimensions for each of the four modeling constructs PQML, PUMP, PQEP and EOUM. The instrument with sixteen questions measuring the quality of the constructs, using a 7-point likert scale is given in Appendix B – Part A.
Exploratory Factor Analysis. We carried out an Exploratory Factor Analysis (EFA) subjecting the 107 case in the data set to Principal Component Analysis (PCA) [Jol02]. The Promax rotation method was used since the data exhibited strong correlations among the extracted factors. To identify the suitable number of factors underlying the CMPQ construct we used the three recommended steps in [TF07]. We dropped all factors with at most 0.4 values. This condition prevented cross-loading on more than one factor at 0.4 and above. We also applied and repeated factor analysis using 3, 4, 5 and 6 factor loadings. All factors were extracted at eigenvalue of 1. The 4-factor loadings was found to be the most suitable for the CMPQ construct and explains 70.3% of the variance. The factor loadings of the 16 quality dimensions of the four quality constructs measured through the research instrument are given in Table 6.1.

<table>
<thead>
<tr>
<th>Construct</th>
<th>Code</th>
<th>Quality Dimension</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Cronbach’s α</th>
</tr>
</thead>
<tbody>
<tr>
<td>PQML</td>
<td>ML1</td>
<td>Understandability</td>
<td>.895</td>
<td></td>
<td></td>
<td></td>
<td>.866</td>
</tr>
<tr>
<td></td>
<td>ML2</td>
<td>Clarity</td>
<td>.798</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ML3</td>
<td>Syntax Correctness</td>
<td>.886</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>ML4</td>
<td>Conceptual Minimalism</td>
<td>.787</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PUMP</td>
<td>MP5</td>
<td>Efficiency</td>
<td></td>
<td>.718</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MP6</td>
<td>Effectiveness</td>
<td></td>
<td>.883</td>
<td></td>
<td></td>
<td>.850</td>
</tr>
<tr>
<td></td>
<td>MP7</td>
<td>Satisfaction</td>
<td></td>
<td>.842</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>MP8</td>
<td>Commitment &amp; Shared Understanding</td>
<td></td>
<td>.882</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PQEP</td>
<td>EP9</td>
<td>Product Quality</td>
<td></td>
<td></td>
<td>.833</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EP10</td>
<td>Understandability</td>
<td></td>
<td></td>
<td>.840</td>
<td></td>
<td>.834</td>
</tr>
<tr>
<td></td>
<td>EP11</td>
<td>Modifiability &amp; Maintainability</td>
<td></td>
<td></td>
<td>.795</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>EP12</td>
<td>Satisfaction</td>
<td></td>
<td></td>
<td>.795</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EOUM</td>
<td>ST13</td>
<td>Functionality</td>
<td></td>
<td></td>
<td></td>
<td>.817</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ST14</td>
<td>Usability</td>
<td></td>
<td></td>
<td></td>
<td>.944</td>
<td>.833</td>
</tr>
<tr>
<td></td>
<td>ST15</td>
<td>Satisfaction &amp; Enjoyment</td>
<td></td>
<td></td>
<td></td>
<td>.702</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ST16</td>
<td>Collaboration Communication &amp; Facilitation</td>
<td></td>
<td></td>
<td></td>
<td>.661</td>
<td></td>
</tr>
</tbody>
</table>


Reliability Tests and Construct Validity. We note from the results presented that all factor loadings of the 16 items load on a single factor for each of the PQML, PUMP, PQEP and EOUM constructs. This is preliminary evidence of uni-dimensional reliability of the
6.3. Exploratory and Explanatory Modeling Sessions

To check whether the research instrument is an effective measure of the CMPQ theoretical construct, we had to check the instrument for “construct validity” which is established through either “discriminant, convergent” or “factorial validity” [HTAB98]. The presence of eigenvalues of or above 1, loadings of at least 0.40 and no cross-loadings above 0.40, is confirmation of discriminant, convergent and factorial validity and hence confirms construct validity for EFA method using the PCA technique [SBG04]. As is evident from Table 6.1, the eigenvalues are above 1.0 and all loadings are above the threshold value and there are no cross-loadings for the 4-factor model used. Therefore the research instrument is an effective measure of the CMPQ construct.

**Table 6.2: Factor Loadings and Model Fit Test Results.**

<table>
<thead>
<tr>
<th>Construct</th>
<th>Code</th>
<th>Quality Dimension</th>
<th>Factor Loading</th>
<th>Model Fit Indices</th>
</tr>
</thead>
<tbody>
<tr>
<td>PQML</td>
<td>ML1</td>
<td>Understandability</td>
<td>0.76</td>
<td>Model 1: 142.923</td>
</tr>
<tr>
<td></td>
<td>ML2</td>
<td>Clarity</td>
<td>0.75</td>
<td>Model 2: 143.738</td>
</tr>
<tr>
<td></td>
<td>ML3</td>
<td>Syntax Correctness</td>
<td>0.84</td>
<td>$\chi^2$ : SB</td>
</tr>
<tr>
<td></td>
<td>ML4</td>
<td>Conceptual Minimalism</td>
<td>0.80</td>
<td>GFI : &gt; 0.90</td>
</tr>
<tr>
<td>PUMP</td>
<td>MP5</td>
<td>Efficiency</td>
<td>0.62</td>
<td>Model 1: 86.3</td>
</tr>
<tr>
<td></td>
<td>MP6</td>
<td>Effectiveness</td>
<td>0.94</td>
<td>Model 2: 86.1</td>
</tr>
<tr>
<td></td>
<td>MP7</td>
<td>Satisfaction</td>
<td>0.71</td>
<td>$F_{2/d.f}$ : 1 &lt; 3</td>
</tr>
<tr>
<td></td>
<td>MP8</td>
<td>Commitment &amp; Shared Understanding</td>
<td>0.78</td>
<td>RMR : &lt; 0.10</td>
</tr>
<tr>
<td>PQEP</td>
<td>EP9</td>
<td>Product Quality</td>
<td>0.78</td>
<td>GFI : &gt; 0.90</td>
</tr>
<tr>
<td></td>
<td>EP10</td>
<td>Understandability</td>
<td>0.77</td>
<td>AGFI : &gt; 0.80</td>
</tr>
<tr>
<td></td>
<td>EP11</td>
<td>Modifiability &amp; Maintainability</td>
<td>0.07</td>
<td>NFI : &gt; 0.90</td>
</tr>
<tr>
<td></td>
<td>EP12</td>
<td>Satisfaction</td>
<td>0.74</td>
<td>TLI : &gt; 0.90</td>
</tr>
<tr>
<td>EOUM</td>
<td>ST13</td>
<td>Functionality</td>
<td>0.68</td>
<td>CFI : &gt; 0.90</td>
</tr>
<tr>
<td></td>
<td>ST14</td>
<td>Usability</td>
<td>0.67</td>
<td>RMSEA : &lt; 0.08</td>
</tr>
<tr>
<td></td>
<td>ST15</td>
<td>Satisfaction &amp; Enjoyment</td>
<td>0.80</td>
<td>CAIC : &gt; 0.90</td>
</tr>
<tr>
<td></td>
<td>ST16</td>
<td>Collaboration Communication &amp; Facilitation</td>
<td>0.81</td>
<td>Key</td>
</tr>
</tbody>
</table>

To check whether the research instrument is an effective measure of the CMPQ theoretical construct, we had to check the instrument for “construct validity” which is established through either “discriminant, convergent” or “factorial validity” [HTAB98]. The presence of eigenvalues of or above 1, loadings of at least 0.40 and no cross-loadings above 0.40, is confirmation of discriminant, convergent and factorial validity and hence confirms construct validity for EFA method using the PCA technique [SBG04]. As is evident from Table 6.1, the eigenvalues are above 1.0 and all loadings are above the threshold value and there are no cross-loadings for the 4-factor model used. Therefore the research instrument is an effective measure of the CMPQ construct.

**Confirmatory Factor Analysis.** In the previous section, a data-driven and theory development method – EFA [Bro06] – was used to develop and identify the patterns of relationships between the PQML, PUMP, PQEP, and EOUM constructs and their quality dimensions in measuring the CMPQ construct. To further confirm the identified patterns of relationships between the constructs measuring the CMPQ construct, and test the theory of these relationships, we carried out a Confirmatory Factor Analysis on the data.
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set [AH08]. CFA being a special case of Structural Equation Modeling (SEM) [RM06] requires special SEM tools, e.g., AMOS, LISREL, EQS, Mplus or SAS/STAT CALIS [AH08, Arb09, Byr01a, Byr01b, RM06]. We used AMOS 18.0 [Arb09] on the data set used in EFA by applying the maximum likelihood (ML) method. Results of the CFA analysis are shown in Table 6.2. As can be seen CFA results confirm the construct validity and reliability of the result instrument, since the values of Goodness-of-Fit Index (GFI), Normed Fit Index (NFI), and Adjusted Goodness-of-Fit Index (AGFI) are close to the threshold values and Cronbach’s alpha for AMOS is above 0.70 [GSB00, Nun78].

6.4 Explanatory Controlled Experiments

The exploratory and partial explanatory modeling experiments carried out during the initial phases of the research gave us insights about the structure of the modeling process or the act of modeling and how quality of such modeling processes can be determined. To further study, analyse and evaluate these collaborative modeling processes, and to concretize the concepts and insights gained from them, we carried out a number of “controlled experiments” which are explained in the following sections. The first explanatory modeling experiment, in addition to testing further the concepts in the RIM and COME framework, tested the impact of a Computer-Mediated Communication (CMC) tool on the efficiency and effectiveness of modeling process. To test this impact, two groups of participants were used: one group (the control group) using the Face-to-Face (FTF) communication while the second group (the controlled/study group) used the CMC tool. The nature of this modeling experiment for the control group was designed along the concept of digital dialogue games [Rav07, Rav06, RMS10] illustrating, once again, the game metaphorical nature of collaborative modeling, see section 2.3.1 for dialogues, arguments and dialogue games. The CMC offers an environment for studying and analyzing the communicative process using a support-tool which is compared and contrasted with the FTF environment. In McAlister et al. [MRS04], group interaction is combined with design in supporting the collaborative argumentative process using a synchronous CMC tool. The concept here is very much similar to studying and analyzing collaborative modeling using the communicative process. As pointed out in the overview, we take a deep study and analysis of one of the components of the meta-model while taking broad analysis of the other but cognizant of its existence and the role it plays in the meta-model. In this part emphasis is on the analytic part of the meta-model, i.e., the RIM framework and on the impact of the support-tool on the effectiveness and efficiency of the collaborative modeling process.

6.4.1 Experiment Design, Preparation and Execution

This explanatory controlled experiment was performed by graduate students undertaking a masters degree in computer science in the Institute of Computing and Information Science (iCIS) in the Science Faculty at Radboud University Nijmegen (RUN) – The Netherlands. Unlike the first exploratory and explanatory modeling experiments that were driven entirely by the modelers themselves, this type of modeling session required a “skilled facilitator” [Sch94] playing a key role in the modeling session. The reason for this was due to the Group Model Building (GMB) approach [AVRR07, RA95, Ven96] that we employed in eliciting mental model knowledge and building the models. GMB, which mainly uses the Systems Dynamics (SD) methodology [For61, For87, Ste00] is an ap-
6.4. Explanatory Controlled Experiments

The approach that enables stakeholders or clients in a modeling session to get deeply involved in model construction [Ven96, Ven99, RVT00]. The modeling experiment was designed to elicit the mental model knowledge [RAMS94, RVA+89] of the modelers and, collaboratively, under the guidance of the skilled facilitator, develop the models either through Face-to-Face (FTF) or Computer-Mediated Communication (CMC). The modeling experiments involving the two groups (FTF and CMC) were conducted on two separate days. They both involved working on the same case with the facilitator. Modelers in both experiments were required to collaboratively develop a model for the case under the guidance of the facilitator. The models were developed using a Systems Dynamics Tool, Vensim [EP92, Ven11] manipulated by the facilitator with contributions from the modelers.

Figure 6.9: GMB face-to-face developed model.

♦ The FTF Group Model Building Session. The modeling session was designed to be a synchronous (same place, same time) [BGBG95, p.742] session and had 3 participants. Like all the previous exploratory and partial explanatory modeling sessions, modelers started by filling out a pre-survey questionnaire (AHP-researcher designed) before starting the actual modeling session. After this, the facilitator introduced the case to work on which involved a current analysis of a policy introduced in the education system by the government. This was chosen on the basis that modelers being students and having heard about it and known its impact on their education, would readily generate enough ideas. They were required to first write down their individual ideas using a brainstorming approach after which they presented their ideas in a round-robin approach to the facilitator, see section 2.3.3 – Table 2.3. Note here that this approach results in a communicative process with arguments, propositions, rejects/accepts of, and decision-making/negotiation about, the generated ideas offering the ingredients to the analytic part.
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(RIM) of the meta-model – mainly the interaction component and the model (proposition) component with the planning, creation, collaboration goals [BHP07] as the obvious elements of the rule/goals component.

From the contributions of the modelers, the facilitator developed a “feed-back or causal-loop” model for the case, see Figure 6.9, which was visible to all the participants and to which they were free to add or subtract through a communicative and argumentative process before finally reaching consensus about what should remain in the model. The modeling experiment was concluded by the participants filling-out a post-survey questionnaire (researcher-designed extended instrument) given in Appendix B. The actual modeling session was recorded on camera. This helped to track the communicative dialogue (speech act) exchanges and the dynamic development of the model through these exchanges.

Figure 6.10: GMB basic dialogue game components.

♦ The CMC Group Model Building Session. This was a synchronous (same time, different places/remote interaction) [BGBG95, p.742] modeling session with 3 participants. The second modeling group (controlled group), like the FTF group, started by filling out the pre-survey questionnaire. The session facilitator introduced the modeling case and briefed the participants about the problem to be solved and the objective or the goals of carrying out the session. The researcher’s goal was to study the impact the support-tool may have on the effectiveness and efficiency of the modeling process. After the initial briefing, each participant had to move to their own specially prepared rooms. To this end, a Computer-Mediated Communication (CMC) tool – InterLoc [Int11] – that allows synchronous (collocated or distant, same time) [BGBG95, p.742] communication and collaborative problem solving and learning was used on every PC of the participant. Although CMC learning and collaboration have been studied and analyzed before with respect to participant dialogues, mainly by the HCI Group at Patras with tools such as “Synergo” and “ModelingSpace” implemented using the Object-oriented Collaboration Analysis Frame-
work (OCAF) [ADK03, AKF04, AKMF04, ADKM03, AKFM03, ADKF02, AMK04b] (see also [PFD04]), none of these tools is automated in such a way that the elements of the communicative and argumentation process are embedded. As stated before, collaborative modeling is metaphorically speaking a game. And most of the collaborative modeling tasks were designed as dialogue games to fit within this metaphor. InterLoc is one of the few tools that allows participants to play, digitally (and “online”), such dialogue games [Rav07, MRS04, RMS10]. The other tool that falls within this category is Rittgen’s COMA tool [Rit10d, Rit08a].

The InterLoc tool implements user-designed collaborative digital dialogue games played by the participants under the direction of the facilitator. Noting, from the exploratory modeling sessions, that collaborative modeling is driven by the communicative process with communicative dialogues or speech acts consisting of proposal, arguments, accepts/rejects, questions/clarifications, etc., the InterLoc digital game should have these as its basic components. Figure 6.10 shows these components which were implemented in the InterLoc tool while Figure 6.11 shows how the modelers (players) and the facilitator used these components to carry along the communicative dialogue in InterLoc. Like was done with the FTF modeling session, participants had to first brainstorm about the modeling case,
first, individually, by generating in a freewheeling fashion a number of ideas and jotting down their ideas on a piece of paper, and, second, by introducing their ideas to other members in a round-robin approach of the Nominal Group Technique (NGT), see section 2.3.3 – Table 2.3. These ideas acted as sort of initial propositions on which the argumentation, negotiation and decision-making processes were later based. The collaborative digital dialogue game that was designed for InterLoc included such functionalities for proposals, rejects, accepts, etc., see Figure 6.10.

The generated ideas were communicated to the facilitator through the InterLoc Tool who used them to develop a Systems Dynamics feedback (causal-loop) model shown in Figure 6.12 using the Vensim tool [Ven11]. The facilitator’s model screen was visible to all the modelers through Oneeko [One11] – a screen-sharing and collaborative tool that uses the “looking glass concept”, see Figure 6.12. The Oneeko tool was also used by the facilitator to invite the participants to take part in the modeling session using a Oneeko generated web-link. This could be sent to the participants via e-mail or via a social medium like Skype. This particular modeling session was also recorded on camera from the facilitator’s room since, although he communicated with the participants via the InterLoc tool, he was always requested to “speak to himself”, i.e., speak aloud his thoughts using a Think Aloud Protocol (TAP) method [SBS94].
6.4.2 Data Analysis Procedures and Results

In this section we look at a few sample results obtained from the explanatory modeling session discussed in the preceding section in which we set out to compare and contrast the effectiveness and efficiency of the Face-to-Face (FTF) and the Computer-Mediated Communication (CMC). It should be noted that in this particular controlled modeling experiment, we implemented the micro and macro communicative dialogue categories, see Figures 6.4 – 6.5, that were generated in the exploratory and partial explanatory modeling experiments and used them in a digital dialogue game. These are the micro and macro components shown in Figure 6.10. It is, therefore, not necessary to transcribe the communicative dialogues shown in Figure 6.11 into the Atlas.ti tool to identify these components. Successful application of this analytic part of the meta-model in the modeling session is indicative of its effectiveness and versatility in helping us study and analyse the modeling session. It should also be noted that we took a position to deeply look at one part of the meta-model (RIM) while suspending the other (COME) but being still aware of, and recognizing, the link between the two through the interaction component in the meta-model. To determine the impact of the support-tool on the effectiveness and efficiency of the modeling process, needs “awakening” the other part of the meta-model (COME) that has been in abeyance. We, therefore, present the results using the COME framework to show how this impact was assessed. The results presented were analyzed using the AHP methodology through the steps of the COME framework in section 4.2 and those of the AHP methodology in section 4.4 and section 4.5. Using the researcher-designed AHP-based instrument, see Appendix A, modelers in both modeling sessions (FTF and CMC) evaluated the modeling artifacts used in, and produced during, the session. Note here that the modelers or evaluators (decision-makers) act in their own right rather than as a group. We, thus, use the Aggregation of Individual Priorities (AIP) procedure described in section 4.5.2 to aggregate the individual priorities into group priorities. The individual pairwise comparison matrices and their corresponding priorities, see Equation 4.8, with consistency values, see Equation 4.12, obtained using the AHP steps are given below for the three modelers ($M_1, M_2$ and $M_3$). The results are for the modeling procedure artifact with quality dimensions in Table 4.3 along and on top of the matrix in the order shown.

♦ The FTF Group Model Building Session.

$A^{[M_1]} = \begin{bmatrix} 1 & 4 & 3 & 5 \\ 1/4 & 1 & 2 & 1 \\ 1/3 & 1/2 & 1 & 1/2 \\ 1/5 & 1 & 2 & 1 \end{bmatrix}$  \hspace{1cm} w^{[M_1]} = (0.565, 0.165, 0.111, 0.158)^T

$\lambda_{\text{max}} = 4.157, \ CI = 0.053, \ CR = 0.059$

$A^{[M_2]} = \begin{bmatrix} 1 & 1/5 & 1/3 & 1/5 \\ 5 & 1 & 3 & 1 \\ 3 & 1/3 & 1 & 1 \\ 5 & 1 & 1 & 1 \end{bmatrix}$  \hspace{1cm} w^{[M_2]} = (0.069, 0.412, 0.210, 0.310)^T
\[ \lambda_{\text{max}} = 4.115, \; CI = 0.038, \; CR = 0.041 \]
\[
\mathbf{A}^{[M3]} = \begin{bmatrix}
1 & 1/5 & 1/3 & 1/4 \\
5 & 1 & 5 & 4 \\
3 & 1/5 & 1 & 1/2 \\
4 & 1/4 & 2 & 1
\end{bmatrix}
\]
\[ \mathbf{w}^{[M3]} = (0.067 \; 0.584 \; 0.134 \; 0.214)^T \]
\[ \lambda_{\text{max}} = 4.188, \; CI = 0.063, \; CR = 0.070 \]

The CMC Group Model Building Session.

\[
\mathbf{A}^{[M1]} = \begin{bmatrix}
1 & 2 & 1 & 4 \\
1/2 & 1 & 1 & 3 \\
1 & 1 & 1 & 5 \\
1/4 & 1/3 & 1/2 & 1
\end{bmatrix}
\]
\[ \mathbf{w}^{[M1]} = (0.362 \; 0.240 \; 0.322 \; 0.077)^T \]
\[ \lambda_{\text{max}} = 4.060, \; CI = 0.020, \; CR = 0.022 \]

\[
\mathbf{A}^{[M2]} = \begin{bmatrix}
1 & 5 & 2 & 3 \\
1/5 & 1 & 1 & 2 \\
1/1 & 1 & 1 & 3 \\
1/3 & 1/2 & 1/3 & 1
\end{bmatrix}
\]
\[ \mathbf{w}^{[M2]} = (0.502 \; 0.167 \; 0.228 \; 0.103)^T \]
\[ \lambda_{\text{max}} = 4.187, \; CI = 0.062, \; CR = 0.070 \]

\[
\mathbf{A}^{[M3]} = \begin{bmatrix}
1 & 3 & 4 & 4 \\
1/3 & 1 & 3 & 3 \\
1/4 & 1/3 & 1 & 2 \\
1/4 & 1/3 & 1/2 & 1
\end{bmatrix}
\]
\[ \mathbf{w}^{[M3]} = (0.523 \; 0.261 \; 0.126 \; 0.089)^T \]
\[ \lambda_{\text{max}} = 4.143, \; CI = 0.048, \; CR = 0.054 \]

We note that all the values satisfy the consistency condition, see Equation 4.13. Using the weighted geometric mean method (WGMM) as the aggregation method and the eigenvalue method (EGVM) as the prioritization procedure, we aggregated the individual priorities using Equation 4.16 and Equation 4.19. The results for the group judgement (evaluation) matrices \(\mathbf{A}^{[G1]}_{\text{FTF}}\) and \(\mathbf{A}^{[G2]}_{\text{CMC}}\) and priority vectors \(\mathbf{w}^{[G1]}_{\text{FTF}}\) and \(\mathbf{w}^{[G2]}_{\text{CMC}}\), for the FTF group (G1) and CMC group (G2) are shown below:

\[
\mathbf{A}^{[G1]}_{\text{FTF}} = \begin{bmatrix}
1 & 0.543 & 0.693 & 0.630 \\
1.842 & 1 & 3.107 & 1.587 \\
1.442 & 10.322 & 1 & 0.630 \\
1.587 & 0.630 & 1.587 & 1
\end{bmatrix}
\]
\[ \mathbf{w}^{[G1]}_{\text{FTF}} = (0.288 \; 0.341 \; 0.146 \; 0.219)^T \; \lambda_{\text{max}} = 4.067, \; CI = 0.022, \; CR = 0.025 \]

\[
\mathbf{A}^{[G2]}_{\text{CMC}} = \begin{bmatrix}
1 & 2.466 & 3.302 & 3.302 \\
0.405 & 1 & 1.587 & 1.817 \\
0.303 & 0.630 & 1 & 1.101 \\
10.303 & 0.630 & 0.909 & 1
\end{bmatrix}
\]
6.5. Concluding Remarks

This chapter has presented a number of modeling experiments including exploratory, explanatory and controlled experiments that were designed to test the concepts in the meta-model through the RIM and COME frameworks. Taking a “depth–breadth” approach we have shown how one part of the meta-model can be studied and analyzed in great detail while putting the other in abeyance without the losing the link between the two. The chapter has shown the scientific rigour as required of the design science approach, through a number of artifact and experimental design, data collection, analysis and evaluation. Using the collaborative digital dialogue games we have shown how the concepts in the analytic part of the meta-model (RIM) can be applied to study and analyse a modeling process. Using some of the coding schemes of grounded theory (GT) we have shown how the micro and macro categories of communicative dialogues are obtained. A Collaborative Modeling Process Quality (CMPQ) construct was developed to show how the quality of the four modeling artifacts can be obtained through the perceived quality of the modeling language (PQML), perceived quality of the end-product (model) (PQEP), perceived use of the modeling procedure (PUMP) and perceived ease of use of the medium (support-tool) (EOUM).

In addition to determining the quality of the artifacts, the CMPQ construct can be used to assess the (inter-) relationships between the PQML, PQEP, PUMP and EOUM constructs. Through a number of statistical tests, the validity and reliability of the instrument used to measure quality through CMPQ were established. To determine the impact of the medium or support-tool on the effectiveness and efficiency of the modeling process, we used the AHP methodology to assess this impact. This, in a way, brought in the evaluative part (COME) of the meta-meta which had been in suspension during the study and application of the analytic part. This chapter has demonstrated the rigour and applicability of the meta-model and the frameworks. In the next chapter we look at some of the modeling experiments that we carried out with IT experts in the field to further assess the relevance of the meta-model and frameworks and their applicability in practice.

\[ w_{CMC}^{G2} = \begin{pmatrix} 0.456 & 0.219 & 0.210 & 0.089 \end{pmatrix}^T \lambda_{max} = 4.008, CI = 0.003, CR = 0.003 \]
7 Meta-model Validation: Practice

Validation is checking that you are not claiming more than you can justify. It is estimating the risk that you are wrong. It is not reducing that risk to zero. The will to validate is acceptance to live with uncertainty.

– Wieringa, 2010

7.1 Overview

The previous chapter has demonstrated one aspect in the application of the rigour cycle which is the selection of the appropriate methods for constructing, analyzing and evaluating the designed artifact – the meta-model and its associated RIM and COME frameworks. This chapter looks at the relevance of meta-model and the frameworks, their applicability and acceptability in practice. Motivated by the desire to study, analyze and understand what takes place during the actual modeling sessions in practice and the desire to improve the modeling environment with a support tool, we test and get insights from the field experts about the designed artifact. Noting also that the application domain of any designed artifact consists of stakeholders, organizational systems and other technical systems which interact in harmony towards realization of the goals, objectives, visions and missions of any enterprise, it is desirable to take back the designed solution to the problem domain and see how far it it accepted and whether it improves the environment.

It is, thus, against this background that this chapter looks at the explanatory and confirmatory modeling experiments that we carried out to validate the concepts in the meta-model and the frameworks with some experts in the field or modeling domain. While a number of research instruments and data analysis methods are described in the previous chapter, we look at some of the research instruments that were used to gauge the acceptability of the meta-model and the RIM and COME frameworks. The chapter, therefore, starts by looking at the explanatory and confirmatory modeling experiments that were carried out. We describe the research design, preparation and execution and discuss data analysis procedures and a few results obtained. We, finally, discuss a few insights gained from these field experiments and how they helped enhance the developed artifacts. Remarks about the explanatory and confirmatory experiments, the results obtained and insights gained from them conclude the chapter.

7.2 Explanatory Validation Experiment 1

In this section we look at the first explanatory and confirmatory modeling experiment that was carried out to validate the concepts of the meta-model and the frameworks. This modeling session experiment involved IT experts in the IT Department of Infocom, a

This chapter is an extended version of the following publications: [SHP13, SHP09c].
big Telecommunication Company in Uganda which offers Telephone and Internet connectivity and Web-design, Web-hosting services among other services. The goal of the explanatory and confirmatory modeling session experiments described here and in the next section was four-fold:

(i) to validate the meta-model and the RIM and COME frameworks which, as explained in the previous chapter, had been tried in numerous exploratory experiments that involved mainly university students.

(ii) to validate the research instruments that were designed and had been tested mainly with university students in exploratory and explanatory modeling session experiments.

(iii) to determine the acceptability of the meta-model and frameworks by the experts and get their views and insights.

(iv) to determine the performance of the collaborative modeling evaluation (COME) approach.

7.2.1 Research Design, Preparation and Execution

Selection of Subjects. The participants that took part in the modeling experiment came mainly from the IT Department of the organization. We preferred persons with some background in computing, although not necessarily with modeling skills to take part in the modeling experiment. These participants had varied background in computing e.g., in databases, web-design and hosting, networking, programming and modeling in entity-relationships (E-R), Object-role Modeling (ORM) and Unified Modeling Language (UML).

Modeling Task. The main task that was given to the participants was about developing a model for the University Teaching Hospital’s Pharmacy and Medical Equipment Department showing the procurement process of medical drugs and equipment and distributing these to the different wards and departments of the University Teaching Hospital. This task was chosen on the basis that since procurement and distribution of drugs and equipment is not different from that of IT products, it would be found interesting by the participants and thus it would be easier for them to brainstorm and generate ideas about the problem being addressed. Participants were asked to first generate, individually, as many ideas in the idea-generation task [McG91, McG84], see Figure 3.1 and Table 2.3, about the problem. Figure 7.1 is a snapshot of part of the models that were generated.

Modeling Session Experiment. The modeling session experiment had two phases which in total lasted for three hours. The first phase required modelers to generate a model of a case that was given to them using a Unified Modeling Language (UML)-based environment embedded within the Collaborative Modeling Architecture (COMA) tool [Rit08a]. Prior to the actual modeling session, modelers were introduced to the inner workings of the modeling tool and working definitions of what is meant by the modeling language, the modeling procedure, the end-product (model) and support-tool; and their quality dimensions, as defined in Tables 4.2 – 4.5, were introduced to them. Our choice for the
COMA tool was based on a number of factors prominent among which are: its simplicity, its integration of two of the modeling artifacts: the modeling language (UML) and the support-tool, which is COMA itself. The third modeling artifact – the end-product (model) – was to be developed using the COMA environment while the fourth modeling artifact – the modeling procedure – was left to the participants to determine and follow. At the end of the first phase, modelers were given a paper-based pre-survey instrument, see Appendix A, to evaluate the modeling artifacts that had been introduced to them. The goal of this questionnaire was to get the individual scores to the modeling artifact quality dimensions. This questionnaire used the AHP fundamental scale of Saaty [Saa80], see Appendix C – Table 1. The second phase of the modeling session experiment required participants to, collectively, use a post-survey research instrument, which is a computer-based evaluation tool that employs the AHP methodology implemented in Expert-Choice Software [EC11] to evaluate the modeling artifacts used in, and produced during, the modeling session in phase one.

♦ **Modeling Artifact Selection.** Step 1 of the COME framework conceptual model, see Figure 4.1, requires selection of the modeling artifacts to be used in the evaluation process. Although, the COME framework is generic in that it allows selection of one or more modeling artifacts to evaluate and allows selection of any other evaluation method other than an MCDA-based method and also gives freedom in the evaluation approach selection, we already argued our case that in collaborative modeling all four artifacts have an impact.
Chapter 7. Meta-model Validation: Practice

on the effectiveness and efficiency of the modeling session, see also [SHP09b, SHP10a]. We, therefore, selected all the four modeling artifacts: modeling language, modeling procedure, end-product (model) and support-tool.

♦ Choosing the Evaluation Method. Step 2 of the COME framework conceptual model requires choosing an evaluation method to use in the evaluation of the modeling artifacts. We selected an MCDA method – the AHP method – due to our goal of trying to find an appropriate technique to help the modelers score (rate/rank/weigh) the different modeling artifact quality dimensions (criteria or factors) and a method that can help us aggregate the individual and group scores (and, thus priorities and preferences) given to the different quality dimensions of the modeling artifacts. Our choice for AHP was also prompted by its ability to reduce the subjectivity or bias associated with the individual judgments when computing and aggregating the individual and group priorities. Within Step 2 of the COME framework, sub-step 1 requires generation of the dimensions of the modeling artifact(s) to be used in the evaluation of that particular modeling artifact. This is normally done during either a brain-storming session [Jar96] where participants, during a planning or an idea-generation task, see [McG91, McG84], generate the dimensions in a freewheeling fashion or a literature survey is done to identify relevant quality dimensions for each artifact, see for example [PN05].

Each participant was thus, initially, given a piece of paper on which to write down the dimensions he/she felt were relevant for evaluating each of the identified modeling artifacts discouraging discussion and criticism at this stage. Sub-step 2 requires assessing and selecting the dimensions to finally use. Through the modeling session facilitator, each participant presented their quality dimensions in a round-robin fashion and other members were allowed to discuss them, thus allowing group interaction – mainly negotiation – and through Delbecq and Van de Ven’s [DVG75] Nominal Group Technique (NGT) these were “subjectively” ranked, voted on and agreed upon – thus resulting into group-accepted quality dimensions. It should be noted that this procedure, though done democratically through a voting process, does not eliminate or reduce the subjectivity or bias still inherent in the quality dimensions that are generated, since many times many people may tend to just follow, simply give-in to, or go-by, what the majority has proposed. Through guidance from the modeling session facilitator, the generated and subjectively ranked quality dimensions were categorized and grouped into some of the quality categories that exist in the literature. These categories for the four modeling artifacts are given in sections 4.3.1 – 4.3.4, see also [SHP10a, SHP09b]. Due to the subjective nature of the evaluation and ranking of the generated quality dimensions, the participants had to evaluate the groupings of these quality dimensions as a group using sub-step 3 of step 2 in the COME framework in Figure 4.1. This involved using the AHP-based evaluations using pair-wise comparisons of the quality dimensions.

♦ Selection of the Evaluation/Validation Approach. The COME framework requires that an evaluation and validation approach be selected in step 3 in Figure 4.1. We selected the discursive, participant, expert-based approach for the evaluation and validation. In this approach, the group participants had to collectively, agree on the final score to give to a quality dimension through a communicative and negotiation process (employing the discursive, participant, expert-based evaluation approach) and, one of the group members
7.2. Explanatory Validation Experiment 1

had to enter the final score in the AHP Expert-Choice Software [EC11]. After entering all the agreed-upon quality dimension scores, they had to analyze the consistency ratio to see whether it is below the accepted value as given in Equation 4.13 – thus indicating that the matrix of the pair-wise comparisons is consistent and the modelers’ evaluations and judgments are free from subjectivity and bias. If this was not the case, the modelers had to re-evaluate their judgments and give new scores that would reduce the consistency ratio to an acceptable value. It should be noted that this process is done collaboratively through a communicative process and leads to consensus about the final score.

7.2.2 Data Analysis Procedures and Results

This section gives the and discusses some of the sample results from the modeling session experiment. We use these results to explain and validate the main concepts discussed, especially, from the AHP evaluation method, since this is the method that is at the center of the COME evaluation framework. Figure 7.2 gives the structural decomposition step of AHP, see Figure 4.2, with its two sub-steps: problem identification and hierarchical construction obtained using the general form in Figure 4.3.

![Figure 7.2: Structural decomposition of modeling process evaluation.](image)

It should be noted that the alternatives are shown only for one of the secondary criterion (commitment and shared understanding), but they do exist for all the other secondary criteria as well. This is done to avoid cluttering the diagram. In this particular explanatory modeling experiment, two collaborative modeling approaches (CMA) which constitute the alternatives were paid much attention to. These were the Face-to-Face (FTF) and the Collaborative Modeling Architecture (COMA). Face-to-Face was used during the communicative process where modelers negotiated and agreed on the final score as a group using the AHP Expert-choice while the COMA tool was mainly used to develop the models. Compendium and InterLoc Suite were used as dummy alternatives that could facilitate idea generation/issue building and for synchronous conversational dialogue exchanges.
Table 7.1 shows results of the comparative judgment step in Figure 4.2 with its three sub-steps: pair-wise comparison, relative weight estimation and consistency checking obtained using Equations 4.3 – 4.12.

Table 7.1: Pair-wise comparative matrix and priority vector of the modeling language.

<table>
<thead>
<tr>
<th>Modeling Language (ML)</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
<th>Priorities Vector((\mathbf{w}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understandability (1)</td>
<td>1</td>
<td>1/6</td>
<td>1/3</td>
<td>1/3</td>
<td>0.067</td>
</tr>
<tr>
<td>Clarity (2)</td>
<td>6</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>0.603</td>
</tr>
<tr>
<td>Syntax Correctness (3)</td>
<td>3</td>
<td>1/5</td>
<td>1</td>
<td>2</td>
<td>0.190</td>
</tr>
<tr>
<td>Conceptual Minimalism (4)</td>
<td>3</td>
<td>1/4</td>
<td>1/2</td>
<td>1</td>
<td>0.141</td>
</tr>
</tbody>
</table>

\[ \lambda_{\text{max}} = 4.168 \quad \text{C.I} = 0.056 \quad \text{C.R} = 0.063 \]

The group scores, (6, 3, 3, 5, 4, 2), that were given by participants in the collaborative modeling session are given in the upper (grey-coloured) part of the comparative matrix (above the main diagonal of 1’s) with the reciprocals of 6, 3 and 3 being entered as these come from the right-half of the questionnaire, see Figure 4.6 and Appendix A. As can be seen from these values, the consistency ratio (C.R) is less than 0.08, which is the threshold value given in Equation 4.13 above which the matrix and the hence the evaluations would be inconsistent and thus biased or subjective. This means that the evaluations are consistent and they are, therefore, acceptable.

Table 7.2: AHP synthesized results.

<table>
<thead>
<tr>
<th>Criteria Alt.</th>
<th>Modeling Language (0.239)</th>
<th>Modeling Procedure (0.191)</th>
<th>End Products (0.404)</th>
<th>Support Tool (0.167)</th>
<th>Alt. Global Priorities (Normalized)</th>
<th>Alt. Global Priorities (Idealized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMA1</td>
<td>0.207</td>
<td>0.437</td>
<td>0.318</td>
<td>0.314</td>
<td>0.310</td>
<td>1.000</td>
</tr>
<tr>
<td>CMA2</td>
<td>0.160</td>
<td>0.178</td>
<td>0.162</td>
<td>0.219</td>
<td>0.175</td>
<td>0.565</td>
</tr>
<tr>
<td>CMA3</td>
<td>0.367</td>
<td>0.157</td>
<td>0.323</td>
<td>0.235</td>
<td>0.290</td>
<td>0.935</td>
</tr>
<tr>
<td>CMA4</td>
<td>0.266</td>
<td>0.228</td>
<td>0.197</td>
<td>0.231</td>
<td>0.225</td>
<td>0.726</td>
</tr>
</tbody>
</table>

Key: CMA1: FTF, CMA2: COMA, CMA3: Compendium, CMA4: InterLoc Suite

Table 7.2 gives the synthesized final global priorities for the alternatives (collaborative modeling approaches – CMAs) which are computed using Equation 4.14 and Table 4.6. Both normalized and idealized priorities are given in the last column of the table. As pointed out before, more emphasis was paid to only CMA1 (FTF) and CMA2 (COMA) while CMA3 and CMA4 were used as dummy approaches. Interpretation of these results shows that the Face-to-Face (FTF) approach is judged a better approach than the COMA
7.3. Explanatory Validation Experiment 2

In this section, we report on the second explanatory and confirmatory experiment that was carried out to further test and validate the concepts of the meta-model and the frameworks. Unlike the modeling experiment discussed in the previous section, in this session more attention was paid to the performance of the modelers in the modeling session and their underlying psychological and behaviour factors which we feel have an impact on the overall quality of the modeling process. Performance factors are concerned with the overall performance of participants in the modeling session and the overall quality of the modeling artifacts used in, and produced during, the modeling session. Performance is assessed through the Collaborative Modeling Process Quality (CMPQ) which measures the quality of both the process of modeling and the products of the modeling process through the four modeling artifacts.

Table 7.3: Definitions of performance construct factors.

<table>
<thead>
<tr>
<th>Code</th>
<th>Quality Dimension</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>SEMQ</td>
<td>Semantic Quality</td>
<td>Semantic correctness &amp; completeness: how well the models describe the structure/behavior of the real world</td>
</tr>
<tr>
<td>SYNQ</td>
<td>Syntactic Quality</td>
<td>The extent to which the models conform to the rules of the modeling language</td>
</tr>
<tr>
<td>PRAQ</td>
<td>Pragmatic Quality</td>
<td>How well the model’s meaning coincides with the stakeholders’ interpretation, how well the model is understood, and how the person/group or organization benefits</td>
</tr>
<tr>
<td>SOCQ</td>
<td>Social Quality</td>
<td>The degree to which the stakeholders agree on their interpretations of the models</td>
</tr>
<tr>
<td>CLA</td>
<td>Clarity</td>
<td>How understandable the models are</td>
</tr>
<tr>
<td>LSU</td>
<td>Learning &amp; Shared</td>
<td>The extent to which the stakeholders acquire new knowledge and reach a shared understanding before, during and after the modeling session</td>
</tr>
</tbody>
</table>

In trying to determine the performance of the modelers in a modeling session, we seek an answer to the following question: How well did the subject perform the task? In essence, this helped us determine the efficiency, which is the effort required to apply the method and effectiveness which is defined as how well the method achieves its objectives. Efficiency is better measured by the input parameters such as time, cost or (cognitive) effort while effectiveness is measured by output parameters such as the quantity or the quality of the results from the modeling session. Because of this, our emphasis was on the semantic, pragmatic, syntactic, social quality and clarity of the end-products as well as learning and shared understanding by the modelers from the modeling session.

Behavioural factors are psychological in nature and we used them to measure the attitude and perception of the modelers about the quality of the different modeling artifacts and their intention to use and/or adopt the modeling approach and/or evaluation techniques employed during quality evaluation and assessment of the artifacts. For the psychological and behavioural factors we made use of, mainly, perceptions about, and intentions to use, the evaluation approach. For this, we sought the question: How effective did the participants perceive the evaluation framework to be and how ready are they to adopt it in practice? Thus, we make use of a number of constructs defined in Table 7.3 to define and measure the overall quality and we operationalize this using a conceptual approach, i.e., CMA2 is 56.5% as good as the CMA1 approach.
model shown in Figure 7.3. Appendix B – Part B gives a questionnaire used to test these. We also made use of concepts from the Theory of Reasoned Action (TRA) and Theory of Planned Behaviour (TPB) which are implemented through the Technology Acceptance Model (TAM) and Method Evaluation Model (MEM). These are shown in Table 7.4 and Appendix B – Part C gives a questionnaire in which we tested these concepts.

Table 7.4: Adapted TRA and TPB concepts for the adoption and acceptability.

<table>
<thead>
<tr>
<th>Code</th>
<th>Quality Dimension</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>BI</td>
<td>Behavioural Intention</td>
<td>Participant’s likelihood that s/he will (intends to) use the evaluation approach – the strength of the conscious plans to use the evaluation method and his/her intention to adopt it in practice.</td>
</tr>
<tr>
<td>NB</td>
<td>Normative Beliefs</td>
<td>Participant’s perception about how other participants or his/her employees feel about his/her use of the evaluation approach and his/her adoption in practice.</td>
</tr>
<tr>
<td>SN</td>
<td>Subjective Norm</td>
<td>Participant’s perception of whether others important to him/her think that evaluation approach should be used - their perception about whether the person will or will not use and adopt the evaluation method.</td>
</tr>
<tr>
<td>PP</td>
<td>Perceived Power</td>
<td>Perceived existence and/or possession of power and other control factors to use and adopt the evaluation method.</td>
</tr>
<tr>
<td>ATT</td>
<td>Attitude</td>
<td>Positive or negative responses of the participant judged with respect to the evaluative or affective dimension in using/adopting or not using/adopting the evaluation method in practice.</td>
</tr>
<tr>
<td>BB</td>
<td>Behavioural Beliefs</td>
<td>Subjective likelihood that using the evaluation method will lead to agreement and consensus.</td>
</tr>
<tr>
<td>MC</td>
<td>Motivation to Comply</td>
<td>Extent to which the participant wishes to comply to group decision and his/her commitment to abide by it.</td>
</tr>
<tr>
<td>PC</td>
<td>Perceived Control</td>
<td>The perception that the participant has the resources and ability or skills to use/adopt the evaluation method</td>
</tr>
<tr>
<td>CB</td>
<td>Control Beliefs</td>
<td>Participant’s perception of the availability of the resources, skills and opportunities to the achievement of the outcome – His/her assessment of the importance of those resources.</td>
</tr>
<tr>
<td>E</td>
<td>Evaluation</td>
<td>The rating of the desirability of the modeling artifact used in, and or produced during, the modeling process.</td>
</tr>
</tbody>
</table>

Moody (2004) notes quite rightly that a method which improves performance but
is not used in practice will never lead to improved practices. Adoption in practice is determined through perception and intention factors of the TAM model.

### 7.3.1 Research Design, Preparation and Execution

Although the modeling sessions that were carried out included developing a model and evaluation of the modeling artifacts, the goal of this session was more on the study of the *performance* and *efficacy* than on the communicative process. We were, therefore, more interested in the results of the evaluations from both the pre-survey and post-survey questionnaires that were used to measure performance and efficacy. A series of modeling experiments were carried out that in total involved 6 participants divided into two groups of at least three persons. Each modeling experiment lasted for two hours with five phases: briefing phase, pre-survey questionnaire fill-out phase, actual modeling phase, a post-survey questionnaire fill-out phase, and the de-briefing phase. Performance was measured using the *Collaborative Modeling Process Quality (CMPQ)* construct through four performance construct factors, see [Moo03, MSBS03]: Semantic Quality (SEMQ), Syntactic Quality (SYNQ), Pragmatic Quality (PRAQ), Social Quality (SOCQ), Clarity (CLA) and Learning and Shared Understanding (LSU) which are defined in Table 7.3.

### 7.3.2 Data Analysis Procedures and Results

In this section we describe the analysis procedures and the results obtained from the modeling session filled-out questionnaires. Results of the questionnaire were meant to be analyzed using, first, an Exploratory Factor Analysis (EFA) method, and, second, by the Confirmatory Factor Analysis (CFA) Method.

#### Preliminary Analysis

The first step before EFA or CFA is carried out is to subject the data to preliminary analysis that includes three analyzes: data screening, assumption testing and sampling adequacy [Fie09, p.656]. Data screening, in addition to giving basic statistics, reveals the missing cases as well as outliers, which if not properly handled, can ruin the analysis. Assumption testing reveals whether the sampling distribution is normal in addition to testing the homogeneity of variance, independence of data and whether data is measured at interval level (which it is, if a Likert scale is used). Sampling adequacy tests whether the sample size is adequate for factor analysis to proceed. The SPSS-coded data-set was subjected to this preliminary analysis of data screening, assumption testing and sampling adequacy with emphasis on normality and sample size. This preliminary analysis revealed inadequacy of sample size. However, the sample distribution for the sample of six IT expert participants who took part in the modeling session experiments and evaluations was not significantly different from a normal one as shown by the Kolmogorov-Smirnov and Shapiro-Wilk tests, see Table 7.5. This therefore ruled out application of the EFA and CFA analysis techniques.

In section 8.2.2 we discuss the theoretical and practical implications, use of the calculated scores and evaluation results, and experiences, benefits, and consequences of using the COME Framework from the perspective of the IT experts.
**Tests of Normality**

<table>
<thead>
<tr>
<th></th>
<th>Kolmogorov-Smirnov a</th>
<th>Shapiro-Wilk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Statistic</td>
<td>df</td>
</tr>
<tr>
<td>SEMQ1</td>
<td>.209</td>
<td>6</td>
</tr>
<tr>
<td>SEMQ2</td>
<td>.202</td>
<td>6</td>
</tr>
<tr>
<td>SEMQ3</td>
<td>.407</td>
<td>6</td>
</tr>
</tbody>
</table>

a. Lilliefors Significance Correction

* This is a lower bound of the true significance.

### 7.4 Concluding Remarks

In this chapter we have presented two sets of modeling experiments that were carried out to validate the concepts in the meta-model and the frameworks. This experiments are both explanatory and confirmatory in the sense that they guide us towards an explanatory theory about the analysis and evaluation of modeling processes. The experiments have demonstrated the relevance and applicability of the designed artifact which is the meta-model that integrates the analysis framework (RIM) and evaluation (COME) framework and the acceptability and adoption in practice of the evaluative part of the meta-model. Using concepts from the TRA/TPB that are implemented through the TAM and MEM model, we have been able to show how the actual efficacy measured through efficiency and effectiveness is attained for the modeling method used to evaluated the quality of the different modeling artifacts used in, and produced from, the modeling sessions. The performance as well as the psychological factors that have an impact on the overall quality of the modeling process have been identified.

Although the sample size used does not allow the application of factor analysis techniques to check the validity and reliability measures and tests, use of the correlational analysis techniques has demonstrated and confirmed these validity and reliability measures a confirmation of those obtained in the explanatory controlled modeling experiment discussed in the previous chapter. We have pointed out insights gained from these explanatory and confirmatory experiments that were used to further enhance the concepts in the meta-model and the frameworks which also helped us to design better explanatory and controlled experiments. One major observations from the explanatory and confirmatory experiments with IT experts is that the quality of the modeling process and its associated products can be assessed and measured by the stakeholders in the modeling session themselves rather than being left in the hands of the so-called modeling experts.
PART IV

Discussion and Conclusion
This part of the book contains two chapters in which we discuss the main findings of the research and in which we summarize the main contributions of the research.

**Chapter 8** discusses the main findings of the research and gives our theory for the analysis and evaluation of collaborative modeling. We start with an overview in Section 8.1 and the major observations and findings are introduced in Section 8.2. Observations and findings about the RIM and COME frameworks are discussed in Sections 8.2.1 and 8.2.2 respectively. The theory about the analysis and evaluation of collaborative modeling is introduced in Section 8.3. We describe in Section 8.3.1 how the theory can help us study collaborative modeling processes. Section 8.3.2 describes how the theory can help us analyze collaborative modeling processes and the evaluation of collaborative modeling processes is discussed in Section 8.3.3. In Section 8.4 we discuss the requirements for a support-tool that can help us study, analyze and evaluate collaborative modeling processes. We, specifically, look at the social and organizational requirements which are discussed in Section 8.4.1, while technological and technical requirements are discussed in Section 8.4.2. This chapter is ended with some concluding remarks in Section 8.5.

**Chapter 9** summarizes the main contributions of the research. It starts with an overview in Section 9.1 and we give, in Section 9.2, our research contributions. Section 9.3 discusses the limitations and further research that needs to be done. Specifically, Section 9.3.1 discusses the theoretical/methodological limitations as well as the technological/practical limitations. Section 9.3.2 looks at further theoretical research while Section 9.3.3 looks at further practical research. We give some concluding remarks in Section 9.4, especially, a note about the frameworks and the meta-model in Section 9.4.1, a note on the theory in Section 9.4.2 and finally a note on the support-tool requirements and guidelines in Section 9.4.3. We conclude and wrap-up this chapter with our final conclusions in Section 9.5.
8 Discussion

Knowledge is not true or untrue as the Aristotelian tradition would like us to believe. It only has some strong and consequently weak aspects. Any product of knowledge can be improved upon.

– Reuling, 1986

8.1 Overview

This chapter discusses and analyzes some of our major observations and findings about the process or the act of modeling – especially the study, analysis, evaluation and understanding of collaborative modeling processes – an area that this research concentrated on. Using the frameworks, the meta-model and the results obtained from the exploratory, explanatory and confirmatory modeling experiments discussed in Chapters 6 and 7, and the observations about these results, we propose a theory that can be used to study, analyse and evaluate collaborative modeling processes. The chapter starts by looking at the findings and observations. It goes on to give an explanatory and descriptive theory about the study, analysis and evaluation of the modeling processes that leads to better understanding of what takes place during a collaborative modeling session. Since the study, analysis and evaluation of the modeling processes is premised on the goal of understanding this process, and, with a view of developing a support-tool that integrates the analysis and evaluation through the meta-model, the chapter looks at the requirements of such a tool and guidelines of developing such a support-tool. These requirements are categorized as human, social, organizational and technological requirements. The chapter is ended with some concluding remarks about the theory and the requirements and guidelines about the development of the support-tool.

8.2 Observations and Findings

In this section, we point out the major findings of this research which are a result of the observations about the data analysis results from the exploratory, explanatory and confirmatory modeling experiments. From these findings, we derive an explanatory theory that can help us study, analyze and evaluate the modeling processes with a view of understanding the modeling process better and supporting it with a tool.

8.2.1 RIM Framework – Analysis Findings

Structuring the modeling Process. In Chapters 6 and 7 the modeling experiments that were carried out can be categorized as chauffeured or facilitator-driven and non-facilitated or modeler-driven modeling experiments. Chauffeured modeling sessions were mainly conducted using the Group Model Building (GMB) approach, see section 1.3.4.

This chapter is an extended version of the following publications: [SHP09a, SHP09d, SHP10a].
Within this kind of modeling sessions, the facilitator elicits the required knowledge from the mental models of the participants through a systematic and well-organized process. However, this method has often been criticized since the (non-professional) facilitator may be tempted to “force the participants” produce what he wants to see rather than letting the process naturally produce what he anticipated to see. The necessity of a highly organized process and the role of the facilitator has been criticized, see for example [Rit10a]. The role of the facilitator is often seen as a bottleneck and passive involvement of the participants leads to limited understanding and acceptance of the model [Rit09c, Rit08b]. Therefore, letting modelers be in charge of the modeling process themselves, as seen in the non-chauffeured modeling experiments brings out important observations. The first observation is that the modelers tend to structure the process and assign roles during the course of the modeling process. Non-chauffeured modeling sessions showed three clearly distinguishable phases each with its own typical proportion of interaction types. The noticed phases are shown in Table 8.1.

Table 8.1: Structuring the collaborative modeling process by modelers.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Phase Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Setting of the main approach: choosing the language and sub-division of work.</td>
</tr>
<tr>
<td>II.</td>
<td>Exploring and deciding which actors play a role in the first partial process model.</td>
</tr>
<tr>
<td>III.</td>
<td>Modeling the sub-process.</td>
</tr>
</tbody>
</table>

In view of our focus on “the rules of the game” that come from the game metaphorical approach taken for collaborative modeling, the first phase can be seen as dedicated to such rule setting, whereas in the two other (main) phases, sporadic rule setting as required by the situation in the modeling experiments occurred. We conclude that two modes of rule setting seem to occur:

1. Planned, Pro-active Rule Setting – Phase I.
   (i) *Choosing the main approach*
   (ii) *Sub-division of work*
   (iii) *Choosing the language*

2. Ad-hoc, Reactive Rule Setting – Phases II and III.
   (i) *Exploring modeling process*
   (ii) *Assigning roles*
   (iii) *Modeling the sub-process*

A relatively similar structuring process was noted by Rittgen [Rit07] with two rules: acceptance rule and rejection rule structured along three levels: social, pragmatic and language levels, see Figure 8.1. At the social level the two rules – acceptance and rejection – can further be categorized as “rules of majority”, where the majority of group members support or oppose a proposal, and “rules of seniority” – where the weight of a group
member’s support or opposition is related to his status in terms of experience or position within the group. At the pragmatic level, modelers exhibit two types of behaviour. They exhibit behavioural actions that are aimed at helping them understand either the description of the given task/case or the modeling language.

![Figure 8.1: Modelers’ structuring of the modeling process [Rit07].](image)

Secondly, they exhibit behavioural actions that are aimed at organizing the process of modeling either in terms of performing the next activity on the agenda (setting the agenda) or in terms of negotiation. At the language level, two sub-levels are identified: syntactic – which deals with activities that directly affect either the segmenting of textual units from the natural language domain or the transforming of diagrams in terms of using graphical elements of the modeling language, and semantic level: that handles activities that are connected to the concept of business processes. At this level activities are about either analyzing natural language phrases or they are classifying them into generic concepts. Although there is a slight divergence in the way modelers structured the modeling process in our research and Rittgen’s, there is convergence on a number of issues. Choosing the main approach and exploring the modeling process includes the agenda setting, sub-division of work and assigning roles is done according to identified and presumed levels of skills, competencies and knowledge – thus creating a “seniority structure”. Choosing the language and modeling the sub-process involves choosing the language to use and tackling the modeling task. Therefore, this research confirms that “modeling can actually be seen as a relatively well-structured activity that includes a limited number of sub-activities” [Rit07]. The structuring process is akin to the division of labour in Activity Theory where activity “harmonization is categorized in three main gradual levels of sophistication: coordination, cooperation, and co-construction [BG10, Nar95]. It should be noted, however, that although collaboration is addressed in Activity Theory by the notion of division of labor [Nar95], the way participants share the activities among themselves in collaborative modeling is more implicit than explicit. It only becomes clear, especially for Face-to-Face collaborative modeling sessions, when some modelers play a more (pro-)active role due to their seniority and/or when they possess more expertise, skills, knowledge, etc. In such a situation they sort of “hijack” or dominate the modeling process.
□ **Interaction Types and Topics.** In line with [Rit07], it can be noted from the transcriptions and categorizations of the communicative dialogues (of macro and micro categories) that the communication among the modelers can broadly be categorized as a negotiation. It consists of interaction types which include: *argumentations* (argue for/against) by the modelers which results in either *acceptance/agreement* (agree with) by all modelers, or *rejection/disagreement* (disagree with) of the proposals, etc. Figure 8.2 shows an example of how these micro communicative dialogue interaction types are distributed within the phases. Explicit agreement only occurs at some points in the negotiations, whereas “silence means agreement” is the convention applied most in the case conversational dialogues. Rejection may come explicitly, as a result of a disagreement (objection) to a proposal or as a result of an agreement to drop a proposal. All interactions either contribute toward the setting of a goal or toward goal fulfillment.

![Distribution of the interactions in the phases](image)

**Figure 8.2:** Distribution of the number of interaction types per phase.

Within the communicative dialogues, interaction topics can also be identified. These conversations center around topics such as: planning, collaboration, creation, grammar, content, etc. Interactions of one type can fulfill several goals at the same time; for example, content setting should respect the modeling language grammar rules and thus fulfills grammar goals, but content setting also, and primarily, fulfills creation goals. Interactions either set some proposition, or else concern one: they ask a question about one, argue for or against it, agree with it/accept it or disagree with/reject it. Accepted propositions set either rules or content. Accepted content becomes part of the model leading to what we called a model proposition. Figure 8.3 shows an excerpt of the number of interaction topics per interaction type.

□ **Rule and Goal Types.** Like interactions, we identified some rules that were set for the collaborative modeling games (CMGs) by the researcher for the modeling tasks to be
solved and others set in by players. The majority of the rules encountered were goal rules, e.g. creation goal rules or grammar goal rules. A special class of goal rule is a goal setting goal rule. This type drives the modelers to set some explicit goal(s) which is a new rule different from the theoretical ones defined in QoMo [BHP07]. Three goal rules were explicitly set for the game (i.e. in the assignments/tasks given to the modelers): a creation goal, a grammar goal setting goal, and a validation goal. Rules set in the collaborative modeling games mainly concern the modeling language (which concepts to use: grammar goals), and in some cases how to divide the main task into sub-tasks and sub-models (an agreed refinement of the assigned creation goal). The major identified rules and goal types are summarized below. It should be noted that this is just a small operationalized subset of the QoMo theoretical rules and goals.

1.) Rules/goals set in the CMG: Goal setting rules
   
   (i) Creation
   (ii) Grammar

2.) Rules/goals set for the CMG: Goal setting rules
   
   (i) Creation
   (ii) Grammar
   (iii) Validation
Figure 8.4: Rules and interaction types and topics within a structured modeling process.

Figure 8.4 shows the rules and interaction types and topics within a structured modeling process. These interaction (micro dialogue) types can again be compared with those existing in the literature, see for example Figure 8.5 for the negotiation patterns by Rittgen [Rit07]. One of the major findings in this research, is the existence of the different negotiation topics associated with these negotiation patterns and the rules set for and set in the collaborative modeling game.

Figure 8.4: Rules and interaction types and topics within a structured modeling process.

Comparison with Existing Frameworks. In this section we compare our RIM analysis framework to two relevant approaches from the literature: Quality of Modeling (QoMo) [BHP07, BHPR09] and Collaborative Modeling Architecture (COMA) [Rit08a].

Comparison with QoMo. The QoMo framework involves an analysis of aspects for quality-of-modeling based on the product-oriented SEQUAL framework [KSJ06]. Roughly speaking, QoMo rephrases the SEQUAL aspects (and some additional ones) as “goals for modeling”. The QoMo goals are theoretical in nature; our research provides an opportunity for a reality check on QoMo. We compare the QoMo goals-for-modeling from [BHP07] (which is the most mature version) with the concerns-for-modeling that transpired from our close study of explicit interactions in the modeling sessions. QoMo distinguishes Usage Goals, Creation Goals, Validation Goals, Argumentation Goals, Grammar Goals, Interpretation Goals, and Abstraction Goals. Usage goals were not explicitly
encountered, as they were out of the scope for most of the modeling tasks, but implicitly they are part of the assigned domain description which provides a rough use context for which the (process) models developed are intended. Creation goals were clearly and explicitly encountered in most of the modeling sessions, rough ones were set for the CMGs. In addition, several topics of interaction were identified that suggest extension of the theory-based QoMo goal set: Planning, Collaboration, and possibly also Help goals. However, they are arguably not directly quality-oriented, and hence this finding seems not so much to point out a gap in QoMo but rather the somewhat insufficient scope of a strict quality-oriented perspective on modeling goals.

♦ Comparison with COMA. COMA is an interactive and collaborative modeling approach and tool which can be viewed as incorporating and thus setting various modeling goals and /or rules and interaction mechanisms, some of them as options, some of them “hard”. Looking at the COMA tool [Rit08a] (its initial incarnation), the following rules are built into the system. The tool is based on a standard UML editor for 5 types of diagram, including activity diagrams. This means that the Grammar Goals are hard-coded (though use of advanced concepts is often optional). The other relevant goal category is that of Validation Goals. Rittgen built in support for validation in the form of an acceptation mechanism with decision parameters. This boils down to offering a choice out of vari-

Figure 8.5: Negotiation patterns [Rit07].
ous popular decision mechanisms observed to occur in collaborative modeling: a choice of detailed validation rules. In other words, COMA has a **Goal Setting Goal** underlying the validation parametrization. Finally, COMA is negotiation-oriented and supports **argumentation** for or against (partial) model diagrams. This is of course closely related to our speech act categories, and even amounts to the setting of an **Argumentation Goal**. All in all, it seems that indeed, COMA comes close to embodying the main modeling goals as recognized in our analysis framework. However, COMA is relatively restrictive in setting some main goals (so some refinement should be useful), and further ignores other aspects, like interpretation (negotiation about meaning), collaboration (team organization) and planning (delivery and task decomposition).

◆ **GMB InterLoc Dialogue Game Rules.** While rules in non-chauffeured sessions as discussed in COMA and QoMo are easier to explicitly state, those involving the facilitator are harder to make explicit [HR12]. However, analysis of the scripts can reveal and point to some of the rules that can be termed “facilitation rules”. The following types of rules are some of the facilitation rules that can be most prominently phrased [ibid., p.32]:

- triggers for switching between game modes (i.e., decisions to switch).
- re-occurring patterns in prompting for specific conceptualization.
- re-occurring patterns in checking for adequate understanding of proposals.
- re-occurring patterns in asking for confirmation of acceptance of proposals or of reflections thereof in the model.
- points at which explicit conceptualizations occurring in the dialogue are to be reflected in the causal loop diagram, and the way how this is done.

### 8.2.2 COME Framework – Evaluation Findings

◆ **CMPQ Construct – Theoretical and Practical Implications.** In Figure 6.8 we presented an a-priori conceptual model and competing model for the Collaborative Modeling Quality (CMPQ) construct and results from the Exploratory Factor Analysis (EFA) and Confirmatory Factor Analysis (CFA) in Tables 6.1 and 6.2. The first observation about the results of CFA is that the (standardized) factor loadings of the conceptual model (Model 1) and the competing model (Model 2) are close. In fact they are the same for the PQML and PUMP constructs while slight differences are noticed for the PQEP and EOUM. This closeness of the results indicates that the Model used in the EFA was a good conceptual model. To determine the possibility of Model 2 being preferred to Model 1, we compare the model fit indices of both models to determine which ones are near or better than the threshold values, see [GSB00, HTAB98, SBG04, TSS08] for these threshold values.

Comparison of the fit indices in Table 6.2 indicates that the values are close. Model 1 has better fit indices than model 2 for the following indices: chi-square value ($\chi^2$), degrees of freedom (d.f), probability value (p-value), chi-square to degree of freedom ratio ($\chi^2$/d.f), root-mean square residual (RMR), goodness-of-fit index (GFI), normed fit index (NFI), Tucker-Lewis index (TLI) and comparative fit index (CFI). Model 2 has better fit indices than Model 1 for the following indices: adjusted goodness-of-fit index (AGFI),
root-mean square-error for approximation (RMSEA), Akaike information criterion (AIC) and consistent Akaike information criterion (CAIC). The fit index values of both models for RMR, GFI and NFI are below the threshold values. Since the AIC value of Model 2 is better than Model 1, Model 2 is the most parsimonious model [RM06] and this means is preferred to Model 1. We, however, believe that Model 1 could be used if (inter-)dependencies between the quality constructs PQML, PUMP, PQEP and EOUM are of interest. Model 2 could be used if particular explanatory relationships (latent regressions) [RM06] are postulated among the quality constructs rather than analyzing only the (inter-)relationships among the quality constructs as is the case for model 1.

One of the theoretical implications of this research is that a conceptual domain for the CMPQ construct has been defined based on the modeling artifacts used in, and produced during, the modeling process together with their quality dimensions. Rather than assessing the quality of the modeling process by defining quality dimensions directly for the CMPQ construct, these could be defined for the PQML, PUMP, PQEP and EOUM and the quality assessed via these constructs. This approach has been operationalized by applying the EFA and CFA methods which have, respectively, produced and confirmed the existence of measurable quality indicators for the four quality constructs. The practical implication of the study is that the developed research instrument offers a means of assessing and measuring the quality of the CMPQ construct. This can be used by collaborative modelers and facilitators to assess their perceived quality, usefulness or ease of use of not only the modeling process and the outcomes, but also the modeling language and the support-tool or medium.

♦ Use of the Calculated Scores and Evaluation Results. A number of observations can be made about the calculated scores in the COME framework using the AHP methodology, see for example Table 7.1 and Table 7.2. The last column in each of these tables is the most interesting since it gives calculated priorities and/or preferences using the assigned scores to the quality dimensions of the modeling artifacts. These calculated priorities are used to determine the level of satisfaction about the quality by the modelers and which of the quality dimensions and/or modeling artifacts meets their quality goals. The higher the value of the calculated priority, the higher the satisfaction with the quality of the dimensions and/or modeling artifacts. This means that a dimension and/or modeling quality with a higher priority value is preferred and satisfies the quality goals of the modelers. Table 7.1 and Table 7.2 give, respectively, the results of the evaluation for the modeling language and the modeling approaches. They are used to determine which of the quality dimensions satisfies the quality goals of the modelers or which modeling approach is of better quality.

♦ Experiences, Benefits, and Consequences of Using the COME Framework Although we could not directly apply the Theory of Reasoned Action/Theory of Planned Behaviour (TRA/TPB) models in the modeling sessions reported about to capture the perceptions of the modelers and their intention to use the evaluation approach in future, these were assessed through post-survey interviews. Modelers were asked about their experiences using the evaluation method – the COME evaluation framework. Most of the participants found the method easy to understand and use. They enjoyed using both the modeling tool - COMA and the AHP’s Expert-choice tool. However, selection of the modeling
artifacts and generation of the quality dimensions were the difficult parts and most of them observed that it would not be possible to select the artifacts or generate the required dimensions without guidance from the modeling session facilitator. This may not be a surprising observation since most of them, although had background in computing, had never been involved in decision analysis and evaluations.

From the experiences of using the COME framework in the modeling experiments, and from the results obtained, we can draw the following benefits and/or consequences, see [SHP13]:

1) the COME framework integrates all the four modeling artifacts in the evaluation process which we feel have an impact on the overall quality of the modeling process and its success. It should be noted, however, that it is still possible to evaluate any of these modeling artifacts at any time, if one so wishes.

2) the COME framework provides a mechanism for developing and generating quality dimensions for the modeling artifacts and metrics for scoring, weighting and/or ranking the modeling artifacts and their quality dimensions.

3) it is possible to aggregate both the individual and group scores to obtain the final score.

4) evaluation of the modeling artifacts can be done collaboratively by the modelers themselves through the COME framework and their subjectivity or bias (inconsistency judgment) is then reduced/minimized or eliminated through the Multi-criteria Decision Analysis (MCDA) techniques such as the AHP approach.

5) the COME framework can be used to determine the most effective modeling approach for collaborative modeling by synthesizing the priorities as shown in Table 7.2.

8.3 Towards a Theory for Analysis and Evaluation

In this section, we tie together the concepts that we have looked at about the RIM framework in Chapter 3, the COME framework in Chapter 4, the meta-model in Chapter 5 as well as the observations and insight from the modeling experiments in Chapters 6 and 7 into what we call a theory for analysis and evaluation of collaborative modeling processes. As argued in section 1.3.2, rather than taking an inductive approach, by moving from the specific observations that are strongly grounded in the data to generalizations and eventually to the theory, we take an abductive approach in the derivation of the theory. This means that the explanatory and descriptive theory adduced leads to hypotheses and propositions which can be tested rather than those that are simply asserted. Although the theory is not a “grounded theory” in the sense of Glasser and Strauss’s Grounded Theory (GT) [GS67], it is still grounded in the observations, patterns, categories of the data analyzed from the modeling experiments and the (inter-)relationships of the concepts in the RIM and COME frameworks. In section 1.3.3, we argued our case for using the design science approach and we identified the meta-model derived from the RIM and COME frameworks as the main artifact and the goal stated therein is to give an explanatory descriptive theory
for the analysis and evaluation of collaborative modeling processes for better understanding the act or process of modeling.

☐ Theory and Theorizing in Design Science Research. Before outlining the theory for the analysis and evaluation of collaborative modeling processes, we need to first understand what is meant by theory and how different scholars have addressed theorizing, especially for design science research, in information systems. One of the most captivating definitions of theory are given by Shirley Gregor [GJ07, Gre06]. She views theory from the following perspectives, see also [HC10, ch.4]:

1. “Theory as statements that say how something should be done in practice.

   *Provides prescriptions to be followed in practice. Prescribed methods will be better than alternatives."

2. “Theory as statements that provide a lens for viewing and explaining the world.

   *Theory is the desirable end-product. No formal testing is envisaged."

3. “Theory as statements of relationships among the constructs that can be tested.

   *Theory leads to testable propositions that can be investigated empirically."

4. Dictionary definitions of theory.

   “a mental view” or “contemplation”, “a concept or mental scheme of something to be done or the method of doing it, a systematic statement of rules of procedures to be followed”, a “system of ideas or statement held as explanation or account of a group of facts or phenomenon, a hypothesis that has been confirmed or established by observation or experiment and propounded or accepted as accounting for the known facts, a statement of what are held to be general laws, principles or causes of something known or observed”, a “mere hypothesis, speculation or conjecture”[Gre06].

From these perspectives Gregor summarizes theories as abstract entities whose goal is to not only describe, explain, and enhance our understanding of the world, but also provide predictions about the future. Theorizing, therefore, is a process that “involves the specification of universal statements in a form that enables them to be tested against observations of what occurs in the real world” [Pop80, p.59]. Realizing the importance theory and theorizing plays in research, Simon [Sim96], in “The Science of the Artificial”, sounded the first call for theory and theorizing in design science. This is in addition to his call for “the need to develop an inventive and creative problem solving activity one in which new technologies are the primary products”. This call has been taken up by a number of researchers over years. The work in [Ven06b] nicely summarizes how this call has been answered and gives some of the theories and the theorizing that has been done. Herbert Simon’s call was answered, first, by the work of Nunamaker et al. [NJCP91] on multi-methodological approach to information systems and later other researchers have answered that call, e.g. Information Systems Design Theory (ISDT) by Walls et al. [WWES04, WWES92] – a prescriptive theory that integrate normative and
descriptive theories into design paths, March and Smith’s work [MS95] on Design Science Research (DSR) approach – with two processes build and evaluate and two other activities theorize and justify, Venable and Travis’s work [VT99], see also [Ven06a, Ven06b], on the role of theory and theory building – an extension of Nunamaker’s work on Computer Based Information Systems, Markus et al.’s work [MMG02] on DSR – an extension of Walls et al.’s ISDT and March et al.’s work on DSR, better theories as a desired product by Rossi and Sein [RS03] and another step in DSR, Hevner et al.’s work [HMPR04] that extends the process and activities in March and Smith’s DSR to develop/build and justify/evaluate with seven guidelines and Vaishnavi and Kuechler’s work [VK04], see also [VK08], on abstraction knowledge levels for the embedded emergent theory of a phenomenon. All these point out the importance of theory and theory building in research.

Theory Building Cycles. Debates abound about the right procedure for constructing or developing a theory in research. Two prominent methods are available. These are: hypothetico-deductive and inductive-deductive methods.

Hypothetico-Deductive. The hypothetico-deductive method of scientific inquiry has had a strong impact on the way theory is constructed. It provides three steps of theory building [SG03, p.236]:

1. generation of conjectures (as a result of observations).
2. deduction of observational predictions (hypotheses from the conjectures).
3. generation of theory (and its acceptance if predictions match the hypotheses, and its refutation/rejection if the predictions and hypotheses mismatch).

Figure 8.6: Theory building in the hypothetico-deductive scientific inquiry.

Figure 8.6 shows the cycles in the hypothetico-deductive theory building process. Shirley Gregor [Gre08], observes that the hypothetico-deductive method offers both a narrow and
wide view to theory development. Step 1 leads to the narrow view – often referred to as “theory generation” to which Glaser and Strauss’s Grounded Theory (GT) belongs. For a wider view, the process of theory building encompasses “cycles of activities” that include observations, hypothesizing, testing and theory refinement where the theory becomes stronger in the successive cycle so that the explanatory and predictive power of the theory is enhanced [Gre08]. Although the notion of theories becoming stronger and stronger in more tests has been criticized, see for example [Pop80], there is strong recognition that theories are built through a cumulative tradition [SG03].

♦ Inductive versus Deductive. Theory development within the inductive inquiry starts from the general observations to broader generations about identified patterns to hypotheses about these patterns and then the theory is inductively constructed from these hypotheses. On the other hand, theory development using the deductive inquiry starts from the general theory and hypotheses are drawn from the general theory to be tested to specific observations and then the theory is confirmed. Cycles followed in the inductive theory building process and deductive theory confirmation process are shown in Figure 8.7.

Figure 8.7: Theory building/confirmation in deductive-inductive scientific inquiry.

♦ Descriptive and Normative Stages of Theory Building. Two stages are identified in [CC05] for theory building, see also [HC10, ch.4]. These are the descriptive stage and the normative stage. Within each of these stages, theory building progresses through three steps:

(1) Observation. The phenomenon is observed and a description (in words) or measurement (numbers) is made about the phenomenon. Abstractions (constructs) from the
messy phenomenon are identified.

(2) Categorization. The phenomenon is classified into categories or classification schemes (*frameworks or typologies*) that highlight possible consequential relationships.

(3) Association. Associations between category-defining attributes and outcomes observed (*models*) are established and made explicit using, e.g. regression analysis and other probabilistic statements of associations, etc.

These stages are shown in Figure 8.8. For the descriptive theory building, we follow a bottom-up approach using the three steps above and the theory takes shape when we cycle from the top of the pyramid back to bottom in a deductive process – thus testing the hypothesis that were inductively formulated on the way up.

Figure 8.8: *Stages of descriptive theory building* [HC10].

If correlations exist between attributes and hold in all the data sets (original and new), then the theory is confirmed. When an anomaly is encountered, new attributes are identified or further categorizations are sought that explain the new anomaly. This situation provides an opportunity to improve the theory. While descriptive theory building gives statements of correlations, normative theory defines what “causes the outcome of interest” [HC10, p.36] by following the same three steps. In normative theory building, causality is paramount. If the causality is confirmed to be correct, we cycle deductively to the bottom and test that causality. An anomaly provides a situation to delve into further categorization and the cycle continues up and down the pyramid to resolve and improve the theory for the new identified anomaly.

It should be noted that the concepts developed in the RIM and COME frameworks were developed without any a-priori presuppositions, hypotheses or theories. Although in
the hindsight we knew that modelers would engage in a communicative process, including argumentation, negotiation and decision-making, little did we know about the structuring process that modelers would devise, the patterns of the communicative dialogues (macro and micro speech acts) and their frequencies of occurrences in the conversations or their distribution within the phases of the structuring process. Similarly, it was hard to forecast or predict the rules and goals that would be enacted before, during and/or after the modeling process, especially, during the post-modeling evaluation process. Therefore, all the observations were as a result of an abductive process [Pei55, SC96, Sta93] that we employed. This abductive process followed the steps shown in Figure 8.8 and aims at providing an explanation for a new or surprising fact, pattern, etc. The theory that we work towards comes from this abductive process. The concepts at each of the three steps in the descriptive theory building process are traceable in the RIM and COME frameworks, the meta-model and observations from the exploratory, explanatory, and confirmatory modeling experiments.

The rules, interactions and models are the identified, observed and described constructs at the first step (observation) for the RIM framework while the modeling artifacts together with their associated quality dimensions/factors are the constructs for the COME framework. The consequential relations and associations were identified based on the categories or patterns observed for the rules, interactions and models and the measured attributes (assigned scores) of modeling artifact quality dimensions. This is what leads to the RIM and COME frameworks which are the outcome of the second step (categorization/classification). This categorization or classification leads to what we call the analytic part and evaluative part. Associations between the rules, interactions and models and the interplay between them and the (inter-) relationships between the modeling artifacts are exploited and integrated into a meta-model – a process that completes the third step (statements of associations). The interaction plays the key association role by providing the link between the RIM and COME framework in the meta-model. It should also be noted that the modeling experiments provide the environment for cycling back and forth (bottom-top and top-bottom) the pyramid, first, abductively (rather than inductively) up and, then, deductively down. We give below the descriptive and explanatory theory for the study, analysis and evaluation of the collaborative modeling process.

8.3.1 Studying Collaborative Modeling Processes

The aim of studying collaborative modeling processes is two-fold: 1) to understand what takes place during a collaborative modeling session, i.e. “what actually happens when people model” [Rit07], and, 2) to understand how participants in such a collaborative modeling effort do whatever they do. Two issues can be identified in the study of collaborative modeling processes: the process and the end-products (models), see for example [Moo05]. While a lot of effort has been spent on the models as pointed out in chapter 1 and through the cited works in chapter 2, less attention has been paid to the process. Thus, studying collaborative modeling processes should concentrate more on the “process or act of modeling” than on the end-products (models). Studying this process and understanding it, requires one to look at the communicative (conversational) dialogues between and/or among the participants. The study of the collaborative modeling processes, through the communicative process, is aimed at determining how participants in the modeling process engage in the communicative dialogues. The collaboration (quality)
parameters given in Table 8.2, which may be observed from the video recordings or mined from the (support-tool) logged communicative actions (chat messages) and model-related activities, see [KCV+09, MSR07, VMK+08], help determine not only the success of collaboration but also to understand the act of modeling and how modelers do whatever they do.

### Table 8.2: Collaboration quality parameters

<table>
<thead>
<tr>
<th>Collaboration Parameter</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Collaboration flow</strong></td>
<td>can be used to study how far participants in a modeling process manage the communication dialogue and (model-related or other) actions.</td>
</tr>
<tr>
<td><strong>Sustained mutual understanding (common ground)</strong></td>
<td>can be used to study the extent of working towards a shared basis of understanding.</td>
</tr>
<tr>
<td><strong>Joint information exchange (knowledge exchange)</strong></td>
<td>can be used to study the effectiveness of information exchanged and explanations given.</td>
</tr>
<tr>
<td><strong>Joint information exchange (argumentation)</strong></td>
<td>can be used to study how participants search for good arguments for and against the options under discussion, until a sustainable consensus is established.</td>
</tr>
<tr>
<td><strong>Structuring the problem solving process (coordination)</strong></td>
<td>can be used to study how far participants in a collaborative effort follow a coherent and efficient plan for jointly solving the problem.</td>
</tr>
<tr>
<td><strong>Cooperative orientation (relationship management)</strong></td>
<td>can be used to study how far participants constructively handle conflicts and disagreements.</td>
</tr>
<tr>
<td><strong>Individual task orientation (motivation)</strong></td>
<td>can be used to study the degree of commitment of the participants to solving the task and actively engaging in its solution.</td>
</tr>
</tbody>
</table>

It should be noted that argumentation, as a joint (collaboration) information exchange parameter, embodies persuasion, negotiation, decision-making, inquiry, information-seeking, deliberation, etc., which are given in Table 2.1. The collaboration parameters above are all key to studying and understanding what takes place and how modelers do their modeling and how they carry out and maintain their communicative actions – including, argumentation, negotiation, and decision-making, etc. However, the study and understanding of the entire collaborative modeling process depends largely on how modelers structure the whole collaborative process, i.e., how they coordinate whatever they do. Note that structuring is of major concern in non-chauffeured (facilitator-independent) modeling sessions since in facilitator-led modeling sessions, the modelers’ actions are well-defined and well-structured through procedures defined, used and followed by the facilitator together with the participants. It is through the structuring process that participants in a collaborative modeling process enact rules and goals to realize. This structuring process with phases as shown in Table 8.1, is rule and goal-based, see for example Figure 8.1 and Figure 8.4. One of the most versatile theory in literature that backs the observed structuring process is *Action Theory* [FZ94, Hac94]. In action theory, four stages can be identified in a complete
cycle of goal realization.

1. **Goal-Setting**: setting the goals and sub-goals.

2. **Planning**: planning the way to execute the goals and deciding on the means essential for the execution.

3. **Execution**: physical execution of the plan.

4. **Evaluation**: evaluation and control of the results with feedback in future goal setting and problem solving.

The first three stages are equivalent to the phases II and III in the ad-hoc reactive rule setting shown in Figure 8.4 and explained in Table 8.1. Although action theory offers salient capabilities which include: *generative* and *exploratory* capabilities, i.e., it produces “patterned-actions” of participants in a problem solving activity which recur during the problem solving, see for example Figure 8.5 and Table 8.4, and it systematically explores, defines and explains how humans work in order to realize set goals, it is non-predictive since it cannot directly offer ways of how human performance can be improved.

**Table 8.3**: Three levels of action from action theory

<table>
<thead>
<tr>
<th>Level</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skilled-based:</td>
<td>The action at this level are highly integrated and they are done in a nearly unconscious fashion by the user. The behaviours of the users are highly automated and they do not need any serious work during the realization of the work.</td>
</tr>
<tr>
<td>Rule-based:</td>
<td>The actions at this level are well-structured and well-defined and they are executed by the users through a well-defined and well-structured procedure. Such procedures are given to users during training or they may learn by experience.</td>
</tr>
<tr>
<td>Knowledge-based:</td>
<td>At this level users use their mental capacities during a problem solving activity. It is at this level that users need to set goals/sub-goals in order to organize their actions for achieving the solution.</td>
</tr>
</tbody>
</table>

The purpose of studying collaborative modeling process is to understand both the actions and/or behaviour of the participants so that they can be supported and improved with, possibly, a support-tool. Studying modelers’ actions requires us to distinguish facilitator-led from non-facilitator led modeling sessions. This distinction is necessary so that study of the actions and the structuring process can be done using an appropriate level of action theory. These levels are explained in Table 8.3.

### 8.3.2 Analyzing Collaborative Modeling Processes

Whereas the study of collaborative modeling processes answers both “what takes place” and “how modelers do whatever they do”, collaborative modeling analysis seeks answers to the following questions: 1) “how, where and/or when the analysis should be conducted”, 2) “what drives the modeling session”, 3) “what the main categories (both
macro and micro) are of the communicative dialogues and speech acts”. The drivers can be mined using the RIM framework. Analysis using the RIM framework does reveal not only the rules set in the modeling game and/or the goals strived for, but also the interactions and model propositions that are as a result of the communicative dialogues. These are the main drivers of the collaborative modeling process. The rules and goals mined can be compared to the theoretical ones defined in QoMo [BHP07] to determine which ones were applied by the modelers.

Table 8.4: Micro categories of communicative dialogues

<table>
<thead>
<tr>
<th>Type</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>propose ((m, p, t))</td>
<td>Proposal (p) is put forward by modeler (m) at time (t). Action is taken after other modelers have argued for or against (p). It is either accepted or rejected.</td>
</tr>
<tr>
<td>counterpropose ((m, p', t))</td>
<td>Proposal (p') is given by modeler (m) as a counter proposal to an earlier proposal (p). Action is taken after other modelers have argued for or against (p'). It is either accepted or rejected.</td>
</tr>
<tr>
<td>ask ((m, q, t))</td>
<td>Modeler (m) asks question (q), at time (t). Modeler (m) may be seeking clarification for understanding the language or understanding the text.</td>
</tr>
<tr>
<td>answer ((m, q, a, t))</td>
<td>Modeler (m) provides answer (a) to question (q) at time (t). The given explanation has to be accepted by all or the majority of the modelers for it to become part of the accepted shared model.</td>
</tr>
<tr>
<td>argue_for ((m, p, t))</td>
<td>Modeler (m) gives an explanation that supports proposal (p) at time (t). Support for (p) is taken to be an agreement with, and acceptance of, the proposal.</td>
</tr>
<tr>
<td>argue_against ((m, p, t))</td>
<td>Proposal (p) is objected to by modeler (m) at time (t). Objection to (p) is taken to be a disagreement with (p).</td>
</tr>
<tr>
<td>agree_with ((m, p, t))</td>
<td>Modeler (m) agrees with the proposal (p) at time (t). Individual agreements add, cumulatively, to the collective or group agreement for the proposal to be accepted by all.</td>
</tr>
<tr>
<td>disagree_with ((m, p, t))</td>
<td>Modeler (m) disagrees with proposal (p) at time (t). Collective disagreement results in the rejection of the proposal by all or majority of the modelers.</td>
</tr>
<tr>
<td>accept ((M, p, t))</td>
<td>Proposal (p) is accepted, at time (t), if all or the majority of modelers ((M = \bigcup_{m=1}^{n}(m))), where (n) is the number of modelers) support it. It then becomes part of the accepted and shared model. Collective agreement is needed for (p), although individual modelers may have argued for (p).</td>
</tr>
<tr>
<td>reject ((M, p, t))</td>
<td>Proposal (p) is rejected, at time (t), if all or the majority of modelers ((M = \bigcup_{m=1}^{n}(m))) object to it. Collective disagreement is needed for (p) even though a few may have argued against it.</td>
</tr>
</tbody>
</table>
8.3. Towards a Theory for Analysis and Evaluation

To categorize the mined interactions from the RIM framework into macro and micro communicative dialogue and speech acts, content analysis [Ber52, Bry08] and discourse analysis [Gol03] is used. Other approaches that can be used in the analysis include “interaction analysis [FPD04, JH95, KAK11], a “script analysis [AR97, CHA+10, RJH+04] or “collaboration script analysis” [KFH06]. Some of the interaction types mined by the RIM framework that are at the center of any communicative dialogue are shown in Table 3.7. The macro categories with micro elements for negotiation, for example, are given in Figure 6.5. The different types of interaction speech acts resulting from the modelers’ negotiation process, see Figure 8.2 – 8.3, during the modeling session are summarized in Table 8.4, see for example [Rit07]. These interactions are obtained as a result of the negotiation process where modelers undergo an argumentative process before finally reaching consensus. This consensus is illustrated by the the acceptance or rejection by all or the majority of the group members in the modeling process. By “proposal p”, is meant either a proposal initiated by one of the modelers, an argument or an explanation put forward in support of, or in disagreement with, a proposal; a counter proposal, an earlier argument or explanation. When a proposal is put forward, an explanation may accompany it as to why it is put forward or why it should be supported. Critiques and arguments may be generated as a result of this. Argue for means supporting an already put-forward proposal, explanation or an an argument. Argue against means objection to, challenging or critiquing, the proposal, explanation or an argument. Agree with means accepting the proposal, explanation or argument whereas disagree with refers to the rejection of the proposal, explanation or argument.

The negotiation process can be initiated in form of proposals or in form of a “question” to which an “answer” must be given before the process continues. Therefore, “ask/answer” is another separate category. We also observe that individual members can accept or reject proposals after the argumentative and negotiation process, consensus is reached where and when a group position to accept or reject a proposal is reached. Two other categories can be distinguished as being separate from each other. These are the accept/reject category and the agree/disagree with category as shown in Table 8.4. To show agreement or disagreement with a proposal, modelers normally give explanations or critiques to the proposal. However, to accept or reject a proposal in collaborative modeling requires all modelers to agree to its acceptance or rejection. This is normally done through sort of a negotiation process where consensus is reached before a final decision is taken.

8.3.3 Evaluating Collaborative Modeling Processes

The goal of evaluating collaborative modeling processes is to determine 1) “when and/or where such evaluation should be conducted”, 2) “how such quality can be established”, and, 3) “what (degree or level of) quality the different modeling artifacts used in, and produced during, the modeling process possess”. Such modeling artifacts, as presented in chapter 4, include the modeling language, the modeling procedure, the models and the support-tool. The evaluation can still be done within the communicative process using the Collaborative Modeling Evaluation (COME) framework by following the three steps presented therein. This collaborative or joint evaluation of the different artifacts can be anchored on a Multi-criteria Decision Analysis (MCDA) [GM98] techniques using, for example, the Analytic Hierarchy Process (AHP) method [Saa80]. Anchoring the evalua-
Chapter 8. Discussion

Discussion of the different artifacts on the MCDA technique helps the different participants not only score, weigh or rank the artifacts, but it also helps them aggregate their individual as well as group scores. This process further helps them find a consensually agreeable final score to use in determining the quality of the artifact.

8.4 Support-tool Requirements and Guidelines

In some of the modeling experiments, we employed two approaches: Computer-Mediated Communication (CMC) and Face-to-Face (FTF) communication. This was purposely to determine: 1) the impact a tool may have on the effectiveness and efficiency of the modeling session and whether there was any significant difference between modeling sessions supported with a tool (CMC) and non-supported sessions (FTF), 2) to determine what human, social, organizational and/or technical and technological requirements a tool should satisfy if it is to be used to support the collaborative modeling process, especially, if the analysis and evaluation are to be embedded within the tool. We note that the analysis is centered around the modelers’ communicative process, in which participants may engage in different types of communication including: negotiation, decision-making, argumentation, etc. The evaluation of the different modeling artifacts may still be done collaboratively and through a communicative process. This research has shown that this is possible. However, embedding it within a support tool still presents some challenges.

Although, a number of authors have analyzed and classified a sample of modeling tools, with regards to their collaborative features for supporting the modeling task, see for example [DDE04, DLOV94, DOLV94, DOV00, PF08], most of these do not fully satisfy, and lack the required functionality for, the collaborative nature of the modeling process. Riemer et al. [RHI11] rightly observe that: “while a broad range of process modeling aspects have been researched, little is known about how to support modeling with collaborative tools”. The authors further observe that “collaborative support for joint business process modeling appears to be in its infancy, which offers abundant opportunities for Information Systems researchers”. Recently, the collaborative modeling community has seen development of collaboration tools that offer evaluation capabilities for the products in addition to the communication and negotiation functionalities, see for example, [Rit10b, Rit10d, Rit10e, Rit08a, Rit08b]. We, however, believe such tools could be enhanced if both analysis and evaluation functionalities are embedded. The development of the meta-model in Chapter 5 was intended for the realization of this integration.

We analyze below the requirements or functionality that a collaborative modeling support-tool should have and we present a few guidelines towards its construction. It should be noted that construction of such a support-tool results in the instantiation and implementation of the designed artifact – the meta-model from the design science approach we employed. These requirements and guidelines are further bench-marked on two existing support-tools: COMA [Rit08a] and InterLoc [Int11] which were used in the modeling sessions in Chapter 6 and Chapter 7. Building on their strengths while still recognizing their current limitations will help us construct a support-tool that takes into account not only the communicative process of the modelers, but also the collaboration, coordination and cooperation within the social interaction of the modelers. Additionally, the support-tool should be able to incorporate the analytic as well as the evaluative components of the meta-model which, as argued in Chapter 5, acts as a blueprint for the development of the support-tool. Three areas from literature – Computer Supported Co-
operative Work (CSCW) [GK07, Gre88, Gru88, KG06, LSVM90], Groupware [EGR91, Joh88, Gru94b] and Human Computer Interaction (HCI) [BGBG95, DFAB98, Str97a] – inform the derivation of the requirements and guidelines.

Our selection of these areas is due to a number of reasons. Firstly, the individual in CSCW ceases to be an individual entity and is considered as being integrated within the society or community where he works and interacts [PGLT07] not only with fellow participants but also with a support-tool. Secondly, CSCW systems possess technological aspects of collaboration and also integrate psychological, social, and organizational effects within the collaboration [Wol10]. Thirdly, Groupware as computer-based systems, support groups of people engaged in a common task (or goal) and provide an interface to a shared environment [EGR91] while HCI develops mechanisms and heuristics for designing and evaluating the functionality and usability of the (technological support) tool interfaces. Fourthly, CSCW describes the research of how CSCW tools can help people accomplish their tasks while groupware describes the technology [Gru94a] and HCI describes how technologies with the required psychological, social, and organizational requirements, usability and functionalities can be developed [PRS+94]. Note that it is not our intention to go into the details of the HCI interface designs for the purposes of attaining the required usability and functionality of the support-tool. Our aim is to point out the requirements of the support-tool in view of the strengths and weaknesses of those we used in the modeling experiments so that a more versatile tool that incorporates the analysis and evaluation can be developed using the concepts of the meta-model.

\section*{Computer Supported Cooperative Work.} Computer Supported Cooperative Work (CSCW) [Gre88] is an area that is concerned with not only understanding the social interaction in groups, teams and communities, but is also concerned with the design, development and evaluation of technical/technological systems that support such interactions [GK07, KG06]. Being a multidisciplinary field that brings on board researchers from computer science, social science, psychology and HCI, there have been many definitions of CSCW. These definitions by different researchers are nicely summarized in [KG06, pp.165–166], see also [Gri11, Wol10].

1. “CSCW examines the possibilities and effects of technological support for humans involved in collaborative group communication and work processes” [BB91, p.V].
2. CSCW is a “computer-assisted coordinated activity such as communication and problem solving carried out by a group of collaborating individuals” [Gre91, p.XI] (see also [BGBG95, p.141]).
3. CSCW is “a generic term which combines the understanding of the way people work in groups with the enabling technologies of computer networking, and associated hardware software, services and techniques” [Wl91].

Ellis et al. [EGR91, p.39] note that: “CSCW looks at how groups work and seeks to discover how technology (especially computers) can help them work”. The first two definitions in [KG06] are more generic and applicable to our case. Comparison of the Computer-Mediated Communication (CMC) (using the COMA and InterLoc tools) and Face-to-Face (FTF) communication was meant to explore the possibilities and uncover
the effects of using or not using a support-tool during a collaborative modeling session. This research has found out that CMC at times supersedes FTF (cf. Table 4.9 and Table 7.2) which necessitates use of a support-tool to aid the communicative process and the group collaborative modeling processes.

**Groupware.** If collaborative modeling is to be supported with a tool, there needs to be not only the hardware, but also the software that controls the communication, collaboration, coordination and cooperation between and among the different participants in the modeling process. This software, which is distinguished from the ordinary (individual-oriented) software, is connoted with the word group and is referred to as “Groupware”. The work in [Gri11] gives a few definitions of groupware from a number of authors.

1. **Groupware is distinguished from ordinary software by the basic assumption that it makes:** groupware makes the individual aware that he is part of the group, while most other software seeks to hide and protect users from each other...Groupware...is software that accentuates the multiple user environment, coordinating, and orchestrating things so that users can “see each other yet do not conflict with each other” [LSVM90] (see also [BGBG95, p.141]).

2. **Groupware are “applications written to support collaboration of several users”** [DFAB98, p.463]

3. **Groupware are “intentional group processes plus software to support them ... software that supports group processes”** [PGLT07].

One definition that appeals to the construction of the support-tool with the embedded groupware to aid collaborative modeling, and the associated social interactions (communication, coordination, cooperation), is that given by Ellis at al. [EGR91]. These authors observe that “the goal of groupware is to assist groups in communicating, in collaborating, and in coordinating their activities” and they define groupware as: “computer-based systems that support groups of people engaged in a common task (or goal) and that provide an interface to a shared environment” [ibid., p.40]. This definition brings out two issues: common task and shared environment. These two factors were observed and were directly present within the modeling tasks that involved, mainly, the COMA and InterLoc tools. The second factor was indirectly present since within the Face-to-Face modeling sessions, especially those that were chauffeured within the Group Model Building (GMB) sessions, the environment was solely owned by the facilitator and he simply screen-shared the model generation tool with the modelers through the Oneekoon tool, see section 6.4.1 – Figure 6.12.

In addition to helping the modelers work on a common task within a shared environment, groupware should also help us structure the group activity by providing an effective way of designing the continually “evolving collections of group practices” which constitute a recurring activity, see for example [Win89] – a concept similar to “ThinkLets” in Collaboration Engineering (CE) [VB05, KBAV04]. The exploratory work on combining ThinkLets and dialogue games in [HS11] is quite a promising one for exploring recurring activities for group practice using the concept of “Focus Conceptualizations (FoCon)”. These collections of group practices that constitute a recurring activity, see also [Rit09b]
for a similar concept of recurring activities, were identified using the theoretical RIM framework in which we characterized, categorized and analyzed the recurring activities into propositions and counter-propositions, argumentations for or against, acceptances and rejections, etc., and in the COME framework as scoring and evaluations of the different modeling artifacts and their quality dimensions. Their successful implementation within the GMB InterLoc digital dialogue games, see Figures 6.10 – 6.11, point to how groupware can be used to help the group communicate, collaborate, and coordinate their activities.

**Synchronicity: The Time–Space Groupware/CSCW Matrix.** Any support-tool that aids collaborative modeling along the communicative dimension should possess synchronicity functionalities. Such a tool should aid participants in a collaborative session to communicate synchronously (at the same time – collocated) or asynchronously (at different times) and the communication should be done either remotely (at different places) or concurrently (at the same place). A nice categorization of collaboration technologies within groupware and CSCW is done using the groupware/CSCW matrix of Johansen [Joh88], see also [BGBG95, EGR91, Gri11]. This matrix is shown in Table 8.5.

<table>
<thead>
<tr>
<th>Communication mode</th>
<th>One meeting site (same places)</th>
<th>Multiple meeting sites (different places)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Synchronous communication (same time)</td>
<td>Face to Face Interactions</td>
<td>Remote Interactions</td>
</tr>
<tr>
<td>Asynchronous communication (different time)</td>
<td>Ongoing Tasks</td>
<td>Communication and Coordination</td>
</tr>
</tbody>
</table>

Although the CSCW matrix is a nice array that has been used for other classifications of CSCW support systems and technologies, the time-space CSCW matrix has often been criticized for being restrictive [SR96] by assuming that interaction takes place at different times and at different places, and the matrix is criticized by Penichet et al. [PGLT07] for not being able to categorize recent collaboration support-tools that “have become more and more complicated over time”. These authors observe that “an application can be synchronous, asynchronous or both and at the same time, considering the space, it can be in the same or in a different one” [ibid, p.242].

**Monitoring, Mirroring, and Guiding support-tools.** Determining the requirements and developing guidelines for construction of a support-tool for collaborative modeling analysis, evaluation and appropriate groupware, requires determining the cardinal role of such a tool. A support-tool can play one or more of the following three key roles: monitoring, mirroring and guiding [JSM01, SMJM05], see also [KAK11]. Although this categorization and classification comes from the variant of CSCW – Computer Supported Collaborative Learning (CSCL) – a closely related area to collaborative modeling – the categorization is appropriate for support-tool classification within the collaborative mod-
eling domain and can be used as a basis for drawing up the required functionalities and
guidelines for the construction of collaborative tools that include analysis and evaluation
functionalities.

♦ Monitoring Tools. A monitoring tool offers the following functionalities: 1) awareness
– understanding the activities of others [DB92], 2) coordination – structuring the col-
laboration activities, 3) communication – technologically seamless synchronous or asyn-
chronous (collocated or distant) communication [KAK11]. Participants should be aware
of their individual and group activities, through a monitoring support-tool, for successful
collaboration and coordination of group activities. Awareness provides not only the con-
text of the individual and group activities but also the “object” of collaboration and the
way the “object” is generated as constituents of the context [DB92]. A monitoring tool
lacks analysis functionalities [KAK11].

♦ Mirroring or Meta-cognitive Tools. A mirroring or a meta-cognitive tool [JD08, JSM01],
unlike a monitoring tool, includes analysis functionalities that are capable of processing
the data stored in the logfiles. Such tools send or enable visualization of the analysis
results to participants so that an intervention or remedy can be effected or their individ-
ual contributions can be determined so as to determine the extent of the collaboration
[KAK11, SMJM05]. The analysis enables the participants to adapt their behaviour for
the benefit of the collaboration.

♦ Guiding Tools. Guiding tools, like mirroring or meta-cognitive tools, have the analysis
functionality. As noted in [KAK11], they go a step further by intervening directly, and
evaluate the performance of the participants and, thus, complement the roles of a human
facilitator in the intervention. The analysis information is relayed to the participants for
interpretation and “the system uses this information to make decisions about how to mod-
erate the groups’ interaction” [SMJM05].

In order to give the requirements and guidelines for the support-tool that is designed us-
ing the meta model, we point out, first, the categorization, and, second, a synthesis of
the strengths and weaknesses of the two support-tools – the COMA and InterLoc tools –
that were used in the modeling sessions. The two tools are bench-marked on the the fol-
lowing general groupware functionalities by Andriessen [And03]: (i) person interchange
processes – communication, (ii) task-oriented processes – cooperation, coordination and
information sharing, and, (iii) group-oriented processes — social interactions which are
pertinent for an effective collaborative modeling process. In addition, the following ques-
tions given by Penichet et al. [PGLT07] are used to further guide the classification and
evaluation. The classification and evaluation lead to the required functionalities of a
support-tool that incorporates the analysis and evaluation frameworks as integrated in
the meta-model.

Are the users helped to collaborate to attain a goal?, Do they share informa-
tion?, Do they work with it?, Can it be used as a communication method?,
Are users informed about anything?, Do they inform themselves using this
tool?, Does it coordinate processes and persons?, Is the tool used in real
8.4. Support-tool Requirements and Guidelines

The COMA Tool. The COMA tool [Rit08a] is a versatile tool for collaborative modeling employing the negotiation perspective of collaborative modeling. As a support-tool, COMA can be categorized as a monitoring tool. The COMA tool has been evaluated and its perceived usefulness is reported in [Rit10c] and some of its strengths which are discussed in [Rit10e, Rit09a] are summarized below.

- Resolving a conflict, i.e. clarifying a misunderstanding
- Making sense, i.e. trying to understand a situation within or without the modeling language
- Conceptualizing a situation, i.e. expressing a situation in the modeling language
- Communicating a view, i.e. making an individual view accessible to others
- Aligning views, i.e. making different proposals converge
- Clarifying an issue, i.e. getting help with an unclear issue from others
- Discussing a problem, i.e. trying to structure an unstructured problem and arriving at a potential solution alternative
- Evaluating alternatives, i.e. assessing the relative merits of each proposed solution
- Agreeing on a solution, i.e. arriving at a common version of a model
- Ensuring progress, i.e. making sure that we proceed towards a result, e.g. a complete model

It is clear from these strengths that COMA, to a large extent, satisfies Andriessen’s requirements. Despite these strengths, the COMA tool still lacks functionalities for a natural language and a project management component which could be added by integrating conventional groupware functionality e.g., email, chat, brainstorming, etc., [Rit09a].

The InterLoc Tool. The InterLoc tool [Int11, RMS10] as argued in Chapter 6 is a tool that supports communicative digital dialogue games. As a support-tool, it can also be categorized as a monitoring tool like COMA. However, unlike COMA, it does not offer an environment for developing and visualizing a collaborative model by the participants. Note that this was achieved by screen-sharing the model of the facilitator with the participants through the Oneeko tool [One11], see Figure 6.12. It does offer a more powerful environment for brainstorming, discussions, chatting, negotiation and decision-making than COMA. It can be used synchronously and in collocated or distant communication and collaboration. Additional strengths and weaknesses of the COMA and InterLoc tools as observed from the modeling sessions in Chapters 6 and 7 are given in Table 8.6. These tool requirements /functionalities are discussed further in section 8.4.1.
Table 8.6: Support-tool requirements for collaborative modeling.

<table>
<thead>
<tr>
<th>Collaboration Tool</th>
<th>Tool Functionality Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMA</td>
<td>Yes</td>
</tr>
<tr>
<td>InterLoc</td>
<td>Yes</td>
</tr>
</tbody>
</table>

A. Awareness
- Tool helps participants be aware of their individual and group activities: Yes Yes
- Tool helps participants be aware of the shared workspace: Yes Yes
- Tool helps participants be aware of context and object of the individual and group activities: Yes Yes

B. Communication, Negotiation and Group Decision Making
- Tool can be used as a communication medium: Yes Yes
- Tool can be used for sharing information, discussion, brainstorming, agenda setting, chatting, etc: No Yes
- Tool helps participants reach agreement and consensus: Yes Yes

C. Collaboration
- Tool helps participants work on a joint project: Yes Yes
- Tool can be used to help participants collaborate to attain a goal: Yes Yes
- Tool helps participants to work jointly determine the process and/or procedure of working, the (modeling) language to use, etc: No No
- Tool helps participants create a shared meaning, understanding of the process, product, and/or event, etc: Yes Yes

D. Coordination
- Tool coordinates processes, products and/or persons: Somehow Yes
- Tool helps participants in their individual work efforts towards the accomplishment of a larger goal: Yes Yes
- Tool helps participants structure their process: Somehow Yes

G. Synchronicity
- Tool is used in real time (concurrent, same time): No Yes
- Tool is suitable to be used pre-recorded (different times): Yes No
- Tool can be used in the same physical space (collocated communication and collaboration): Yes Yes
- Tool can be used in different spaces (distant communication and collaboration): No Yes

E. Interaction analysis
- Tool stores communication and participants activities data in log-files: Somehow Yes
- Tool analyses and enables visualizes and display of analyzed data: No
- Tool moderates participants interactions: Somehow Yes
- Tool enables versioning of the generated products: Yes N/A
- Tool helps participants enact or triggers rules and goals to guide their activities: No No

F. Collaborative Evaluation
- Tool helps participants select jointly artifacts and their quality dimensions to use in the evaluation: No No
- Tool helps participants select an evaluation method of the artifacts and/or their dimensions: No No
- Tool helps participants score, rate or weigh the artifacts and/or evaluate alternatives: Somehow N/A
- Tool helps participants aggregate their (individual and/or group) scores: No No

8.4.1 Social Interaction and Organizational Requirements

Since many participants in collaborative modeling and design normally adopt social strategies and actions [RAR05] – a process that makes collaborative modeling and design more of a social process than a cognitive process [LB06], see also [PGLT07], any support-tool should possess functionalities that aid this social process and interaction. From the evaluation of the COMA tool and the InterLoc tools, we identify and discuss social actions and interactional processes for which a tool should offer the required functionalities. Social interaction and organizational requirements which are discussed in this section in-
exclude: collaboration, communication, negotiation and decision-making, coordination and awareness.

**Collaboration Requirements.** Collaborative modeling as argued in this thesis, requires participants in the modeling effort to work jointly as a group to achieve some group goal. In most cases the overriding goal is to develop a model of some domain, e.g., a business process model, an enterprise model or architecture, etc. This collaborative effort requires an awareness of the activities of the individual participants and the group, the context and the object to be generated and an awareness of the environment in which they work. It also requires a seamless technological support that offers an environment for communication, negotiation, decision-making, etc. “Negotiation is a form of collaboration where participants reach a mutually acceptable solution for the object of negotiation” [BG10] and collaborative modeling is a negotiation [Rit07]. Communication plays a key role here and may be facilitated by a synchronous or an asynchronous tool and may be collocated or distant. Using the RIM framework we can carry out an “interaction analysis” [FPD04, JH95, KAK11], a “script analysis” [AR97, CHA+10, RJH+04] or a “collaboration script analysis” [KFH06] to determine the rules, goals and model propositions that drive the entire communicative process and the COME framework is used to evaluate the different modeling artifacts used in, and produced during, the modeling session. Participants need to do a joint evaluation of the different modeling artifacts. All these processes are social processes that require different functionalities of a tool to be accomplished. These social processes that lead to an effective and efficient collaborative effort are discussed next.

**Coordination Requirements.** In collocated or distant (distributed) collaborative modeling, coordination of the activities of the modeling processes requires integration, harmonization and/or synchronization of the activities of the individuals as well as the group towards the attainment of the (larger) group goal. This integration and harmonization is accomplished through a number of ways [EGR91]: viewing individual as well as actions of others, triggering the participants’ actions, informing them of the state of their actions and their wait conditions, generating automatic reminders and alerts, etc. A support-tool or system that offers coordination of the participants’ activities can be categorized by one of the four models they embrace:

1. Form-oriented model: focuses on routing of documents (forms) in organizational procedures. Coordination is addressed by modeling the organizational procedure as a fixed activity.


3. Conversational-oriented model: based on the observation that participants coordinate their activities through their conversation. Coordination is based on the Speech-Act Theory (SAT) – through speech acts [Sea69], see also [Win89].

4. Communication-oriented model: which addresses coordination through (organizational) activities in terms of role relationships.
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The support-tool for collaborative modeling should, in addition to the above requirements, possess functionalities that help modelers coordinate not only their individual (and/or group) activities and the generated products, but should also help them structure their processes. In real-time modeling, individual contributions to the models, their turn-taking roles in the conversations and evaluations, etc., should be properly coordinated.

Awareness Requirements. Awareness establishes common ground and shared understanding between and among the participants in a collaborative modeling and/or design process [DÓ6]. Common ground [CB91] helps participants in a collaborative modeling effort to share knowledge in order to be understood so as to have a meaningful communicative (conversational) exchange, shared meaning and shared understanding. Awareness includes social (individual and group) awareness – understanding the activities of others [DB92], situational awareness – that refers to “the up-to-the minute cognizance required to operate or maintain a system”, and workspace awareness – which refers to: “the up-to-the-moment understanding of another person’s interaction with the shared workspace” [GG02]. According to [Sar05], see also [PGLT07], methodologies that enhance awareness can be categorized as: task-oriented awareness – which informs the participants about the state of affair of a specific task or action, social awareness – which presents the information about the presence and activities of the participants in the shared environment, or collocation awareness – which provides a (virtual) shared location that helps participants become acquainted with the environment.

DeSanctis and Gallupe [DG87] level 1 for GDSS offers functionality for achieving awareness in addition to improving group communication and coordination. For collaborative modeling, awareness could be achieved by offering three environments (workspaces) for the participants: personal workspace – where modelers could develop their individual personal models, shared (group) workspace – where the participants upload their models for evaluation, commenting and critiquing by other members with a chat environment for exchange of texts, and the agreed workspace – where the consensually agreed upon models are taken. Of the two tools used in this research, it is COMA that offers these three workspaces.

Communication, Negotiation and Decision-making Requirements. Since the collaborative modeling activity is carried out within a communicative perspective, a support-tool should possess functionalities for aiding this communication to help modelers achieve their group goals. Such functionalities should include those that allow modelers to exchange communication dialogues, engage in a negotiation process – where after an argumentation process they reach a mutually acceptable position for the object of discussion, and have to make decisions and evaluations about selected alternatives. Functionalities should include those that allow the participants to justify why they make a certain proposal or why they critique certain proposals and/or positions. It should allow them to withdraw their proposals, give comments, etc. The components of the communicative process that should be supported include those we referred to as the micro communicative dialogue components given in Figures 6.4 and 6.5. Of the two tools used in the modeling sessions, the InterLoc tool supersedes COMA in this regard. Its argumentation environment obtained through the developed dialogue games is richer than that of COMA in facilitating the argumentation process and negotiation process, although COMA also does offer an
8.4. Support-tool Requirements and Guidelines

environment for giving comments (about the models).

Although the semi-structuring of the argumentation process as seen in the InterLoc tool was initially implemented in tools based on the Issue-Based Information Systems (IBIS) argumentation structure using the three concepts: issues, positions, and arguments, e.g., gIBIS, QUEST Map [Con03] and recently in Compendium [Com11, Con07], this set does not accommodate all the micro dialogues seen with the InterLoc tool which are common in collaborative modeling and Group Model Building Sessions (GMB). The structuring of the argumentation process into a tool that implements the micro-communicative patterns (established through the RIM framework) is achieved using DeSanctis and Gallupe [DG87] Level 3 of GDSS. At this level, as also observed in [Wol10], “users communicate in pre-specified communication patterns, according to a set of communication rules” [ibid, p.84]. Negotiation and decision-making could be implemented by the tool using the awareness shared (group) workspace and DeSanctis and Gallupe level 2.

8.4.2 Technological Requirements

Support-tool technological/technical requirements, which are discussed in this section, include: synchronicity, interaction analysis, and collaborative evaluation.

Media Synchronicity Requirements. Synchronicity requirements of a support-tool for modeling, analysis and evaluation of the collaborative modeling processes refer to the synchronous and/or asynchronous requirements that support the social actions and strategies discussed in the previous section. Collaboration, coordination, communication, negotiation and decision-making as well as awareness may be accomplished in real time (at the same time, concurrently) and may be collocated (same place) or distributed (different places). They may still be accomplished at pre-recorded (different) times and may be collocated (same place) or distributed (different places) – see Figure 8.5.

♦ Media Richness: Uncertainty and Equivocality. The Media Richness Theory (MRT) [DL86, DL84] can be used to explain how different communication media affect task performance by making a distinction between rich and lean media. Reduction in uncertainty – lack of the necessary or required information in carrying out a given task [Koc98] and equivocality – which refers to ambiguity: confusion, disagreement, lack of understanding, i.e., existence of multiple conflicting interpretations, opinions, views, etc. [DLT87], can only be assessed if the support-tool or medium possesses the required functionalities. The right tool functionalities will help reduce uncertainty by requiring someone in the collaborative effort to locate, acquire or generate the required information [DV99] while equivocality reduction requires members to undertake a negotiation process so as to converge to consensus on the same interpretation, meaning, etc. However, the media used in collaborative modeling may or may not possess the required functionality to reduce equivocality since, as argued in [PTE08], the degree of richness of a communication medium channel determines its appropriate application to solve ambiguous or uncertain (collaborative) tasks.

♦ Media Synchronicity: Conveyance and Convergence. While MRT tests concentrate on
"perceptions of media fit", there is a need to determine the “actual effects” of the medium or support-tool on both the quality of the process and the outcome [Ric92]. To this effect, the Media Synchronicity Theory (MST) [DVSM98] can be called upon. MST posits that every communication process is composed of two main processes: conveyance – conveying information and convergence – converging on a shared interpretation, meaning, etc., that enables the group to reach the required outcome of a collaborative/group effort. MST further hypothesizes that the medium has a set of enabling functionalities that support each and every communication process within the collaborative/group task. In this regard, Dennis and Valacich [DV99] observe that communication effectiveness will be enhanced if the medium’s functionalities and abilities are aligned with the collaborative processes. Conveyance, in collaborative modeling, is through the different interactions that modelers are engaged in (mainly communication: negotiation, decision-making). It is the exchange of information and “can be divergent in that not all participants must agree on the same meaning of information nor must they focus on the same information at the same time” [DVSM98, p.5]. Convergence, which is the development of a shared meaning to information, is reached through agreements and consensus where modelers reach a shared and common interpretation, meaning and understanding. Low media synchronicity is generally preferred for conveyance processes whereas high media synchronicity is better suited for convergence [DV99, DVSM98].

![Interaction Analysis Methods Diagram](image-url)

**Figure 8.9:** Overview of interaction analysis techniques, adapted from [KAK11].

In the analysis (RIM) framework described in Chapter 3 which is integrated in the metamodel in Chapter 5 with the evaluation (COME) framework described in Chapter 4, a number of components were identified that can be used in the automation of the analysis and evaluation. We next describe the support-tool requirements and methods to achieve the automated analysis and evaluation for the analytic and evaluative part of the metamodel.

**Interaction Analysis Requirements.** One of the desirable functionalities of a mediating tool is that it collects interaction data which refers to events captured and stores them in
8.4. Support-tool Requirements and Guidelines

a logfile. Tools that mediate and support collaborative modeling should be able to log each and every event that captures most of the aspects of the content and the process of interaction [KAK11]. Such interaction includes the social interchange interactions: communication, negotiation, group decision-making and model-related actions, etc. Storing these interactions in a logfile enables their analysis using interaction analysis techniques and methods [GJH+03]. These interaction analysis methods which are depicted in Figure 8.9 include the following that could be automated and implemented in a support-tool:

1) automatic methods based on:
   i. event logs: for determining collaboration and interaction performance.
   ii. event logs and a priori annotation of verbal content: exchanged communication messages using explicitly or implicitly participant-annotated or researcher-annotated verbal actions, e.g. sentence openers or collaboration scripts.

2) methods that use human evaluations techniques based on:
   i. coding schemes: e.g. content analysis: determining the syntactic structure of a message, its thematic content, and the structuring of dialogue according to speech act theory.
   ii. rating schemes: used in evaluations to make judgments on a larger set of data at a time.

3) training models that use human evaluations based on:
   i. coding data: using keywords (discourse markers) or key (clue) phrases that are linked to specific categories of a coding scheme.
   ii. rating data: automatically rating collaboration quality. [KAK11, KCA10].

Most of the (content) coding and analysis methods used in Chapter 6 and 7 fall under 2. However, since this analysis was based on recorded data, the analysis and coding can be automated so that 1 and/or 3 could be used. A support-tool that offers this functionality could incorporate features of the monitoring, mirroring and guiding tools as explained previously. Interaction analysis should be able to reveal, and should be used to mine, the rules/goals, interactions and model propositions in the RIM framework and the collaborative evaluations of the modeling artifacts using the COME framework. The analysis and evaluation could then be automated using a support-tool that implements an interaction analysis and evaluation methods. This concept is similar to that used in Computer Supported Collaborative Learning (CSCL) – see Figure 8.10 – implemented in the OCAF [ADKM03] approach in the Synergo support-tool [AMK04b, AKFM03, AKF+04, MAK04].

One way of facilitating this interaction process is by using a structured method that uses e.g., “sentence openers” [HR12, KAK11] similar to those of the GMB InterLoc dialogue game [Int11], see Figures 6.10 and 6.11 or “collaboration scripts” – which engage individuals in specific (pre-defined) activities and involve the fading technique that tailors “support for collaboration to the particular needs of the specific collaborators” [KFH06, RW08]. This concept is well-developed in InterLoc dialogue games and
Chapter 8. Discussion

Figure 8.10: Logfile-based interaction analysis framework, adapted from [KAK11].

could be incorporated within a support-tool for collaborative modeling. In GMB facilitated modeling sessions, the concept of scripts is also well-developed, see for example [AR97, CHA⁺10, RJH⁺04]. “Scripts describe in detail what a facilitator does in introducing a task to the group of participants, how he or she guides the group in working on the task and what sort of outcomes may be expected” [HR12, p.21]. A support-tool that incorporates and implements both sentence openers and scripts should be better positioned to enable both chauffeured and non-chauffeured collaborative modeling sessions.

**Collaborative Evaluation Requirements.** The COME framework presented in Chapter 4 provides a methodology that can be used for the joint or collaborative evaluation of the modeling artifacts and their identified quality dimensions. This methodology that is anchored on a Multi-criteria Decision Analysis (MCDA) approach – the Analytic Hierarchy Process (AHP) – gives a novel approach of not only scoring, rating, weighting and/or ranking the artifacts and their dimensions, but also an approach that allows modelers in a collaborative modeling process to reach agreement (and possibly consensus) about the final score. Where individual scores are given, these could be aggregated using the defined aggregation techniques. Of the two support-tool used in the modeling sessions – COMA and InterLoc – it is the COMA tool that has an in-built scoring mechanism for determining the quality of the generated models. This is out of reach for the InterLoc tool since it lacks the workspace for model generation. The scoring mechanism provided
by COMA, however, does not go deep enough in revealing how the individual scores are aggregated into a final score or which of the individual scores is finally agreed upon by the evaluators. As shown in the COME framework and in Chapter 6 and 7 a support-tool should possess functionalities that allow modelers to:

- decide on or select the different modeling artifacts to evaluate
- select or generate the quality dimensions of the modeling artifacts
- score, weigh, rate and/or rank the dimensions and/or modeling artifacts
- aggregate the individual scores or weights
- consensually agree on the final quality score/weight to use

An automated evaluation technique and/or a rating approach integrated with an analysis approach can be used to cover all the stages of the logfile-based interaction analysis framework in Figure 8.10. A set of automated evaluation or rating metrics [KCA10, KCV+09, MSR07, MVK+08, VMK+08] can then be defined and implemented in a support-tool to cover the evaluation of the entire collaborative modeling process (in addition to those of the modeling artifacts and their dimensions) using the logged activities or interactions.

8.5 Concluding Remarks

This chapter has highlighted some of the major findings and observations about the results from the exploratory, explanatory and confirmatory modeling experiments. Major findings about the use of the RIM framework in analyzing collaborative modeling processes have been pointed out. These include explicit and implicit rules set in, and set for, the modeling game as well as their distributions within the phases of the modelers’ structured process. It has been pointed out that without the guidance of a facilitator, modelers tend to structure the modeling process in distinctive phases that help them achieve the goals. Major interaction types and topics from the macro and micro communicative dialogues and rule and goal types from the theoretical ones of QoMo that were enacted in the modeling session have been identified. The chapter has developed, abductively, an explanatory and descriptive theory that can help us study, analyze and evaluate collaborative modeling processes.

Different components of the theory including its means of representation, constructs, statements of relationships, scope, causal explanations, testable propositions/hypotheses and prescriptive statements have been identified. These are traceable in the RIM and COME frameworks, the meta-model as well as the CMPQ construct. The chapter has also given requirements and guidelines for the construction of the support-tool that can be designed as an instantiation and implemented technological artifact of the design science approach that integrates the RIM and COME framework through the meta-model. Using the meta-model concepts as a basis for the data structures, using the requirements and following the guidelines given about the support-tool, this tool can be realized. In the next chapter, we give the major contributions of this research, limitations and future work.
9 Epilogue

Research can be seen as an elaborate argument culminating in an answer to preliminary questions.

– Verschuren & Doorewaard, 2010

9.1 Overview

This chapter is the climax of the journey that started in the first chapter. In it, we look back and assess how far we have moved towards answering the research questions, and how far we have gone in realizing the research objectives that have guided our research through out the chapters. The chapter, thus, starts by looking at the research contributions which come from the answers to the research questions. We point out the sections where these contributions can be traced. Claiming that everything was a smooth ride is far-fetched. We therefore, point out the limitations that prevented us from going further than we had wanted. We identify theoretical as well as practical limitations that prevented us from achieving what we had initially wanted to achieve. From these limitations, we point out areas that need further research to strengthen the developed frameworks, metamodel and the theory. In the concluding remarks of the chapter, we give final notes on the frameworks, the meta-model, the theory and support-tool. The chapter ends with final conclusions about the process of modeling in general, and analysis and evaluation of collaborative modeling processes in particular.

9.2 Research Contributions

To give the research contributions, we look back at the research problem that we set out to solve and the research questions that were posed at the beginning of the research in Chapter 1 – section 1.2.1 and assess how far the research has tried to answer them. Answering the research questions means looking at the research objectives in section 1.2.2 whose fulfilment is indication that the problem has been (wholly or partially) addressed. Rather than referring the reader back and forth, we re-state below the research problem, questions and objectives and then point out our contributions.

□ Research Problem. The research problem that this research set out to investigate comes from the need to understand the process or the act of modeling and the observation that modeling consists of two fundamental parts: the process and the products. Although as argued, a lot has been done and achieved as far as the products are concerned, little is known about the process of which the models are the end-products. Moreover, if the model is developed by a group, little is known about how they go about whatever they do – an indication that a dark cloud still hangs around the act of modeling. We have argued that by positioning the whole collaborative modeling process within a commu-
Communicative perspective, we can get a clue about what takes place in there. But studying, analyzing and understanding this communicative process lacks a well-structured methodology and/or framework that can help us identify the different components. The identified research problem that this research set out to address is, thus: *lack of a well-structured methodology to study, analyze, understand and evaluate the process (act) of modeling in an interactive and collaborative modeling environment.*

**Research Questions and Objectives.** To address this problem, we identified a number of research questions (*RQs*) and objectives (*OBJs*) which are re-stated below and from which our contributions are derived.

**RQ** What is an adequate methodology for the analysis and evaluation of collaborative modeling?

Answering the above research question achieves the following main objective:

**OBJ** Development of a theory that explains and describes what takes place during a collaborative modeling effort and describes a well-structured methodology for evaluating a collaborative modeling process.

We pointed out that the research question and the main objective are too complex to tackle as they stand. Sub-questions and sub-objectives were instead used to manage the complexity of the main question and objective. It is from the answers to the sub-questions and sub-objective attainment that we derive our research contributions. We analyze below each sub-question and its corresponding sub-objective.

**RQ1** *How can the detailed steps resulting from the communicative and collaborative dialogue of the participants in the modeling process be studied and analyzed and what are the key-drivers of a collaborative modeling process in view of the communicative nature of the modeling process?*

**OBJ1** *To develop a framework for studying and analyzing the detailed steps that result from a communicative and collaborative dialogue and identification of key-drivers of a collaborative modeling process.*

**Studying and Analyzing Collaborative Modeling: A New Approach.** Chapter 3 provides an approach for studying the detailed steps resulting from the communicative and collaborative dialogue of the participants in the modeling process which is key in helping us get a glimpse at what takes place inside the modeling process and has helped us open the lid off the black-box of the process of modeling. This study was done through a number of modeling experiments as detailed in Chapters 6 and 7 and involved recording these communicative dialogues and exchange of speech acts between and among the different stakeholders in the modeling process. The study and the analysis of the recorded conversations has revealed the structure and the components of a collaborative modeling process which can help us understand better the modeling process from the communicative perspective. Taking this approach, our research has provided a new approach to studying and analyzing collaborative modeling processes. Using the study and analysis approach
presented in this research, the transcription and coding schemes, we can not only catego-
rize the communicative dialogues and speech acts into micro and macro categorizes, but
can also identify the the key-drivers to collaborative modeling from this communicative
perspective.

□ **Key-drivers.** The key-drivers that this research contributes to the study and analysis of
the modeling process include:

- rules – which modelers use to guide and direct the modeling process, and the goals
  that set the state to strive for.

- interactions – which are the modelers’ conversational statements (speech acts or
  conversational moves) that lead to negotiations, argumentations, propositions, (dis)
  agreements, comments, decision-making, consensus states, etc.

- model propositions – which are generated lists of propositions (statements) derived
  from the entire conversation up to some time $t$, and subject to selection criteria
determining which proposals make it to the common (shared) model after a negoti-
atation and decision-making process.

Tables 3.3 – 3.5 provide the different generic elements of these key-drivers while Chapter
5 gives a meta-model that integrates these key-drivers within the evaluation process.

□ **The RIM Framework.** In section 3.5.1 we presented and discussed a framework that
can be used to study, analyse and help us understand the collaborative modeling pro-
cesses from the communicative perspective. This framework helps us achieve objective
one *(OBJ1)* associated with the first research question *(RQ1)*. This framework, which we
termed the *Rules, Interactions and Models (RIM) framework*, is presented in Figure 3.4.
It is anchored on the key-drivers discussed above. Using this framework, we can diagnose
all the communicative dialogues and have a better understanding of what takes place dur-
ing a collaborative modeling session. The framework helps us understand how modelers
do whatever they do, identify the drivers of this communicative process by answering a
number of other questions such as:

- What are modelers concerned with during a particular modeling session?

- What are the main categories of the rules and/goals governing a (process) modeling
  session?

- How do rule/goal categories found relate to the categories as proposed and used in
  previous relevant frameworks for analysis?

- What further observations can we make concerning rules/goals, rule/goal setting,
  interaction, and model proposition?, etc.

The RIM framework is a modest contribution yet a novel one whose power has been
demonstrated and illustrated using a number of examples in Chapter 3 – section 3.5.2 and
has been used to analyse the exploratory, explanatory and confirmatory modeling experi-
ments discussed in Chapters 6 and 7.
□ **Relationships between the Key-drivers: A Theoretical Model.** The second question research (RQ2) and the associated objective (OBJ2) were meant to help us determine the nature of relationship or causalties that exist between the key-drivers of the modeling session and develop a model that can explain these relationships. This question and objective were stated as:

**RQ2** What are the relationships between the key-drivers of a collaborative modeling process and which theoretical model describes these relationships?

**OBJ2** To identify and establish relationships between the key-drivers and a theoretical model that describes these relationships.

This research has managed to establish and define these relationships as discussed in section 3.5 and we have successfully developed a theoretical model that describes these relationships which is given in Figure 3.3. This is another contribution of this research. These relationships help us study and analyse an interplay between the rules/goals, interactions and models in a collaborative modeling session. This interplay helps us trace how changes in the interaction-log, result in changes in the products produced and how intermediary or end-products lead to further interactions. Similarly, it helps us track how rules/goals of modeling lead to intermediary products and end-products and the how the intermediary products or end-products lead to further rules/goals of play. This interplay is shown in Table 3.6.

□ **Evaluating Collaborative Modeling Processes: A New Approach.** The third research question (RQ3) and its associated research objective (OBJ3) that this research set out to address was meant to determine how the quality of the different modeling artifacts used in, and produced during, the modeling session can be established and how this links to the RIM framework. The research question and objective are re-stated below.

**RQ3** How can the quality of the collaborative modeling process be measured and what is the theoretical framework that describes and links the analysis and evaluation framework?

**OBJ3** To develop a framework that helps us evaluate the quality of a collaborative modeling process and helps determine the success factors and a meta-model that integrates the analysis and valuation framework.

In Chapter 4 we described a new approach that can be used to evaluate the different modeling artifacts used in, and produced during, the modeling sessions. Rather than leaving quality assessment or evaluation in the hands of the model expert (systems analyst), the evaluation approach presented shows how this can be done by the modelers themselves through a communicative process using an approach that minimizes the bias and subjectivity and aggregates their priorities and preferences. This is yet another modest yet strong contribution to the evaluation of the different artifacts in the modeling process.

□ **The COME Framework.** The research has developed a framework – the **Collaborative Modeling Evaluation (COME) framework** that contains the basic phases and steps which are:
1. Selecting the Modeling Artifact(s).

2. Choosing the Evaluation Method.

   (i) generating quality dimensions (criteria, factors) which are the characteristics or features of the modeling artifacts upon which quality assessment will be done

   (ii) Assessing and selecting the dimensions to use (may involve narrowing the scope and grouping the dimensions)

   (iii) rating, weighting and/or ranking the dimensions using an evaluation method


The novelty of this framework is that it based on one of the well-established approaches – the Analytic Hierarchy Process (AHP) from the area of Operations Research (OR) a strong method that aids (group) decision-making. In section 4.5.3 we demonstrated how this approach can be used, and it was applied in Chapters 6 and 7 in the exploratory, explanatory and confirmatory modeling sessions. Insights and opinions of the experts as discussed in Chapters 7 and 8 indicated that it is a versatile and applicable approach and they were ready to adopt it in practice.

☐ The AHP Approach. Using the AHP approach within the evaluation method, see section 4.4, we have demonstrated how the the mental model knowledge, skills and expertise can be combined through a communicative process to obtain group and consensually agreed upon final scores, ratings and/or weighting to the different quality dimensions of the modeling artifacts using a negotiation and decision-making process. By providing such an approach, this research has answered what Moody [Moo05] initially termed lack of empirical testing and validation of developed quality frameworks – a phenomenon that has always led to a “yet another...” syndrome. The approach presented is of practical importance as has been shown throughout the exploratory, explanatory and confirmatory modeling experiments in Chapter 4, Chapter 6 and Chapter 7, and has provided a practical method for scoring the quality factors of the modeling artifacts.

☐ The Meta-model. The research contribution that comes from an answer to RQ3, is the development of the meta-model that integrates and unifies concepts in both the RIM and COME frameworks. This integration serves a number of purposes as discussed in Chapter 5. It provides:

  1) a set of concepts (concept structure) for the RIM and COME frameworks,

  2) a set of (inter-) relationships between the RIM and COME concepts, and

  3) a set of constraints for the relationships.

The concept structure, (inter-) relationships between them and the constraints all combine to help us:

1. derive the actual analysis and evaluation structures for the RIM and COME frameworks.
2. communicate the analysis and evaluation concepts between and among the different stakeholders in a modeling session.

3. derive the requirements and guidelines for construction of a support-tool that incorporates analysis and evaluation concepts.

4. track the flaws in the RIM framework using heuristics developed in the COME framework.

9.3 Limitations and Further Research

Although we have outlined a number of achievements and contributions from this research, we faced a number of limitations that prevented us from going beyond where we reached. This, in a way, curtailed our progress and forced us abandon some of the questions that we wanted to answer and objectives we had wanted to achieve. This section looks at some of these limitations. From these limitations, we point out areas that need further theoretical investigation and practical research.

9.3.1 Limitations

This research set out to investigate the analysis and evaluation of collaborative modeling processes and to develop theoretical frameworks and/or models that can facilitate this analysis and evaluation. Our major goal was, and still is, to better understand what takes place during the modeling place. Although we have succeeded to develop two frameworks that can be used in the analysis and evaluation, and a meta-model that integrates the analysis and evaluation frameworks, we still faced a number of limitations which may be categorized as theoretical/methodological and/or technological/practical limitations.

Theoretical/Methodological Limitations. On the theoretical/methodological side, we faced a lot of challenges analyzing, statistically, the data obtained from the modeling experiments with both students and IT experts, especially, where sample size was small. This was the case with the the CMPQ construct. It was almost impossible to get the recommended minimum size of at least 300 to get statistically significant results. Although we managed to test the construct with students with reasonable sample sizes of at least 100, it was almost impossible to get this number with IT experts in the field! Therefore testing, statistically, the acceptability and adoption of the evaluation method as presented in the COME framework and its use in practice could not be done other than getting the opinions and insights of the IT experts through the researcher-designed AHP-questionnaire and through post-survey interviews. A number of rules of thumb that have been proposed in literature will need to be strictly and religiously followed for further theoretical and statistical validation of the CMPQ construct.

The most common rule of thumb requires that there are between 10 – 15 participants per variable [Fie09]. Nunnally [Nun78] recommends 10 times as many participants as variables while in [KT79, TF07] the recommendation is to have between 5 to 10 participants per variable up to 300 – the value that guarantees stability regardless of participant to variable ratio. In [CL92] a sample size of 100 is regarded as poor, 300 as good while 1000 as excellent. While the above authors stress the sample size, others observe that this also may depend on other factors. For example, [MWZH99] observes that as the communalities become lower, the importance of the sample size increases. With communalities
9.3. Limitations and Further Research

greater than 0.6 small sample sizes of about 100 will be perfect, communalities in the range of 0.5, samples of sizes between 100 and 200 are good if there are few factors with a small number of indicator variables. A sample size of greater than 500 is recommended for communalities of less than 0.5 with a large number of underlying factors. However, Arrindell and van der Ende [AE85] found no compelling evidence for the participant to ratio rule of thumb in their Monte-Carlo simulation experiments. In [GV88] the magnitude size of the loadings is emphasized in the same measure as the sample size. For example, if a factor has 4 or more loadings greater than 0.6, then it is reliable regardless of the sample size, factors with 10 or more loadings greater than 0.4 are reliable if the sample size is greater than 150, and factors with fewer loadings are ignored unless the sample size is greater than 300 [Fie09].

Another statistic that can be used in the factor analysis tests is the Kaiser-Meyer-Olkin (KMO) measurement of sample adequacy. If KMO = 0, then this is an indication of diffusion in the pattern of correlations and therefore factor analysis is inappropriate, KMO = 1 is an indication of the relatively compact patterns of correlations and factor analysis is likely to give reliable factors. Values of KMO less than 0.5 are unacceptable, those between 0.5 and 0.7 are mediocre, between 0.7 and 0.8 are good, between 0.8 and 0.9 are great while those greater than 0.9 are superb. Although, this is a desirable situation to test the models with Factor Analysis (FA) and Structural Equation Modeling (SME), involvement of large groups in collaboration modeling has been noted to have some adverse effects on the quality of the modeling process. In [HV04], it is observed that collaboration in large groups leads to misunderstanding, and it is thus difficult in establishing consensus, see also [AMK04a].

Technological/Practical Limitations. We had hoped to support this process with a support-tool that incorporates the analysis and the evaluation. We could not develop a fully or partially functional prototype of the support-tool that implements the meta-model. This was partly due to: 1) time limitations – the development of the frameworks, their testing and validation in the exploratory, explanatory and confirmatory modeling experiments took some time to mature to the level we were satisfied with, 2) some technological and practical limitations that prevented us from realizing a working or functional prototype of the support-tool. This required a research assistant or student working wholly on the development and programming of the data structures as defined in the meta-model and implementing them in a chosen programming language.

9.3.2 Further Theoretical Research

To strengthen the results presented in this research, further theoretical research must be done on a number issues. These include the following:

Identification and Validation of Qomo Goals. We used the RIM framework to identify a number of of rules and goals that were explicitly set in, and set for the collaborative modeling games (CMGs). However, the following goals were not, and still are not, clear in the modeling sessions that were analyzed. A validation goal was explicitly set in most of the CMGs, but no validation goals were discussed in the game, i.e. the plain initial goal “agree as a group on the model” – a process that led to model propositions or “agree on the score to give to the modeling artifact” – through the COME framework appears to
have been workable for the modelers. Validation goals, thus, seem relevant enough, but in informal or preliminary settings their finer points remained implicit. Our assumption is that the modelers fall back on generic conventions for conversation and argumentation. However, we still expect validation goals to require refinement and specification in later stages of modeling (for example, when formal commitment of stakeholders comes in); further research will have to confirm this. Argumentation goals as well as interpretation goals are specializations of validation, and they too are not made explicit in the CMGs, yet again seem implicitly present as part of regular conventions for interaction. Interpretation, however, does seem to play some explicit role in content setting: phase II of the structuring process of the modeling process, mostly concerns attempts of the modelers to get a grip on poorly understood domain terminology; differences in meaning are discussed at length, and finally resolved – up to a point. This aspect also warrants further research. Abstraction goals were not explicitly encountered and they warrant further research.

Flaws Identification Using the Meta-model. Further research that needs to be carried out about the meta-model concerns, mainly, the issue of tracking and tracing the flaws that occur in the modeling process and using the communicative process, through the RIM model to explicitly point these out. We have argued that using the meta-model, we can determine how the modeling process has gone, by diagnosing it and determining heuristics (quality criteria, factors or dimensions) which can help us to identify the flaws in the modeling process. The diagnosis (of process data) helps us identify weak spots and occurrences of flaws where things (could) have gone wrong during the modeling process and which lead to low assessment of the quality of the artifacts by the modelers or evaluators. This is still a weak spot which, although we could trace occurrences of these flaws in the hindsight using propositions as agreed consensually by the modelers and the quality scores as given by the modelers or evaluators, it was not possible to explicitly point such flaws from the communicative dialogues. Disagreements, rejections and counter proposals could have, probably, guided us towards pointing these flaws out. But this could be due more to divergence in opinions as depicted in the mental models than in the actual flaw.

9.3.3 Further Practical Research

We followed a Design Science approach, where instantiation and/or implementation, design, validation and evaluation of the designed (technological) artifact is paramount. Although this research has developed the artifact in form of frameworks and meta-model using mainly the first three design science artifact concepts: constructs, models and methods, we did not develop these to the level of a working technological (prototype) artifact. For the technological/practical side, further research needs to be done to define and implement data structures for the analytic part of the meta-model and the evaluative part of the meta-model so that a fully functional artifact that implements the RIM and COME framework through the meta-model is constructed. The COMA tool [Rit08a] offers an environment in which the communicative dialogues can be logged – thus offering a repository (interaction-log) that can be analyzed using the RIM framework and offers some form of scoring of the model which is part of the COME framework. However, as argued, evaluation should not be limited to only the model but all the four modeling artifacts that are
used in, and developed during, the modeling session should be evaluated as well.

InterLoc [Int11], a tool that is used to “play digital dialogue games” can log the communicative interactions which can be analyzed using the RIM framework like COMA. But, unlike COMA, it does not embed the model development environment where the model could be developed by one of the participants and then proposed to the group for further development, commenting, critiquing, etc., so that a group acceptable model is developed collaboratively and later evaluated. The ModelingSpace and OCAF [ADK03, ADKF02, ADKM03, AKF+04, AKFM03], unlike COMA and InterLoc, offer an environment and a tool for analyzing a problem solving activity but the tool lacks the functionality for evaluating the products. The practical tool to be developed should recognize and utilize the strengths of the tools above but also work around their limitations to offer a holistic approach for analyzing and evaluating the modeling sessions.

9.4 Concluding Remarks

Before giving our final conclusions about the research carried out in this thesis, we give some concluding remarks about the issues that have directed, and are products of, this research. Three issues have been fundamental in this research and these include: 1) the frameworks: the Rules-Interactions-Models (RIM) framework, the Collaborative Modeling Evaluation (COME) framework, and, the Meta-model, 2) the explanatory and descriptive theory for collaborative modeling analysis and evaluation, and, 3) the guidelines for the support-tool. Concluding remarks about these are given next.

9.4.1 A Note on the Frameworks and Meta-model

We have developed and presented two frameworks: the RIM framework and the COME framework which can, respectively, be used to study and analyze the modeling processes, and for the evaluation of the different artifacts used in, and produced during, these modeling processes. The RIM framework is presented to be a triad of the rules and/goals, the interactions and the the models – components that work in harmony to direct and guide any collaborative modeling effort. These are the direct components that come out of the analysis of the communicative dialogues and speech acts recorded in the interaction-log. We are aware of the negative connotation and ambiguity surrounding use of the words “direct” and “guide”. One argument is that there may be some psychological, behavioural and /or situational factors, e.g., motivation, commitment, etc., that may combine to (further) drive and guide the modeling session. True as this may be, we limited ourselves to the rules and goal sets that are either implicitly or explicitly set in, or for, the modeling game and are a direct consequence of the interaction or communication of the modelers. We have also looked at the interactions from two perspectives: the macro perspective and the micro perspective.

The macro outlook is used to categorize the communicative dialogues and align them with some of the existing argumentation types in the literature, especially those found in argumentation theory [WK95, WRM08] – persuasion, inquiry, negotiation, decision-making, etc. Such categories help us classify the modeling process as a negotiation process [Rit07] that consists of micro speech acts, such as (counter-) propose, accept/reject, support, (dis-) agree with, argue for/against, etc. It is these macro and micro communicative dialogues that direct and guide the modeling session together with the rules and goals. The model propositions are, as pointed out, the explicitly and implicitly agreed upon (lists
of) statements that lead to model construction, after agreement and consensus is attained. Together with the rules/goals and interactions they drive and guide the modeling process. This is due to the interplay between them as depicted in Figure 3.3. Therefore the RIM framework can be used to not only study and analyse the modeling processes in view of the communicative process, but can also be used to help us understand what happens and how modelers do whatever they do. One key aspect that has come out of this is the structuring process that they devise when the modeling session is not chauffeured.

The COME framework that has been developed, does not compete with, nor do we claim that it is superior to the SEQUAL, QoMo and/or GoM frameworks. Rather, it supplements these existing frameworks by offering a new and novel approach that helps modelers do the evaluation themselves using a scoring, rating and ranking approach that is strongly grounded within a Multi-criteria Decision Analysis (MCDA) approach – the Analytic Hierarchy Process (AHP). At the hands of a few illustrations and demonstrations and a few examples from the modeling session data, we have demonstrated both the theoretical and practical importance of this approach. One important observation that needs to be pointed out about this framework is its general applicability in not only scoring the different quality dimensions and/or factors of the modeling artifacts, but its use in reducing the subjectivity and bias associated with such evaluations which are of course a result of the different mental models possessed. Consensus reached on, and agreement about, the scores plays a significant role here if this is done collaboratively through a communicative process, especially through the negotiation and decision-making process. This can still be used to supplement the usual mathematical pooling techniques of the Nominal Group Technique (NGT) or expert opinion solicitation techniques of the Delphi approach, see Table 2.3, and supplements Method 7 – decision by consensus, see Table 2.4. Although in the COME framework we have used all the four modeling artifacts, any one of them can be evaluated as a stand-alone after identifying its quality dimensions as described in Chapter 4.

Our final note is on the meta-model which was developed with a view of unifying the RIM and COME frameworks so that we can get a template or blueprint for: (1) defining the analysis and evaluation concepts – thus providing a concept set, (2) establishing relationships between the analysis and evaluative set – resulting into an (inter-)relationship set, and, (3) defining constraints on the relationships – which provide a constraint set. In addition, the meta-model provides a language through which the RIM and COME concepts can be communicated to or among the different stakeholders involved in the analysis and evaluation of the modeling processes. Out of the concept, (inter-) relationship and constraint sets, data structures can then be derived upon which the implementation and/or instantiation of a functional technological artifact can be based. This integrated platform can then provide an environment that analyzes the collaborative modeling process and evaluates the modeling artifacts. Although this research, as pointed out in the limitations, did not come up with a working prototype of the tool that integrates the two frameworks, it has laid a foundation for defining the necessary data structures for the implementation.

### 9.4.2 A Note on the Theory

Section 8.3 presents a descriptive and explanatory theory for the study, analysis and evaluation of collaborative modeling process. This theory is at the intersection of the analysis, explanation, and design and action theory types in Gregor [Gre06]. For the study of col-
laborative modeling processes, it describes and explains: what takes place during a collaborative modeling session and how participants in such a collaborative modeling effort do whatever they do. For the analysis of collaborative modeling processes, it describes and explains how, where and/or when the analysis should be conducted, what drives the modeling session, what the main categories (both macro and micro) of the communicative dialogues and speech acts are. For the evaluation of collaborative modeling processes, it describes and explains how, when and/or where such evaluation should be conducted, how such quality can be established, what (degree or level of) quality the different modeling artifacts used in, and produced during, the modeling process possess.

All the description and explanation is done without explicitly deriving causal relationships among the study, analysis and evaluation and no predictions are explicitly stated for them. Although the emphasis has been on the study, analysis and evaluation of the collaborative modeling processes with the aim of having a deeper understanding of these processes, they are not taken as interdependent constructs so as to derive or hypothesize any kind of causal relationships between and among them. It should, however, be noted that within the study, analysis or evaluation, there are constructs developed through which the relationships and causality can be hypothesized. Relationships are evident in, for example, Figure 3.3 for the RIM framework, Figure 5.6 for the meta-model and Figure 6.6 for the causality relationships between the quality constructs. Through the RIM framework, the COME framework and the meta-model (together with the support-tool requirements and guidelines), the theory gives, respectively, explicit prescriptions of how the analysis is planned and carried out, how the evaluation is planned and executed, and how the support-tool can be constructed.

9.4.3 A Note on Support-tool Requirements and Guidelines

In section 8.4, we presented social and organizational as well as technological/technical requirements for a support-tool that should integrate the analysis and evaluation of collaborative modeling processes. These requirements were derived from the strengths and weaknesses of the two support-tools – COMA and InterLoc – that were used in the modeling sessions. The meta-model offers a blueprint that can be used to derived the data structures for the implementation of the analysis and evaluation requirements for the envisaged support-tool. One key feature in the construction of the support-tool is the logging of all the activities of a modeling session which include model-oriented activities as well as communication-related activities. In Face-to-Face (FTF) communication, this would necessitate (video) recording of all activities within the modeling environment (for synchronous, collocated sessions), but in Computer-Mediated Communication (CMC), which may be carried out asynchronously, logging would substitute this type of recording. Using some of the interaction analysis techniques mentioned in Figure 8.9, the logfile could be mined to help us study, analyse, and understand what takes place during the modeling session using the drivers of the RIM framework. Logging of all the activities offers a number of advantages which include among others determining the success (effectiveness and efficiency) of the modeling session using the mined collaboration and communication quality parameters.
9.5 Final Conclusions

This research set out to investigate the process or the act of modeling having realized that not much is known about this process. To study, analyse and evaluate this process and understand it better, we zeroed in on a small constituency of modeling – collaborative modeling. Selection of this type of modeling was based on our conviction that if we are to fully understand what takes place during a collaborative modeling process, and know how the different participants do whatever they do, studying their communicative process may unwrap and expose what is hidden inside. However, lack of an approach or a well-structured methodology that can be used to study and analyse the act of modeling presented a challenge. Through numerous exploratory modeling experiments and having obtained a grip on what takes place inside a modeling process through these, we developed a framework that can be used to study and analyze the modeling process.

The Rules-Interaction-Models (RIM) framework offers a versatile and novel method for studying and analyzing the modeling process through the triage of the rules that are set for, or by, the modelers and goals they strive for, the interactions that are the result of the communicative dialogues in which they exchange ideas, through argumentation, negotiation, and/or decision making process and the models which are the intermediary or end-products of the whole collaborative modeling process. For the modelers to collaboratively develop a model and then give it to the so-called model expert (systems analyst) to evaluate it for quality, is a rather absurd situation. This research advocated for the collaborative evaluation of all the modeling artifacts used in, and produced during, the modeling process by the modelers themselves. For this purpose, a Collaborative Modeling Evaluation (COME) framework was developed through which all participants in the modeling process can take part in the evaluation process. This research identified a vital link between the analysis and evaluation frameworks which makes it possible for the communicative process to carry over from the RIM framework to the COME framework, thus, offering a mechanism in which modelers could reach agreement and consensus about the scoring, weighting or ranking of the different quality dimensions.

Noting that the participants in the modeling process have different conceptions and perceptions – manifested in their mental models, skills, knowledge, expertise, it is desirable to have an evaluation mechanism that minimizes or reduces the subjectivity and bias associated with their differences in priorities and preferences. To achieve this, we incorporated within the evaluation framework, a strongly grounded approach – the Analytic Hierarchy Process (AHP) that helps modelers not only assign scores to the quality dimensions of the artifacts, but also helps them check the level of their inconsistencies in their scoring, rating or ranking of the quality dimensions and modeling artifacts. A meta-model that integrates concepts in the RIM and COME framework was developed. This meta-model offers a communication language for communicating the concepts in the analysis and evaluation frameworks to the participants and defines a blueprint or template upon which a support-tool that integrates the RIM and COME framework can be based.
Back Matter
This part of the book contains back matter. This includes:

§ Appendices
§ References
§ Author Index
§ Subject Index
§ Thesis Summary in English
§ Thesis Summary in Dutch (Samenvatting)
§ Curriculum Vitae
§ SIKS Dissertation Series
Appendix A. AHP Research Instrument

**EVALUATION INSTRUMENT FOR THE MODELING ARTIFACTS - USING THE AHP FUNDAMENTAL SCALE**

As part of an on-going research to understand and evaluate the quality of modeling process, we would kindly request you to spend about 10 - 25 minutes of your time and fill out this questionnaire instrument.

Please use the following evaluation instruments to determine the importance of each of the criteria of the modeling artifacts with respect to each other. Tick ✓ or use a cross ✗ in the white-colored/non-shaded circles.

**NOTE:**
1- If the criterion (i) on the left is considered to be "more important than that on the left" (j), use the “LEFT HALF”.
2- If the criterion (j) on the right is "more important than that on the left" (i), use the “RIGHT HALF”.
3- If an element/criterion (i) is compared to itself (equal importance) we give it rank 1. (see, shaded (dark) circles in the questionnaire).
4- Use the following AHP Fundamental scale to rank the elements given in the questionnaire.

<table>
<thead>
<tr>
<th>Intensity of importance on absolute scale (rank)</th>
<th>Definition</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Equal importance</td>
<td>Criterion 1 is equally as important as criterion j</td>
<td></td>
</tr>
<tr>
<td>2 Weak or slight importance</td>
<td>criterion j is weaker or of slight importance than criterion i</td>
<td></td>
</tr>
<tr>
<td>3 Moderate importance</td>
<td>criterion j is of moderate importance than criterion i</td>
<td></td>
</tr>
<tr>
<td>4 Moderate plus</td>
<td>criterion j is moderately &amp; essentially more important than criterion i</td>
<td></td>
</tr>
<tr>
<td>5 Essential or strong importance</td>
<td>criterion j is essentially or strongly more important than criterion i</td>
<td></td>
</tr>
<tr>
<td>6 Strong plus</td>
<td>criterion j is essentially and strongly more important than criterion i</td>
<td></td>
</tr>
<tr>
<td>7 Very strong or demonstrated importance</td>
<td>criterion j is very strongly more important or is of more demonstrated importance than criterion i</td>
<td></td>
</tr>
<tr>
<td>8 Very, very strong</td>
<td>criterion j is very, very strongly more important than criterion i</td>
<td></td>
</tr>
<tr>
<td>9 Extreme importance</td>
<td>criterion j is extremely more important than criterion i</td>
<td></td>
</tr>
</tbody>
</table>

(Experience or judgment moderately favours criterion i to criterion j)

(Experience or judgment strongly favours criterion i to criterion j)

(Experience or judgment very strongly favour criterion i to criterion j)
# EVALUATION INSTRUMENT FOR THE MODELING LANGUAGE - USING THE AHP FUNDAMENTAL SCALE

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<tr>
<td>Clarity</td>
<td></td>
<td></td>
<td>Clarity</td>
</tr>
<tr>
<td>Syntax Correctness</td>
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</tr>
<tr>
<td>Conceptual Minimalism</td>
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<td>Conceptual Minimalism</td>
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# EVALUATION INSTRUMENT FOR THE MODELING PROCEDURE - USING THE AHP FUNDAMENTAL SCALE

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<td>Effectiveness</td>
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<td>Effectiveness</td>
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<td></td>
<td>Satisfaction</td>
</tr>
<tr>
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<td>Commitment &amp; Shared</td>
</tr>
<tr>
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<td></td>
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<tr>
<td>Commitment &amp; Shared</td>
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### Appendix A

#### EVALUATION INSTRUMENT FOR THE END-PRODUCTS - USING THE AHP FUNDAMENTAL SCALE

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<tr>
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<td>Satisfaction</td>
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### EVALUATION INSTRUMENT FOR THE MEDIUM/SUPPORT TOOL - USING THE AHP FUNDAMENTAL SCALE

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<td>Satisfaction and Enjoyment</td>
</tr>
<tr>
<td>Collaboration and Communication Facilitation</td>
<td>○ ○ ○ ○ ○ ○ ○ ○</td>
<td>● ○ ○ ○ ○ ○ ○ ○</td>
<td>Collaboration and Communication Facilitation</td>
</tr>
</tbody>
</table>
### EVALUATION INSTRUMENT FOR THE MODELING ARTIFACTS - USING THE AHP FUNDAMENTAL SCALE

<table>
<thead>
<tr>
<th>Criterion</th>
<th>LEFT HALF SCALE</th>
<th>RIGHT HALF SCALE</th>
<th>Criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Modeling Language</td>
<td>⬛</td>
<td></td>
<td>Modeling Language</td>
</tr>
<tr>
<td>Modeling Language</td>
<td>⬛</td>
<td></td>
<td>Modeling Procedure</td>
</tr>
<tr>
<td>Modeling Language</td>
<td>⬛</td>
<td></td>
<td>End-Products</td>
</tr>
<tr>
<td>Modeling Language</td>
<td>⬛</td>
<td></td>
<td>Medium/Support Tool</td>
</tr>
<tr>
<td>Modeling Procedure</td>
<td>⬛</td>
<td></td>
<td>Modeling Procedure</td>
</tr>
<tr>
<td>Modeling Procedure</td>
<td>⬛</td>
<td></td>
<td>End-Products</td>
</tr>
<tr>
<td>End-Products</td>
<td>⬛</td>
<td></td>
<td>Medium/Support Tool</td>
</tr>
<tr>
<td>End-Products</td>
<td>⬛</td>
<td></td>
<td>End-Products</td>
</tr>
<tr>
<td>Medium/Support Tool</td>
<td>⬛</td>
<td></td>
<td>Medium/Support Tool</td>
</tr>
</tbody>
</table>
# Appendix B. Extended Research Instrument

## Modeling Process Analysis and Evaluation - Questionnaire Instrument

As part of an ongoing research to understand and evaluate the quality of modeling process, we would kindly request you to spend about 10-15 minutes of your time and fill-out this questionnaire instrument.

### Please provide the following information. Circle appropriate category.

<table>
<thead>
<tr>
<th>Gender</th>
<th>Male</th>
<th>Female</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Question</th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you ever used any modeling languages?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If YES, name them.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever used any modeling support tools?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If YES, name them.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Please use the following seven-point Likert Scale to indicate your agreement with the statements given in the questionnaire.

<table>
<thead>
<tr>
<th>Strongly/extremely</th>
<th>Moderately/quite</th>
<th>Slightly</th>
<th>Neutral</th>
<th>Slightly</th>
<th>Moderately/quite</th>
<th>Strongly/extremely</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very/...</td>
<td>Somewhat/...</td>
<td>Neither</td>
<td>Neither</td>
<td>Neither</td>
<td>Somewhat/...</td>
<td>Very/...</td>
</tr>
</tbody>
</table>

**AGREE, POSITIVE, IMPORTANT, EFFECTIVE, APPROVE, MUCH...**

**DISAGREE, NEGATIVE, UNIMPORTANT, INEFFECTIVE, DISAPPROVE, LESS...**

2. Use (X) or Tick (✓) in the questionnaire boxes to indicate your preference/choice.

<table>
<thead>
<tr>
<th>Example:</th>
<th>AGREE</th>
<th>DISAGREE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A facilitated modeling session using a modeling language, modeling procedure and support tool is more effective than a non-facilitated modeling session.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
### PART A:

<table>
<thead>
<tr>
<th>Code</th>
<th>Extended Research Instrument</th>
</tr>
</thead>
</table>

**ML**

1. The modeling language was easy to understand.
2. The modeling language was easy to learn and remember.
3. There are expressions that are not allowed by the modeling language.
4. It was easy to represent all concepts using the available signs and symbols of the modeling language.

**EQP**

1. The intermediary and end-products were accurate in depicting all the identified aspects of the domain and only essential details were represented.
2. When I look at the final models I understand the rules and concepts represented and model is easy to understand and explain to those that never participated in the modeling session.
3. It is easy to modify the model to accommodate new changes, to re-use and restructure the model.
4. I am satisfied with the quality of the intermediary and end-products.

**PUMP**

1. We took a lot of time to negotiate, reach agreement and consensus and at times failed to make important decisions.
2. The modeling procedure enabled us to reach the solution and attain the modeling goal in less time.
3. I was satisfied with the way we communicated/negotiated, reached consensus and agreement and how we made the modeling decisions to obtain the end results.
4. I was in full support of the goals and objectives, had a stake in achieving the goals and objectives of the of the modeling session and contributed to shared understanding.

**EOUST/EOUM**

1. I enjoyed using the modeling tool and it was fun to participate in the session.
2. The modeling tool was easy to use and I intend to use the tool in another modeling session.
3. The modeling tool had all the required functionality to generate the models.
4. The modeling tool facilitated our communication, negotiation, and decision making process.

### PART B:

<table>
<thead>
<tr>
<th>Code</th>
<th>Semantic Quality (SEM)</th>
</tr>
</thead>
</table>

**SEM**

1. The models replicate well the situation or problem focused on.
2. The models replicate well the causes of the problem.
3. The models replicate well the effects and loops identified in the situation.

**SYN**

1. The models are consistent against the naming conventions of the modeling language.
2. The models are consistent against the layout of the (chosen) modeling language.
3. The models are complete against the naming rules of the (chosen) modeling language.

**PRA**

1. The modeling session has helped me to understand better the case.
2. The modeling process session has helped me acquire new knowledge.
3. I have acquired new knowledge and I will transfer this to my colleagues in my organization.

**SOC**

1. In the session we had a common/shared meaning about the concepts used in the model.
2. We resolved our differences to reach a common meaning for the concepts used in the model.
3. We almost always agreed on all the concepts used in the model.

**EE**

1. The models were completed in the designed and allotted time frame.
2. The modeling process conformed to time and other available resources.
3. The developed models provide value and utility.

**CLA**

1. The generated models were easy to read.
2. The models consisted of hanging (redundant) symbols and had many crossing lines.
3. The models flowed in one direction.

**LSU**

1. This modeling session increased my awareness of the modeling process.
2. The modeling session helped me learn new ideas, concepts, etc. about the modeling process.
3. The modeling session increased my understanding and awareness of the innovative and creative approaches during the modeling process.
PART C:

1: extremely likely 2: quite likely 3: slightly likely 4: neither likely 5: slightly likely 6: quite unlikely 7: extremely unlikely

<table>
<thead>
<tr>
<th>Code</th>
<th>BEHAVIOURAL INTENTION (BI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>BI1</td>
<td>i). Modeling Language</td>
</tr>
<tr>
<td>BI2</td>
<td>ii). Modeling Procedure</td>
</tr>
<tr>
<td>BI3</td>
<td>iii). Support Tool</td>
</tr>
</tbody>
</table>

BEHAVIOURAL BELIEF (BB)

If the modeling session uses a modeling language, modeling procedure and/or support tool it is


<table>
<thead>
<tr>
<th>Code</th>
<th>CONTROL BELIEF (CB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CB1</td>
<td>i). Personal skills, experience and competencies</td>
</tr>
<tr>
<td>CB2</td>
<td>ii). Financial resources</td>
</tr>
<tr>
<td>CB3</td>
<td>iii). Up-to-date IT/IS infrastructure</td>
</tr>
</tbody>
</table>


NORMATIVE BELIEFS (NB)

The ----------------------- will very much APPROVE/DISAPPROVE my use of the modeling language, modeling procedure and/or support tool

SUBJECTIVE NORM (SN)

Most people who are important to me would APPROVE/DISAPPROVE my using of the----------

MOTIVATION TO COMPLY (MC)

In general, how MUCH do you/do your firm usually follow what the following persons want or recommend in order to have an effective/efficient modeling session?

EVALUATION (E)

My feeling about the ---------------------------------------------- ------- is: POSITIVE/NEGATIVE

<table>
<thead>
<tr>
<th>Code</th>
<th>EVALUATION (E)</th>
</tr>
</thead>
<tbody>
<tr>
<td>EML1</td>
<td>i). Ease of learning of the language</td>
</tr>
<tr>
<td>EML2</td>
<td>ii). Complexity of the notations and symbols</td>
</tr>
<tr>
<td>EML3</td>
<td>iii). Adequacy of the symbols and notations</td>
</tr>
<tr>
<td>EMP1</td>
<td>i). Adequacy of the procedure used to generate the models</td>
</tr>
<tr>
<td>EMP2</td>
<td>ii). Reduced time due to procedure to negotiate/reach agreement/make decisions</td>
</tr>
<tr>
<td>EMP3</td>
<td>iii). Improved time due to procedure to reach and achieve the modeling goals</td>
</tr>
<tr>
<td>EEP1</td>
<td>i). Modifiability &amp; re-usability of the models</td>
</tr>
<tr>
<td>EEP2</td>
<td>ii). Quality (clarity, correctness, completeness, reduced complexity) of the models</td>
</tr>
<tr>
<td>EEP3</td>
<td>iii). Increased understandability of the models</td>
</tr>
<tr>
<td>EST1</td>
<td>i). Usability of the (support) tool</td>
</tr>
<tr>
<td>EST2</td>
<td>ii). Improved communication/negotiation/decision making using a (support) tool</td>
</tr>
<tr>
<td>EST3</td>
<td>iii). Functionality adequacy of the (support) tool</td>
</tr>
</tbody>
</table>
1: extremely (...) 2: quite (...) 3: slightly (...) 4: neither (...) 5: slightly (...) 6: quite (...) 7: extremely (...)

(Important/Unimportant, Positive/Negative, Easy/Difficult, Effective/Ineffective)

### PERCEIVED POWER (PP)

Using a ------------ in any modeling session would be: IMPORTANT/UNIMPORTANT

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP2</td>
<td>1. Modeling Language</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PP3</td>
<td>2. (Support) Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### ATTITUDE (ATT)

Using a ------------ in any modeling session would be: EFFECTIVE/INEFFECTIVE

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>AT1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AT2</td>
<td>1. Modeling Language</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AT3</td>
<td>2. (Support) Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### PERCEIVED BEHAVIOURAL CONTROL (PC)

To you/your firm/group using a ----- during a modeling session would be: EASY/DIFFICULT

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC2</td>
<td>1. Modeling Language</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC3</td>
<td>2. (Support) Tool</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix C. AHP FS and RI

Table 1: AHP fundamental scale (FS) [SO03, Saa08a].

<table>
<thead>
<tr>
<th>Intensity of Importance of an absolute value</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance Two</td>
<td>Two activities contribute equally to the objective</td>
</tr>
<tr>
<td>2</td>
<td>Weak or slight importance</td>
<td>Equal to moderate importance</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience or judgment strongly favour one activity over another</td>
</tr>
<tr>
<td>4</td>
<td>Moderate plus</td>
<td>Moderate to strong importance</td>
</tr>
<tr>
<td>5</td>
<td>Essential or strong importance</td>
<td>Experience and judgment strongly favour one activity over another</td>
</tr>
<tr>
<td>6</td>
<td>Strong plus</td>
<td>Essential or strong to very strong importance</td>
</tr>
<tr>
<td>7</td>
<td>Very strong importance</td>
<td>An activity is strongly favoured and its dominance is demonstrated in practice</td>
</tr>
<tr>
<td>8</td>
<td>Very, very strong</td>
<td>Very strong to extreme importance</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favouring one activity of the other is of highest possible order of affirmation</td>
</tr>
<tr>
<td>Reciprocals of above</td>
<td>If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i.</td>
<td>A reasonable assumption</td>
</tr>
<tr>
<td>1.1 – 1.9</td>
<td>When the activities are very close a decimal is added to 1 to show their difference as appropriate</td>
<td>May be difficult to assign the best value but when compared with other contrasting activities the size of the small number would be not be too noticeable, yet they can still indicate the relative importance of the activities.</td>
</tr>
</tbody>
</table>

Table 2: AHP random index (RI) table [SO03, Saa08a].

<table>
<thead>
<tr>
<th>Order</th>
<th>RI</th>
<th>1st O.D</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>1</td>
<td>0.52</td>
<td>0.37</td>
</tr>
<tr>
<td>2</td>
<td>0.89</td>
<td>0.22</td>
</tr>
<tr>
<td>3</td>
<td>1.11</td>
<td>0.14</td>
</tr>
<tr>
<td>4</td>
<td>1.25</td>
<td>0.10</td>
</tr>
<tr>
<td>5</td>
<td>1.35</td>
<td>0.05</td>
</tr>
<tr>
<td>6</td>
<td>1.40</td>
<td>0.05</td>
</tr>
<tr>
<td>7</td>
<td>1.45</td>
<td>0.04</td>
</tr>
<tr>
<td>8</td>
<td>1.49</td>
<td>0.03</td>
</tr>
<tr>
<td>9</td>
<td>1.52</td>
<td>0.02</td>
</tr>
<tr>
<td>10</td>
<td>1.56</td>
<td>0.02</td>
</tr>
<tr>
<td>11</td>
<td>1.58</td>
<td>0.02</td>
</tr>
<tr>
<td>12</td>
<td>1.59</td>
<td>0.01</td>
</tr>
</tbody>
</table>

1st O.D = 1st Order differences
Appendix D.
Structural-Measurement Models

<table>
<thead>
<tr>
<th>Latent Variables:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\xi$: Exogenous random variable: acts as a predictor or cause for other constructs in the model. Have only cause arrows leading out of them and not predicted by any other constructs in the model.</td>
</tr>
<tr>
<td>$\eta$: Endogenous random variable: is the dependent variable or outcome variable in at least one causal relationship with one or more arrows leading to it.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structural Model:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$: Regression relations between latent constructs for endogenous construct on exogenous construct</td>
</tr>
<tr>
<td>$\beta$: Regression relations between latent constructs for endogenous construct on another endogenous construct</td>
</tr>
<tr>
<td>$\phi$ : Covariance between exogenous constructs from common predictors outside the model</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Structural Error:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\zeta$: Structural error uncorrelated with the exogenous variables but associated with other error terms or endogenous latent variables.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>MEASUREMENT MODEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>$X$: Manifest variable (actual measure or score) associated with the exogenous latent construct/variable</td>
</tr>
<tr>
<td>$Y$: Manifest variable (actual measure or score) associated with the endogenous latent construct/variable</td>
</tr>
<tr>
<td>$\lambda$: Loadings linking latent constructs to measures. Each construct is measured as a common factor underlying the measures</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Measurement Error:</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\delta$: Measurement error associated with the X measures or scores</td>
</tr>
<tr>
<td>$\epsilon$: Measurement error associated with the Y measures</td>
</tr>
</tbody>
</table>
Appendix E. InterLoc Dialogue Game: XML Code

Table 3: The openers as included in the GMB dialogue game template for InterLoc (adopted from [HR12])

```xml
<DialogueGame title="GMB basic game" filename="GMB basic game.xml">
  <Text name="GMB basic game">(descriptive text on the dialogue game)</Text>
  <DialogueMenu title="Propose">
    <Opener name="suggest">I propose the following IDEA:</Opener>
    <Opener name="suggest">I propose this VARIABLE for the idea:</Opener>
    <Opener name="suggest">I propose the following IDEA as expressed through the following VARIABLE</Opener>
    <Opener name="suggest">I propose the following CAUSE with its POLARITY</Opener>
    <Opener name="suggest">I propose the following CONSEQUENCE with its POLARITY</Opener>
    <Opener name="suggest">I propose that the polarity of this variable is [+/-]:</Opener>
  </DialogueMenu>
  <DialogueMenu title="Ask">
    <Opener name="suggest">I have a question:</Opener>
    <Opener name="suggest">I have a question about this proposition:</Opener>
  </DialogueMenu>
  <DialogueMenu title="Argue">
    <Opener name="suggest">I disagree:</Opener>
    <Opener name="suggest">I agree:</Opener>
  </DialogueMenu>
  <DialogueMenu title="Accept / reject">
    <Opener name="suggest">I accept the proposition.</Opener>
    <Opener name="suggest">I reject the proposition.</Opener>
  </DialogueMenu>
  <DialogueMenu title="Remark">
    <Opener name="suggest">I would like to clarify this:</Opener>
    <Opener name="suggest">I have a remark:</Opener>
  </DialogueMenu>
  <DialogueMenu title="Facilitator statements and questions">
    <Opener name="suggest">Instruction of the Facilitator:</Opener>
    <Opener name="suggest">Directive of the Facilitator:</Opener>
    <Opener name="suggest">This is the problem variable:</Opener>
    <Opener name="suggest">Please write down a number of ideas as to what may influence, or be influenced by, the Problem Variable:</Opener>
    <Opener name="suggest">Please propose and IDEA and if possible a VARIABLE, [player]:</Opener>
    <Opener name="suggest">Which VARIABLE would you link to this idea?</Opener>
    <Opener name="suggest">Which of the variables are a CAUSE for change in the problem variable?</Opener>
    <Opener name="suggest">Which of the variables are a CONSEQUENCE for change in the problem variable?</Opener>
    <Opener name="suggest">Looking at the model, do you see any additional variables?</Opener>
    <Opener name="suggest">What is the POLARITY of this variable [POS/NEG]:</Opener>
    <Opener name="suggest">Looking at the model, do you see any additional variables?</Opener>
  </DialogueMenu>
</DialogueGame>
```
References


References


References


References


References


References
References


References


References


References


References


References


References


References


References


References


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Baker, D. 35, 38, 220
Baker, L.L. 34, 60, 221
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Bellotti, V. 180, 184, 223
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Collaborative modeling is one of the approaches that can enhance productivity in information systems design and re-engineering projects. Such a collaborative effort consists of the modeling process and the products or models generated thereof. This research has argued that although a lot of effort has been spent in establishing the quality of the models, not much effort has been spent on the process that generates these models. This, therefore, makes the process of modeling a gray area – a black-box that needs to be opened so as to have a glimpse inside. We have pointed out in this research that in order to get the seal off the black-box of the modeling process, there is a need to first study, analyze and understand what takes place during a collaborative modeling process. This was observed to be a challenge since there has not been any well-structured methodology that could help us study, analyse and understand the process or the act of modeling. Moreover, such a collaborative effort normally brings on board stakeholders with different levels of knowledge, expertise, skills, competencies, priorities and preferences. This research has argued that such a multi-actor environment presents further challenges. The knowledge stored in the mental models of the stakeholders needs to be elicited, and personal priorities and preferences ought to be reconciled into group priorities and preferences.

In order to understand the process (act) of modeling, we have developed a structured methodology that can be used to study and analyze the modeling process. At the center of this methodology is the Rules, Interactions and Models (RIM) framework which consists of three key-drivers that can help us study and analyze what takes place during a collaborative modeling session. The rules have been identified to be key in guiding and driving the modeling process together with a special type of rules – the goals which set the states that modelers strive for. Interactions, which are the modelers’ conversational statements, have been identified to be key in helping modelers in their negotiations, decision-making process, argumentation and in reaching agreement and consensus. Models are generated from a list of model propositions and are subject to selection criteria. They are the result of a long protracted negotiation and decision-making process that lead to the actual (graphical) model.

Since the modeling process is grounded within the communicative process of the modelers, this research has advocated for the collaborative evaluation of the modeling artifacts used in, and produced during, the modeling effort to be done by the modelers themselves within the communicative process. It has been argued that such collaborative evaluation of the modeling process can be anchored on four modeling artifacts, namely, the modeling language, the modeling procedure, the end-products (models), and the support-tool. Due to the differences in skills, knowledge within the mental models of the modelers, etc.,
coupled with the individual (subjective) priorities and preferences, these evaluations are shrouded with subjectivity, bias and inconsistencies. To overcome these negative effects on the evaluations, we developed a Collaborative Modeling Evaluation (COME) framework, through which the modelers can reconcile their subjective evaluations, priorities and preferences and reach a consensually agreed upon final quality measure for the modeling artifacts or their quality dimensions. The novelty of the COME framework is that it is anchored on one of the well-established methods – the Analytic Hierarchy Process (AHP) from the area of Operations Research (OR). Through three stages in the COME framework, modelers are able to identify the modeling artifacts to evaluate, and by rating, weighing or ranking their quality dimensions, they are able to arrive at a consistent quality measure for the modeling artifacts.

Driven by the desire to have a mechanism for tracing the flaws that occur during the collaborative effort, a desire to have a channel to communicate the concepts in the RIM and COME frameworks between and among the modelers, and a support-tool that incorporates the RIM and COME framework concepts, this research has developed a meta-model that integrates the two frameworks. This meta-model can serve as a template or blueprint for deriving the actual analysis and evaluation structures, a conceptual language for communicating the analysis and evaluation concepts between and among the different stakeholders in a modeling session, and can serve as an appropriate technique for the construction of a support-tool that incorporates analysis and evaluation concepts. For each of the two frameworks, the meta-model provides a set of concepts (concept structure), a set of (inter-)relationships, and a set of constraints that are used to give a sound, formal and theoretical definitional scheme for the analysis and evaluation concepts. We have observed that at the center of the integration of the two frameworks, is the interaction component of the RIM framework. It is has been argued that through this component, we can track what happens during the collaborative effort, trace the flaws in the RIM and use heuristics in the COME framework to pinpoint these flaws. One of the major advantages of the meta-model is that is offers a template for deriving the structures for constructing the support-tool which integrates the analysis and evaluation frameworks.

Through a number of exploratory, explanatory and confirmatory modeling experiments, we tested the practical relevance of the frameworks and the meta-model. Insights from these controlled and validation modeling experiments confirm the theoretical soundness and practical relevance of the developed frameworks for the analysis and evaluation of collaborative modeling processes. A number of findings and observations were noted from these modeling experiments. One of the major findings of this research is a set of (implicit and explicit) rules and goals, a set of (micro and macro) interactions and model propositions that guide and drive further the modeling process through a well-structured relationship interplay. The second finding out of this research was the structuring of the modeling process by the modelers themselves when the modeling session is non-chauffeured. It has been observed that this structuring process is based on two approaches: the planned, pro-active rule setting approach and ad-hoc, reactive rule setting approach. This research identified and categorized a number of communicative dialogues into (micro and macro) interactional speech acts – consisting of propositions, arguments for/against, accepts/rejects, etc., a confirmation that collaborative modeling is a negotiation process.
A number of contributions can be noted from this research. First, this research has contributed two theoretical frameworks: the RIM and COME framework that can, respectively, be used to study, analyze and understand what takes place during a collaborative modeling session, and for evaluating the modeling artifacts used in, and produced during the modeling effort. The second contribution of this research is a meta-model that integrates the two frameworks and offers a language for communicating the concepts in the two frameworks, acts as a blueprint for developing the support-tool and allows tracking of flaws in RIM framework, and uses heuristics developed in the COME framework to pinpoint the flaws. The third contribution is a theory that describes and explains how collaborative modeling processes can be studied, analyzed and evaluated. Through this theory, we derive a structured methodology, using the RIM and COME frameworks and the meta-model, that helps us to study and understand what takes place inside the modeling process. This research has argued that understanding this process is key to developing a support-tool that aids the analysis and evaluation of collaborative modeling processes. The final contribution of this research is a set of minimum (functionality and usability) requirements that a support-tool should satisfy and/or have, and guidelines that direct the construction of such a support-tool.
Samenvatting

‘Collaborative modeling’ (samenwerkend of collaboratief modelleren) is één van de manieren om productiviteit te verhogen in het ontwerp van informatiesystemen en in re-engineering projecten. Dergelijke collaboratieve activiteiten vallen uiteen in het modellerenproces en de producten of modellen die binnen dat proces gegenereerd worden. Dit onderzoek neemt als basis de bevinding dat al veel werk gedaan is betreffende het vaststellen van de kwaliteit van modellen, maar dat relatief weinig werk is gewijd aan de kwaliteit het proces waaruit deze modellen voortkomen. Dit maakt het modellerenproces tot een grijs gebied - een ‘black box’ die erom vraagt geopend te worden zodat we een kijkje kunnen nemen aan de binnenkant. We hebben er in ons onderzoek op gewezen dat we, om het zegel van de black box te kunnen breken, eerst moeten bestuderen, analyseren en begrijpen wat er gebeurt gedurende een collaboratief modellerproces. Dit was voor ons een uitdaging omdat er geen fatsoenlijk gestructureerde methode bestond die ons kon helpen in het bestuderen van het proces van, of de activiteit van, het modelleren. Verder brengt een collaboratieve inspanning veelal belanghebbenden aan boord die verschillen qua niveau van kennis, expertise, vaardigheden, competenties, prioriteiten en voorkeuren.

Teneinde het proces (of de activiteit) van het modelleren te begrijpen hebben we een gestructureerde methodologie ontwikkeld die gebruik kan worden voor het bestuderen en analyseren van modellerprocessen. In het hart van deze methodologie ligt het Regels, Interacties en Modellen (RIM) raamwerk dat de drie sleutelbegrippen omvat die steun kunnen bieden bij het analyseren en begrijpen van collaboratieve modeleersessies. De regels zijn door ons gedefinieerd als essentieel in het sturen en aanjagen van modellerprocessen, in combinatie met een speciaal type regels die stellen welk resultaat nagestreefd wordt door de modeleurs. Interacties zijn de uitingen gedaan door de modeleurs in hun conversatie, het zijn essentiele acties die de modeleurs in staat stellen te onderhandelen, beslissingen te nemen, te argumenteren en overeenstemming te bereiken. Modellen kunnen worden afgeleid van een lijst van voorgestelde modelproposities en zijn daarbij onderhevig aan selectiecriteria. Zij zijn het resultaat van een uitgesponnen onderhandelings- en beslisproces dat leidt tot het uiteindelijke (grafische) model.

Omdat het modellerenproces geworteld is in het communicatieve proces van de modeleurs stellen wij dat het de voorkeur heeft om de collaboratieve evaluatie van de modelleartefacten, die gebruikt worden in en voortkomen uit het modellerenproces, te laten plaatsvinden door de modeleurs zelf, binnen hun communicatieve proces. We argumenteren dat dergelijke collaboratieve evaluatie gegrondvest kan worden op vier modelleartefacten: de modelleertaal, de modeleerprocedure, de eindproducten (modellen), en de ondersteunende modeleertool. Vanwege de verschillen in vaardigheden en in ken-
nis bevat in de mentale modellen van de modelleurs, in combinatie met hun individuele (subjectieve) prioriteiten en voorkeuren, zijn dergelijke evaluaties gehuld in subjectiviteit, vooroordeel en inconsistenties. Om dergelijke negatieve effecten op evaluatie te beteugelen ontwikkelden we het *Collaboratief Modelleren Evaluatie (COME)* raamwerk, waarmee de modelleurs een gezamenlijk inzicht kunnen bereiken in hun subjectieve evaluaties, prioriteiten en voorkeuren, en consensus kunnen bereiken over een uiteindelijke kwaliteitsmaat voor de modellerartefacten en hun kwaliteitsdimensies. De innovatieve bijdrage van het COME raamwerk ligt erin dat het verankerd is in een gerenommeerde methode uit de Operations Research (OR): het *Analytic Hierarchy Process (AHP)*. Middels drie stappen binnen het COME raamwerk zijn modelleurs in staat modellerartefacten te evalueren, en via het aan kwaliteitsdimensies toekennen van indices (rating), weging (weighting), of volgorde (ranking) kunnen zij een consistent kwaliteitsmeting vaststellen voor de artefacten.

Gedreven door de behoefte aan een mechanisme voor het traceren van de onvolkomenheden in een collaboratieve sessie, alsmede behoefte aan effectieve ondersteuning van communicatie tussen modelleren betreffende de concepten in de RIM en COME raamwerken, en aan een ondersteunende tool die de RIM en COME raamwerken omvat, hebben wij een metamodel ontwikkeld dat de twee raamwerken integreert. Dit metamodel kan dienen als een template of blauwdruk voor het afleiden van de feitelijke analyse en evaluatiestructuren, als een conceptuele taal voor het communiceren van de analyse- en evaluatieconcepten tussen de verschillende stakeholders in een modelleersessie, en als een toepasselijke techniek voor de constructie van een ondersteunende tool die de analyse- en evaluatieconcepten omvat. Voor elk van de twee raamwerken biedt het metamodel een verzameling concepten (conceptstructuur), een verzameling relaties, en een verzameling constraints die gebruikt worden om een solide, formele en theoretisch definitieschema te verkrijgen voor de analyse- en evaluatieconcepten omvat. Voor elk van de twee raamwerken biedt het metamodel een verzameling concepten (conceptstructuur), een verzameling relaties, en een verzameling constraints die gebruikt worden om een solide, formele en theoretisch definitieschema te verkrijgen voor de analyse- en evaluatieconcepten omvat. Wij observeerden dat in de kern van de integratie van de twee raamwerken de interactiecomponent ligt van het RIM raamwerk. Het is beargumenteerd dat we middels deze component kunnen volgen wat gebeurt gedurende een collaboratieve modeller sessie, inclusief eventuele contraproduktieve interacties en gebeurtenissen binnen het RIM kader; vervolgens kunnen we heuristieken uit het COME raamwerk gebruiken om de onvolkomenheden nauwkeurig en in volledig detail te traceren. Een groot voordeel van het metamodel is hier dat dit een template biedt voor het afleiden van structuren voor het construeren van een ondersteunende tool die het analytische en het evaluatieve raamwerk integreert.

Via een aantal exploratieve, verklarende en bevestigende modellerexperimenten testen we de praktische relevantie van de raamwerken en het metamodel. Inzichten verkregen door deze gecontroleerde validatie-modellerexperimenten bevestigen de theoretische soliditeit en praktische relevantie van de ontwikkelde raamwerken voor de analyse en evaluatie van collaboratieve modellerprocessen. Een aantal bevindingen en observaties resulteerden uit deze modellerexperimenten. Belangrijke bevindingen zijn o.a. een verzameling (impliciete en expliciete) regels en doelen en een verzameling (micro en macro) interactietypen en modelpropositietypen die het modellerproces sturen en aanjagen binnen een goed gestructureerd samenspel van relaties. Een andere belangrijke bevinding betreft het aanbrengen van structuur in het modellerproces door de modelleurs zelf in het geval de sessie niet actief geleid wordt. We observeerden dat dit structureringsproces gebaseerd is op twee verschillende insteken: de *geplande, pro-actieve regelstellingen* aan-
pak en de *ad hoc, reactieve regelstellings* aanpak. Wij identificeerden en categoriseerden een aantal elementen in dialogen in (micro en macro) interacties (sprakhandelingen of speech acts), en wel proposities, argumenten voor/tegen, acceptaties/afwijzingen, en zo meer, een bevestiging dat collaboratief modelleren een onderhandelproces betreft.

Een aantal bijdragen kunnen worden opgetekend in terugblik op dit onderzoek. Allereerst heeft het twee theoretische raamwerken opgeleverd: RIM en COME, die respectievelijk kunnen worden gebruikt om te analyseren wat plaatsvindt gedurende een collaboratieve modeleersessie en voor het evalueren van de modeleerartefacten gebruikt in en voortgebracht door een modeleersessie. De tweede bijdrage is een metamodel dat de twee raamwerken integreert en een taal biedt om de concepten uit de raamwerken te communiceren, en verder als een blauwdruk kan dienen voor ontwerp van een ondersteunende tool, alsmede de mogelijkheid biedt tot het traceren van onvolkomenheden in het proces. De derde bijdrage is een theorie die beschrijft en verklaart hoe collaboratieve modeleerprocessen kunnen worden bestudeerd, geanalyseerd, en gevalueerd. Middels deze theorie konden we een gestructureerde methodologie afleiden die, met gebruikmaking van de RIM en COME raamwerken en het metamodel, ons helpt te bestuderen en begrijpen wat er plaatsvindt in een modeleerproces. Dit onderzoek beargumenteert dat het begrijpen van dergelijke processen de sleutel is tot het ontwikkelen van een ondersteunende tool die de analyse en evaluatie van collaboratieve modeleerprocessen ondersteunt. De laatste bijdrage is een verzameling minimale (functionele en gebruiks) requirements waaraan een ondersteunende tool zou moeten voldoen, en richtlijnen voor het ontwerp van zulke een tool.
Curriculum Vitae

Denis Ssebuggawo was born in Rakai District – Uganda. From 2001 to 2002, he undertook an international NUFFIC-funded NFP Master-class programme in Scientific Computing at Wiskunde Onderzoekschool (WONDER), the Dutch School in Mathematics, formerly the Mathematical Research Institute (MRI) based at Radboud University Nijmegen in The Netherlands. His research was on the hybrid relaxed incomplete factorization and approximate pre-conditioning methods for solving anisotropic problems. Before this, he had graduated, in 1997, with an MSc. degree in Mathematics – Numerical Analysis and Computer Science – from Makerere University. He is also a holder of a BSc.(Hons) degree in Mathematics from Makerere University which he obtained in 1993. He started his academic career as a junior lecturer at Mbarara University of Science and Technology in 1995 and for over 15 years, he has worked mainly in an academic environment where he remains to-date. He has worked at Uganda Martyrs University – Nkozi, Kampala International University, and he is currently working in the Department of Computer Science, Faculty of Science at Kyambogo University in Uganda where he lectures Computer Science and Information Systems since 2003.

He has presented his research findings at a number of national and international conference and workshops such as: Principle of Enterprise Modeling (PoEM), International Conference on Advanced Information Systems Engineering (CAiSE), International Conference on Enterprise Information Systems (EIS), International Workshop on Cooperation & Interoperability - Architecture & Ontology (CIAO) and his research work appears in a number of peer-reviewed conference proceedings and journals. He is a member of the following international organizations and research schools: Association of Computing Machinery (ACM), Association of Information Systems (AIS), Institute of Electrical and Electronics Engineers (IEEE), IEEE Computer Society (IEEE CS) and SIKS - the Dutch Research School for Information and Knowledge Systems. On March 1st, 2008, he embarked on a four-year-NUFFIC-funded PhD programme in Information Systems at the Institute of Computing and Information Sciences (iCIS) within the Model-Based Systems Development (MBSD) Department at Radboud University Nijmegen. He belonged to the Enterprise Engineering (EE) Team/Research Group.
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Collaborative modeling, which is conceptually similar to Group Model Building (GMB), is a technique that is widely used to jointly develop models by stakeholders in information systems design and business process re-engineering projects. However, little is known about what “takes place in there, and how modelers do their thing”. To understand what happens and how the different participants in such a joint effort do whatever they do, one needs to recognize the different skills, expertise and knowledge that is brought on board. This diversity in skills, expertise and knowledge, sets stage for a communicative process in which modelers engage in an argumentative, negotiation and decision-making process to reconcile not only their perceptions and conception in their mental models, but also their priorities and preferences about the quality of the different modeling artifacts used in, and produced during, a modeling session.

This thesis has developed two frameworks: the Rules, Interactions and Models (RIM) framework, and the Collaborative Modeling Evaluation (COME) framework for, respectively, analysing what takes place in a modeling process, and for evaluating the different modeling artifacts by the modelers themselves through a communicative process. The two frameworks are integrated in a meta-model that helps us track the flaws in the RIM framework and pointing them using heuristics developed in the COME framework. Theoretical significance as well as practical relevance of the frameworks and the meta-model is demonstrated through explanatory and confirmatory modeling experiments.