A RAPID SIMULATION MODELLING PROCESS FOR NOVICE SOFTWARE PROCESS SIMULATION MODELLERS

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ABSTRACT

In recent years, simulation modelling of software processes have has promoted as a tool to understand, study, control, and manage software development processes. Claims have been made that simulation models are useful and effective at gaining insight into software development processes. However, little has been said about the *process* of developing simulation models for software engineering problems.

Simulation modelling is a young discipline in software engineering. Consequently, many number software process simulation modellers are thought to be novices. The simulation modelling process is believed to have had an effect on the quality of a simulation study. Although there is a body of knowledge available in the general simulation literature to guide and educate novices, the software process simulation modelling literature lacks information for novice software process simulation modellers to understand and adopt a simulation modelling process. This thesis aims to develop a simulation modelling process for novice software process simulation modellers.

This thesis reports how the development and evaluation of a simulation modelling process for novice software process simulation modellers. The rapid simulation modelling process (RSMP) is based on an empirical study of the contexts and practices of expert simulation modellers in SPSM and Operational Research (OR). The RSMP is intended to be independent of a particular simulation technique (i.e. system dynamics or discrete event simulation) and guides novice software process simulation modellers through a set of steps that should be undertaken during a simulation study; the RSMP emphasises heavy client contact and provides guidelines for model documentation. The RSMP has been evaluated through controlled experiments with novice software process simulation modellers using system dynamics (SD) modelling. In the future, it will be further evaluated with software process simulation modellers using discrete event simulation. The RSMP has also been evaluated with a panel of expert software process simulation modellers.

The main contribution of this study lies in providing novice software process simulation modellers with a simulation modelling process, which embodies real world simulation practice and is intended to be independent of a particular simulation technique.

PART I: BACKGROUND

1. Chapter one: Introduction

This thesis presents a process framework for novice software process simulation modellers. The rapid simulation modelling process (RSMP) has been developed and evaluated through a set of empirical studies, which are also reported in this thesis. The RSMP is an evolutionary and iterative approach for software process simulation model development. The RSMP aims to bring discipline to the practices of novice software process simulation modellers. The RSMP supports simulation modellers through the different steps involved in a simulation study. This thesis discusses the motivation for and approach taken to establish and evaluate the RSMP.

1.1. An overview of software process simulation modelling (SPSM)

The role of software is rapidly expanding in almost all aspects of human life. Over the last few decades the software industry has observed many accounts of schedule and cost overruns, and poor quality software has raised many concerns in both the commercial and governmental sector. For example, The London Stock Exchange system crashed within a few hours of its operational use in 1987. The poor quality of various major IT projects in the UK has raised quality issues to a higher extent amongst researchers and practitioners. Examples are the computerization of London Ambulance Service, The Passport Office and The House of Common projects [PAC 1999]. Hence, quality and customer satisfaction has become the main goal of software developers and for organisations.

In response, software companies' production and operational processes are getting more and more complex. Companies are now looking for new ways to understand, control and improve their software processes. A wide range of sophisticated case tools, languages and off-the-shelf components are available to deliver timely and quality software. Kellner [1999] raises the question, *"How can the tools, technologies and people work together in order to achieve these increasingly challenging goals?"* One answer is to evolve and improve software development processes. However, change and innovation in the development processes entails uncertainty and risk. The consequences of this change are very difficult to estimate without a reliable forecasting method [Robinson 1997]. Furthermore, improvement in the process needs understanding as a pre-cursor. One solution to understanding organizational process change and forecasting the impact of change and improvement are the simulation models of software processes [Kellner 1999].

1.1.1. The software process

Generally, a process is a logical structure of technology, resources and practices in an environment to accomplish certain tasks [Daniel 1996]. Examples of organisational or business processes are supply chain processes, investment approval process etc. Examples particular to software processes are the requirements gathering process, design process etc.

Paulk et al. [1993] define the software process:

> "*A set of activities, methods, practices and transformations that people use to develop and maintain software and the associated products (e.g., project plans, design documents, code, test cases and user manuals)*"

A software process encompasses activities from requirements gathering to software maintenance and evolution. The choice of methods, work practices, organizational and human factors, management decisions, technology and tools are factors which affect the overall software development process in an organization.

1.1.2. Simulation modelling

A model is an abstraction of a real or conceptual phenomenon. Pidd [1996] defines a model:

> "*A model is an external and explicit representation of part of a reality as seen by the people who wish to use that model to understand, to change, to manage and to control that part of reality.*"

Modelling is a set of activities for building a sufficient representation of a problem using mathematical or visual constructs sometimes using a modelling tool (language, technique) to understand, to change, to manage and to control the features of the underlying problem. It is the modelling process that transforms the part of reality under study into a physical representation i.e. a model. David [2001] defines modelling:

> *"Modelling is the action of developing and intentionally building models, by composition of symbols, that are capable of explaining what is perceived to be a complex phenomenon and amplifying an actor's reasoning when projecting deliberate intervention within the phenomenon, designed in particular to anticipate the consequences of these projects of possible actions."*

Computer simulation came into research and practice nearly 50 years ago [Nance and Sargent 2002]. Since then simulation technology has widely been accepted as a planning and problem solving tool in a variety of domains including military, air traffic control, business process reengineering, economics, engineering, manufacturing, computer science, and healthcare.

A simulation model represents features and characteristics of a real or conceptual system in a dynamic manner. Kellner et al. [1999] states that a computer simulation model is a computerised model designed and implemented to represent significant dynamic features and characteristics of the system which an analyst wishes to study, predict, modify or control.

Banks [2001] defines simulation modelling as:

> *"Simulation is the imitation of the operation of a real world process or system over time. Simulation involves the generation of an artificial history of the system, and the observation of that artificial history to draw inferences concerning the operating characteristics of the real system that is represented"*

Shannon [1975] defines simulation modelling as:

> *"The process of designing a model of a real system and conducting experiments with this model for the purpose of either of understanding behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system"*

1.1.3. Software process simulation modelling (SPSM)

It is argued that development processes have effect on the timeliness, cost and quality of finished products. Improvement in software processes relates to improvement in product cost and quality [Paulk 1993]. However, software process improvement requires change, and changing one process may affect (positively or negatively) the performance of other processes. These effects may ripple through the whole software life cycle. This uncertainty and stochasticity requires means to predict process behaviour in advance. Therefore, Kellner et al. [1999] suggest that simulation modelling of software processes is particularly desirable when:

- Complexity is beyond human intuition.
- There is uncertainty and stochasticity in system behaviour.
- Risks in process change are very high.
- The system has some dynamic behaviour.
- Decisions made at one point in the system may impact on the process in other aspects.

For example, in a software project there are a number of factors or causes that determine the real behaviour of project progress. For example, one possible way to speed up a late software project may be the hiring of new staff. But Brooks law [Brooks 1975] suggests that hiring people late in the project can further delay various phases of the project; because they need training and time to understand and contribute to the project. However, the previous qualification, experience and productivity of additional staff may speed up project progress after initially understanding the project. But then there are other intangible risks associated with new staff e.g. integration and coordination with the new team and the organisational culture. These kind of relationships suggests a complex mechanism in the process. Capturing and forecasting the effects of these complex dynamic and stochastic relationships early in a project may allow better planning and project's progress control. Otherwise unanticipated process behaviour at one process step may ripple through the whole lifecycle of the project.

Therefore, simulation modelling of software processes has been promoted as a tool to understand, study, and manage software development processes. A *software process simulation model* is used to study some particular software activity, such as, development, maintenance or evolution [Kellner et al. 1999]. Studies show that simulation modelling has proved to be an effective tool to study organizational software development processes and forecast potential change and improvement in those processes [Raffo and Kellner 2000].

Software process simulation modelling (SPSM) has attracted increasing interest during the last decade. Although simulation modelling has been applied very commonly in other scientific and business processes [Christie 1999] e.g. defence, air traffic control, demand & supply chains, it is relatively new to software engineering practices. System dynamics and discrete event based techniques are the commonly used techniques and have been reported to be effective in SPSM [Raffo 1998]. Since 1989, when Abdel-Hamid [1989] developed a system dynamics model to study software processes, various issues such as software process improvement [Abdel-Hamid and Madnick 1991, Raffo 1996], long-term software evolution modelling [Wernick 1997], control and operational management [Madachy 1994,] have been addressed through software process simulation modelling. It is generally argued that simulation solutions are unlikely to give exact forecasts of real process behaviour, but nevertheless give projections as to how the process will behave; this stimulates debate and provides ways to learn about, and to improve the software process [Donzelli and Iazeolla 2001].

Christie [1999] suggests other aspects of software development processes in which simulation modelling can promise benefits e.g. requirements management, project management, training, process improvement, architecture related to commercial off-the-shelf component integration, risk management, acquisition management etc.

1.2. Research project motivation

Claims have been made that simulation models are useful and effective at gaining insight into software development [Kellner et al. 1999]. However, little has been said about the process of developing simulation models in software engineering. An extensive literature survey does not reveal any formal process being used for simulation modelling in software engineering. The question arises, if we are promoting simulation modelling as a tool for gaining insights into software engineering practices, why do we not appear to be thinking about the quality of our own process of simulation model development? Most of the software process simulation studies do not discuss the underlying process of model development. No significant debate can be found about the modelling process in the SPSM literature. Only recently, Rus et al. [2003] discuss the need to migrate software process simulation modelling from craft to engineering. Based on their experience they propose a systematic method for the development of discrete event simulation models. Moreover, Pfahl and Ruhe [2002] report their process of developing system dynamics models for software process improvement. However, the approaches reported by these authors are based on their personal experience of simulation modelling.

Simulation researchers in Operational Research (OR) have identified various issues arising from the weakness in the modelling process. An investigation of the simulation modelling literature [Ahmed et al. 2004b] suggests that there are problems related to model quality, model confidence, model documentation, inadequate management of simulation projects, poor communication between stakeholders, model reuse, model implementation and model evaluation. Similar issues are almost certain to arise in the SPSM which does not seem to have much debate about simulation modelling process.

Simulation modelling research and practice has gained interest in software engineering very recently. A number of simulation modellers have come together to form a software process simulation modelling community. Although there is a body of knowledge available in general simulation literature to guide and educate novices, the software process simulation literature lacks information for novice software process simulation modellers to understand and adopt a simulation modelling process. My preliminary investigation of simulation practices in SPSM [Ahmed et al. 2004b] suggests that software process simulation modellers generally have a systematic process for model development; however, the simulation modelling process in SPSM is the most highlighted issue which needs attention. The survey results also suggest that most of the respondents are very methodical, work on large problems; build large models, and document their models formally. However, to most of the respondents say that maintainability of models is not an issue. Evaluation is another issue highlighted by the respondents. Questions arises as to what systematic process they use, what they mean by formal documentation, why maintainability is not an issue, and how do they view evaluation. These interesting questions motivated me to study practices of the expert simulation modellers and devise a process for novice software process simulation modellers, which is close to real world simulation practice. This thesis reports a process framework developed and evaluated for novice software process simulation modellers.

1.3. Statement of contribution to knowledge

This study distinguishes itself from previous work done in software process simulation modelling (SPSM) by emphasising on improving and bringing discipline to the practices of novice software process simulation modellers.

This thesis presents the first process framework for novice software process simulation modellers. No other such framework has been developed. The framework has been developed on the basis of empirical data of best modelling practices. The study will be a major contribution to improving simulation modelling practices of novice software process simulation modellers.

1.4. Hypothesis

The hypothesis that this work addresses is:

A simulation modelling process will be helpful to novice software process simulation modellers to improve their simulation modelling.

1.5. Research questions

The following research questions are answered in order to develop and evaluate a simulation modelling process for novice software process simulation modellers through an empirical investigation. The first three research questions help collect and analyse the data in order to develop a simulation modelling process; the fourth research question aims to evaluate the simulation modelling process:

1. What are the modelling contexts of simulation modellers?

   This research question aims to explore the contexts of simulation modellers and how their contexts affect their approach to simulation modelling. In this research, contexts of simulation modellers mean their problem domain, simulation tools used, the size and complexity of problems and models, and teamwork. For this purpose expert simulation modellers have been interviewed and the data collected have been analysed. Chapter 6 reports the results related to this question.

   Rationale: Software process simulation modellers develop their models in various contexts. The context of a simulation modeller is believed to have effect on the way they go about developing simulation models [Robinson 2002]. The problem domain, the scope of the problem, simulation language/technique/package used, the size and complexity of the problem simulated are a few of the contextual factors which may affect a modeller's approach to simulation model development. Therefore, it is important to investigate the contexts of simulation modellers in order to define the scope under which an empirically developed simulation modelling process should be used.

2. What are the practices of simulation modellers?

   This question aims to explore the practices that simulation modellers employ for simulation model development. For this purpose expert simulation modellers have been interviewed and data collected has been analysed. Chapters 6 reports the results related to this question.

   Rationale: The practices of simulation modellers form their simulation modelling processes. This question explores their habits, behaviour, and approach towards problem understanding, model construction, experimentation, documentation, maintenance, and evaluation. It investigates how they view their overall simulation model development process and what deficiencies they find in simulation practice. It also aims to explore their view of best practices for simulation modelling in their specific contexts.

3. What process emerges by investigating the contexts and practices of simulation modellers?

   This question aims to determine what simulation modelling process may emerge from the empirical data collected about the contexts and practices of simulation modellers. Chapter 7 reports the results to answer this research question.

   Rationale: An investigation of the contexts and practices of expert simulation modellers may reveal real world simulation practices which can be organised into a modelling process. Studying the contexts and practices of both discrete event and continuous simulation modellers may allow the identification of a generic simulation modelling process which is independent of a particular simulation technique.

4. Will a simulation modelling process help novice software process simulation modellers to improve their simulation modelling?

   This question evaluates the RMSP and tests the hypothesis. For this purpose, controlled experiments have been conducted with novices, and expert perspective about the RSMP has been sought. Chapters 8 and 9 report the results related to this question.

   Rationale: The RSMP has been developed by analysing the data collected from expert simulation modellers. To test whether an empirically developed simulation modelling processes will be helpful to novice software process simulation modellers, the RSMP has been evaluated for its scope, understandability, usability, usefulness, and tailorability.

1.6. Objectives of the RSMP

The following objectives of developing a simulation modelling process have been established after an extensive literature analysis (Chapter 2) and a preliminary survey with expert software process simulation modellers (Chapter 5).

I. Provide novice software process simulation modellers with a simulation modelling process which is close to real world simulation practice

II. Develop a simulation modelling process which is independent of a particular simulation technique (i.e. discrete event and system dynamics)

1.7. Methodology

This research project consists of three phases as following:

- Conceptualisation
- Developing the RSMP
- Evaluating the RSMP

Following I summarise each phase of my research

Conceptualisation

The conceptualisation phase consists of literature analysis and a preliminary survey with software process simulation modellers. The overall aim of this phase is to conceptualise the research problem and set the context and scope the research.

The software process simulation modelling literature and general simulation modelling literature is analysed to generate the hypothesis on which this thesis is based. A preliminary questionnaire survey with software process simulation modellers is conducted to explore their practices and establish problems in the simulation modelling.

The conceptualisation results in my hypothesis and research questions and success criteria on which the RSMP is evaluated.

Formulating the RSMP

The second phase aims to answer the first three research questions. This phase consists of semi-structured interviews with expert simulation modellers to explore their modelling contexts and practices.

The results from my preliminary survey indicate that an in-depth comparative study of the practices of software process simulation modellers and general simulation modellers is needed. I gain detailed insights into simulation modelling practices by interviewing simulation modellers from both groups of modellers to explore and compare their practices. The software process simulation modellers include practitioners and researchers who simulate software engineering problems, and general simulation modellers include practitioners and researchers who simulate business, manufacturing, healthcare and defence problems. Simulation modelling is relatively new in software engineering, whereas it is quite an established subject in other disciplines such as operational research and manufacturing. A study of the two groups allows comparison and identification of deficiencies in modelling practices of software process simulation modellers. Analysis of the data related to the contexts and practices of expert simulation modellers underpins the development of the RSMP.

Evaluating the RSMP

Having created a simulation modelling process through an empirical study, this phase of my research project aims to answer the fourth research question by evaluating the RSMP. I evaluate the RSMP in two stages, which includes controlled experiments with novices as the first stage and an expert panel evaluation as the second stage.

I design a two-phased laboratory study to evaluate the RSMP with novices. Two comparative groups of novice software process simulation modellers were drawn for both phases of the experiments. One of the two groups was trained with the RSMP and other group used their own approach to develop a simulation model. The models produced by both groups are evaluated on the assessment criteria and the RSMP is evaluated on the evaluation criteria established prior to developing the RSMP.

In the second stage, a panel of experts is provided with a detailed description of the RMSP and a questionnaire to evaluate the RSMP. The panel of experts evaluate the RSMP for its scope, understandability, usability, usefulness, and tailorability. The results of this evaluation highlighted the strengths and deficiencies in the RSMP and suggested many improvement.

1.8. Thesis organisation

The thesis is organised following the guidelines by Jedlitschka and Pfahl [2005] for reporting empirical studies in software engineering. This includes a thorough background and motivation of the research problem, rigorously reporting and justifying the research methods, research instruments, results and interpretations, and conclusions.

The thesis has been divided in 4 parts comprising of 10 chapters in total. Figure 1.1 summarises the thesis organisation.

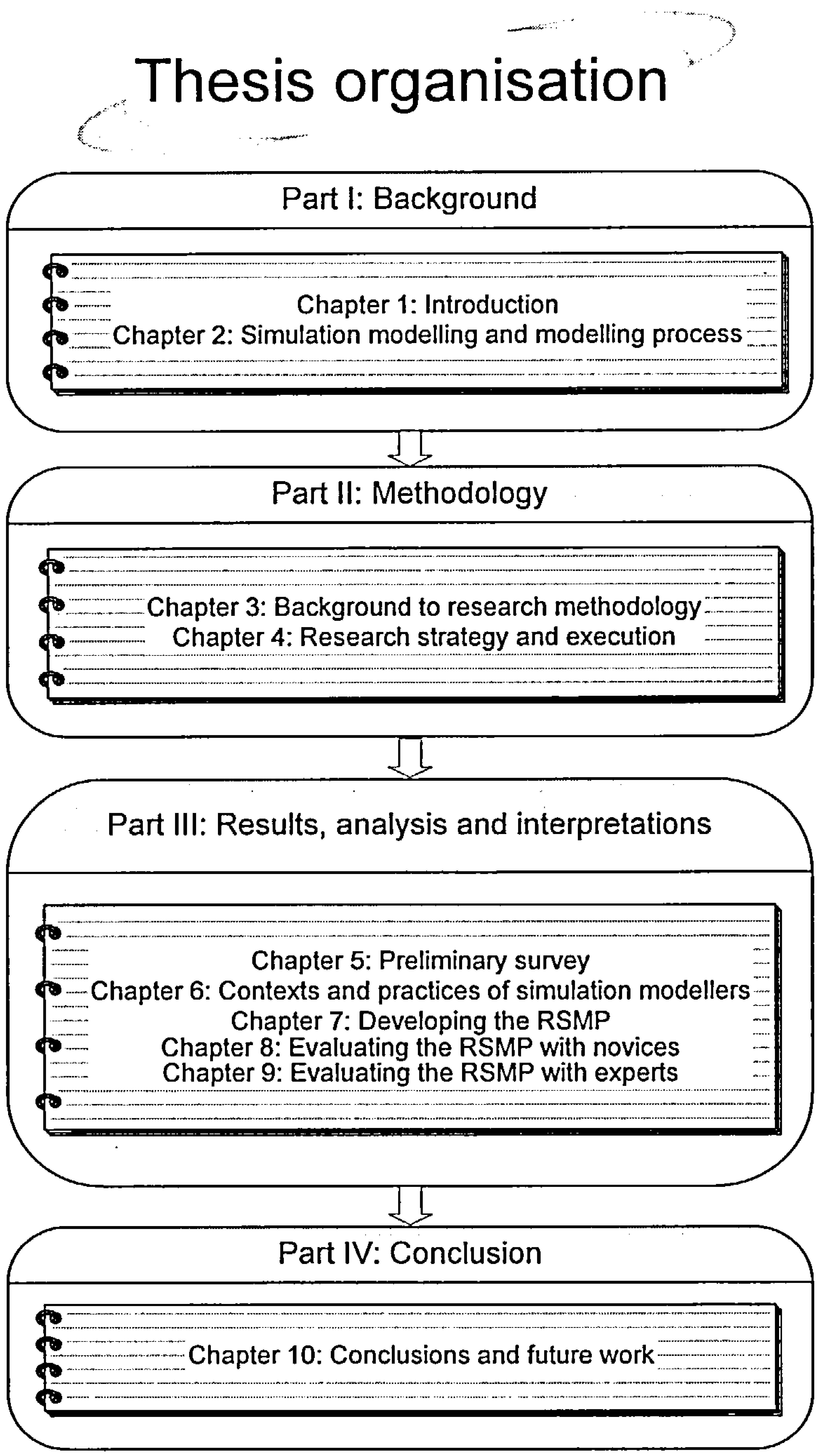
Part I of this thesis provides a background to the study.

Part II presents the background to research methodology and a detail account of the research execution.

Part III reports on the analysis and interpretations of the results of all the empirical studies conducted in this research, which includes a preliminary survey, interviews with expert simulation modellers, developments of the RSMP, and evaluation of the RSMP.

Part IV presents the conclusions and future work.

Figure 1.1: Thesis organisation



1.8.1. Part I: Background

Chapter 1: Introduction

Chapter 2: Simulation modelling and modelling process

Chapter 2 sets out to present a review of the literature regarding software process simulation modelling (SPSM) and simulation modelling processes reported in the literature. It also explores the issues related to simulation modelling process. It builds an argument that there is a need of discipline in simulation modelling alongside creativity. It also establishes a justification for a process framework for novices in SPSM.

1.8.2. Part II: Methodology

Chapter 3: Background to research methodology

Chapter 3 discusses the background to the research methodology employed in this research project. The chapter aims to provide a thorough background to my research methods and a justification of employing these methods. It summarises empirical methods in software engineering, a brief discussion on qualitative and quantitative research methods and combining these methods; it also provide a justification as to how these research methods suit for my research problem. The chapter also provides a detailed overview of grounded theory, which is the prime research approach used in this project. It gives a background to the data collection and analysis methods used in this research.

Chapter 4: Research strategy and execution

Chapter 4 reports on the strategy and execution of the research in the context of the research methodology discussed in chapter 3. It describes each phase of the research; the activities performed for data collection and analysis, and rationale for each activity. The chapter also report on each of the research instrument, preliminary survey, semi-structured interviews, controlled experiments, and expert panel evaluation used during different phases of this research.

1.8.3. Part III: Results, analysis, and interpretations

Chapter 5: Preliminary survey

Chapter 5 reports on the first phase of this research which is based on a preliminary survey of software process simulation modellers. The objective of the survey is to identify the current state-of-the-art in software process simulation modelling. The chapter presents results of data collected from the survey respondents. The results from this study focus and conceptualise the problem area for the rest of the study. The output of this phase was the final research questions. The results from this survey provide the rationale for exploring various concepts in more depth for developing a rapid simulation modelling process.

Chapter 6: Contexts and practices of simulation modellers

This chapter presents the results of the semi-structured interviews conducted with expert simulation modellers in software engineering and operational research. The research findings in this chapter present an overview of contexts and practices of simulation modellers participated in this study. These research findings relate the contexts of simulation modellers and their practices which ultimately helps developing the RSMP. This chapter answers first and second research questions of my thesis.

Chapter 7: Developing the RSMP

Chapter 7 describes the approach to developing the RSMP for novice SPSM modellers and answers the third research question. The RSMP is based on the analysis of empirical data collected in semi-structured interviews with expert modellers. It reports the analysis of simulation modelling processes of each participant of the interview study. The chapter describes each step taken during the development of the RSMP. It also compares the RSMP with other processes reported in the literature.

Chapter 8: Evaluating the RSMP with novices

Chapter 8 sets out to present the results of first stage of evaluation plan for the RSMP, which are controlled experiment with novices in SPSM. This chapter aims to answer fourth research question of this thesis. The RSMP has been evaluated for its understandability, usability, and usefulness through two phased study of controlled experiments with novices in SPSM.

Chapter 9: Evaluating the RSMP with experts

Chapter 9 also aims to answer the fourth research question. It presents the results of expert panel evaluation of the RSMP. Expert panel evaluation is second of two staged plan for evaluating the RSMP. The RSMP has been evaluated for its scope, understandability, usability, usefulness, and tailorability through expert panel evaluation.

1.8.4. Part IV: Conclusions

Chapter 10: Conclusions and future work

Chapter 10 presents a summary of the research. It concludes the main findings of this research and discusses the contribution to knowledge on software process simulation modelling. It discusses how well the research hypothesis has been proved. The chapter also acknowledges on the weaknesses of the research process and methods and possibility of improving the methods in future. Chapter 10 also discusses how the findings from this research can be further expanded as future research work.

2. Chapter two: Simulation modelling and modelling process

This chapter presents a discussion of the literature that underpins and provides the context for this research project. This literature review also helps determine the objectives of the RSMP. The reviewed literature includes discussion of software process simulation modelling and its application in software engineering, simulation modelling process issues and studies of training novices in conceptual modelling. The overall aims of this literature review are:

- To gain an understanding of simulation modelling and its applications in software engineering
- To investigate the simulation modelling process and issues related to it
- To justify the need for a process framework for novice software process simulation modellers

The chapter has been organised in 7 sections. Section 2.1 gives a brief account of the types of simulation modelling being applied in software engineering. Section 2.2 discusses the areas of software engineering in which simulation modelling has been applied. Section 2.3 discusses characterisation of simulation modelling practice on the basis of types of models, the modelling process, and the modeller. Section 2.4 argues that there is a need for disciplined process of simulation model development. Section 2.5 reflects on the simulation modelling processes reported in the literature and their limitations. Section 2.6 describes the rationale behind the development of a process framework for novice software process simulation modellers. Section 2.7 concludes the chapter.

2.1. Software process simulation modelling

Growing competition in the software industry has resulted in increasingly complex software processes to address issues related to quality, cost and time to market. The software process is a collection of different activities, for example, cost estimation, size estimation, requirement specification and analysis, initial design, detailed design, implementation, code inspections, and testing ,etc.; all these activities have various issues and complexity; few examples are shown in next subsections.

Simulation can provide insights into complex process behaviour which allows the managers to study the issues such as cost, quality, and schedule and take appropriate decisions. The software process includes activities that can be identified as sequential that are discrete events and also continuous that can be performed concurrently. Therefore, discrete event and continuous simulation are the commonly used simulation techniques for the simulation of software processes.

2.1.1. Discrete event simulation

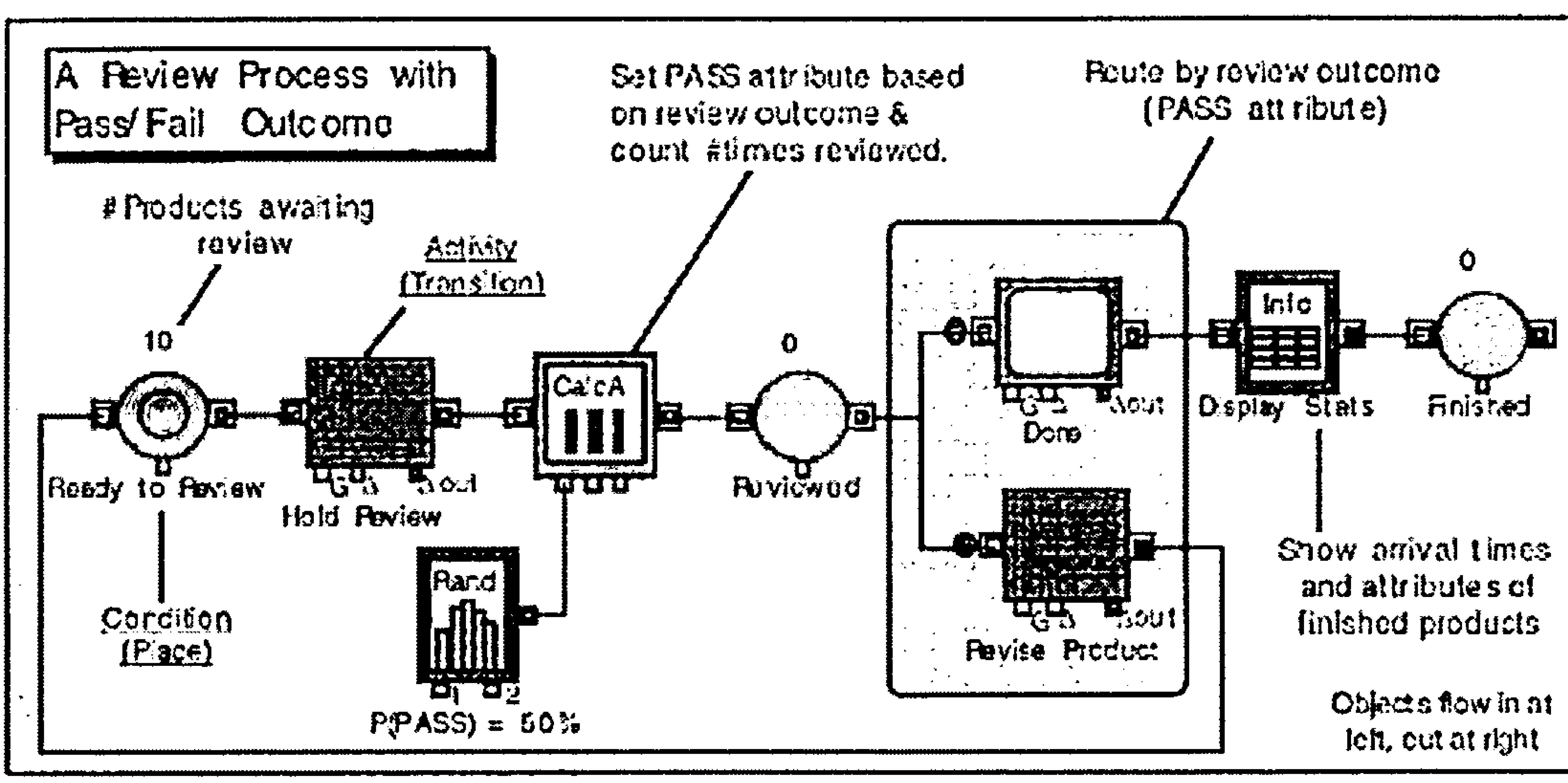
Discrete event models have been widely used for simulating supply chains and the assembly lines of manufacturing plants [Christie 1999]. This type of modelling is particularly appealing when a process is viewed as a sequence of activities. Discrete event models represent a finite number of events in a system between which nothing important happens. A number of studies have been reported in the software engineering literature that make use of discrete event simulation modelling [Kellner et al. 1999].

Donzelli and Iazeolla [2001] say that the software development process, historically, has been considered as a sequence of discrete activities. Lifecycle models like the waterfall or spiral model propose a generic set of activities for the control and management of software development. Moreover, recently, the Capability Maturity Model (CMM) stresses the importance of a description of the process as a detailed sequence of repeatable activities [Paulk et al. 1993]. A discrete event model allows us to represent the sequential interdependence that occurs between activities in a project. Activities in a development process, for example, may be delayed when a programmer is diverted to another task. Testing may be delayed until a test bed is released. If a model can capture these dependencies at a sufficiently detailed level, it may show ways to alter the process to reduce risk or increase efficiency [Martin and Raffo 1999].

A discrete model advances time only when an event occurs. This means that continuously changing variables are only updated at the times when events happen. In a discrete event model, interdependence between events or activities is sequential; therefore, discrete event models are not well suited to represent dynamic concurrent activities interconnected through feedback loops [Martin and Raffo 1999].

Figure 3.1 represent a review process modelled using a discrete event simulation environment [Huff 1997]. Figure 3.1 shows that review process is a sequential activity. It has ten items waiting to be reviewed; each item goes through the review process sequentially.

Figure 2.1: An example of discrete event model [Huff 1997]



2.1.2. Continuous models

In continuous models the system is represented by continuous quantities that may change at every instant of time. The structure of the system is typically shown by causal feedback loops, and system state is shown by flows and level variable values. System dynamics modelling is the popular approach used for continuous time simulation [Donzelli and Iazeolla 2001]. Abdel-Hamid and Madnick [1991] extended this work to software projects. Later work by Madachy [1994] modelled a more detailed development process. Tvedt and Collefello [1995] used system dynamics to model the software inspection process.

System dynamic models are based on cause-effect relationships that can be observed in real systems [Tvedt and Collefello 1995]. An example of cause-effect relationships may be a project behind schedule [Tvedt and Collefello 1995]. There are a number of factors or causes that determine the real behaviour of project progress. For example, one possible way to speed up the project may be the hiring of new staff. But Brooks law [Brooks 1975] states that hiring people late in the project can further delay the project, because they need training and time to understand the project. However, people's qualification, experience and productivity may speed up project progress as anticipated. This kind of relationship suggests a feedback mechanism in the process. Therefore, the most powerful feature of system dynamics modelling is realised when multiple cause-effect relationships are connected together to form a circular relationship, called a feedback loop [Donzelli and Iazeolla 2001].

Donzelli and Iazeolla [2001] say that while the behaviour of continuous variables can be described well in a system dynamics model, it is a difficult way to describe process steps sequentially. Although it is possible to represent discrete activities in a system dynamics model, the nature of the approach require that all variables should be updated at every time interval. If the process contains sequential activities, mechanisms must be added to prevent all activities from executing at once [Donzelli and Iazeolla 2001]. For example, Martin and Raffo [1999] say if we model the software process as define, design, code and test activities, as soon as some code is defined, design starts. If we want to model a process that completes all design work before coding starts, we would have to create an explicit mechanism to control the sequencing.

The FEAST project at Imperial College London [FEAST I &II] has been an influential simulation study for software processes after Abdel-Hamid's [1989]. Figure 2.2 represents a cause-effect relationship (called an influence diagram) in a so called ideal software evolution process [Lehman and Ramil 1999]. Figure 2.2 shows that *productivity* influences and is influenced by many factors. Productivity affects implementation flow, and implementation flow affects cumulative progressive work and finally cumulative progressive work affects productivity. In real software process these complex feedback loops influence the software process significantly and it is desirable to understand and take account of these effects in advance.

Figure 2.2: A software evolution process (cause-effect relationship) [Lehman and Ramil 1999]

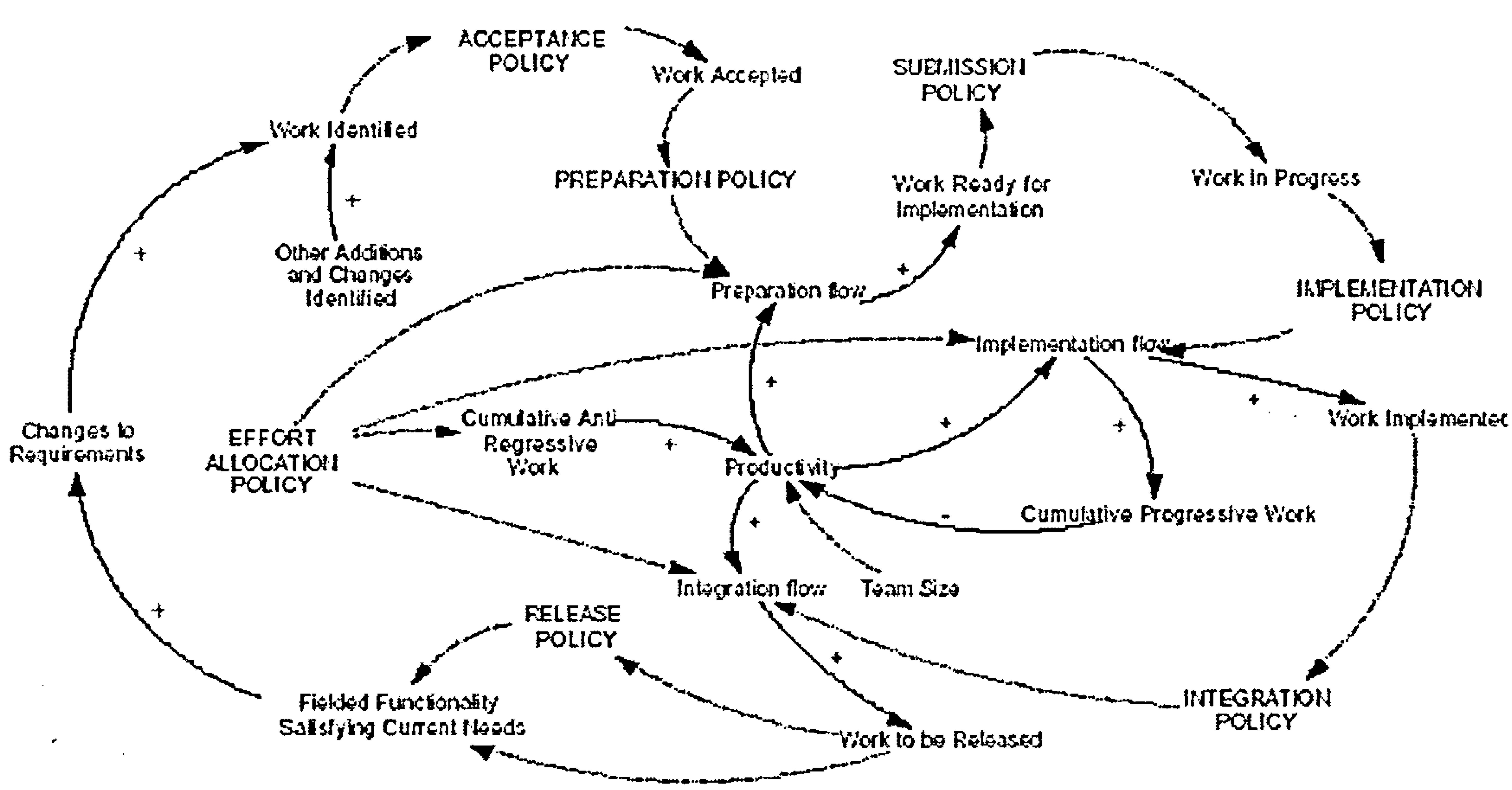
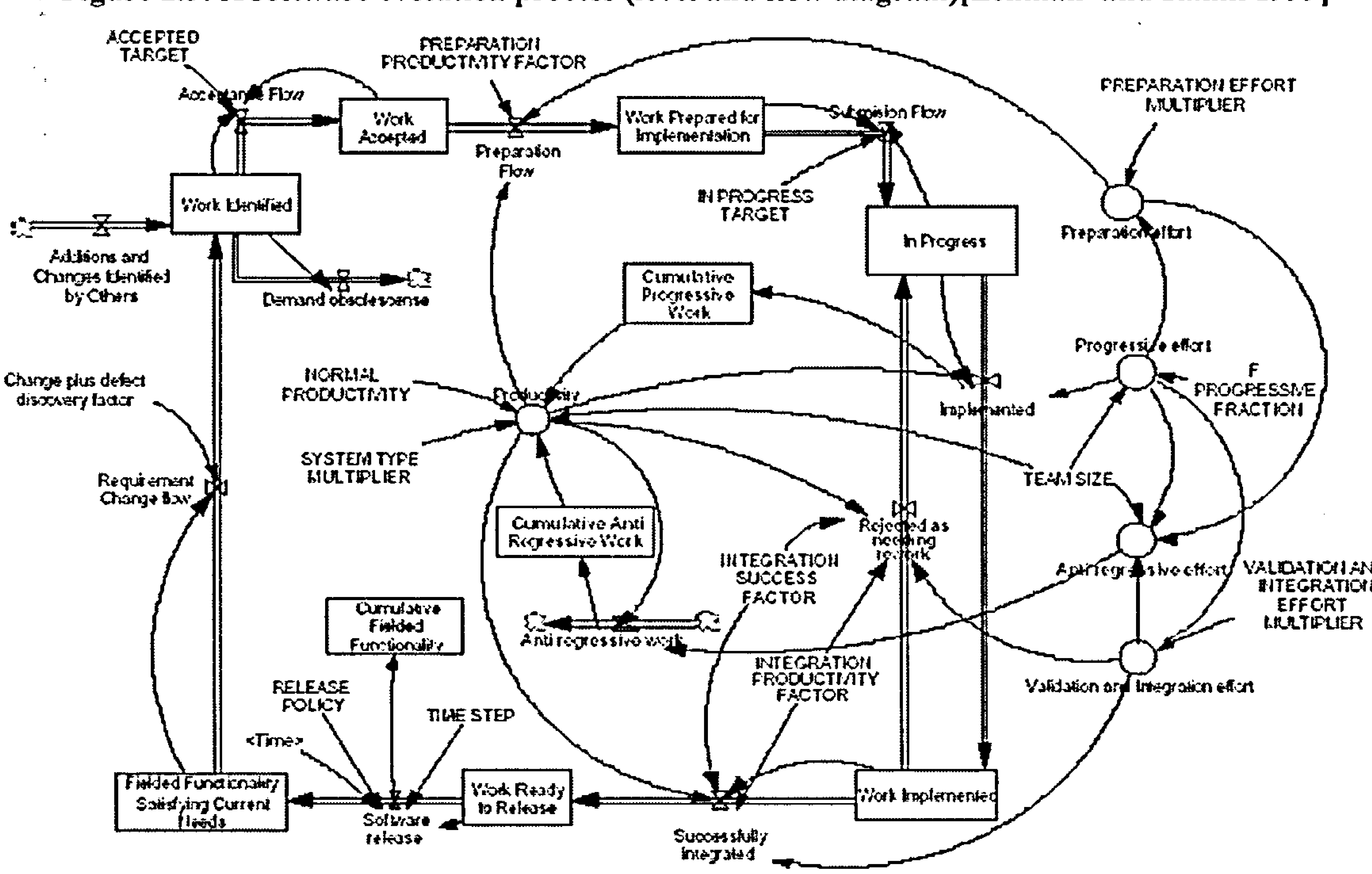


Figure 2.3: A software evolution process (level and flow diagram)[Lehman and Ramil 1999]



System dynamics models describe the system in terms of "flows" that accumulate in various "levels". The flows can be dynamic functions or can be the consequence of other "auxiliary" variables. As the simulation advances time in small evenly spaced increments, it computes the changes in levels and flow rates. For example, the error generation rate may be treated as a "flow" and the current number of errors could be treated as a "level". This allows the model to capture the stability or instability of feedback loops. A system dynamics model can be valuable in finding the levels where a model can become unstable, or in predicting the unanticipated side effects of a change in a system variable. Fig 2.3 is a stock-flow diagram representing an ideal software evolution process [Lehman and Ramil 1999] developed for the FEAST project at Imperial College London.

2.1.3. Hybrid models

As the above discussion suggests, it is not possible to capture all aspects of a software development process by using only one simulation modelling technique. Simulation modellers may come up with combined models that facilitate all aspects of a software process. Rus et al. [1999] used a combined technique for software reliability management for a defence project. Donzelli and Iazeolla [2001] developed a hybrid model for waterfall development approach that combines discrete modelling, system dynamics and another technique called analytical modelling. Martin and Raffo [1999] discuss the issues involved in development of combined models, especially the integration between discrete and continuous models.

2.2. Application areas of software process simulation modelling

A wide range of simulation studies can be found in the literature applied in different areas of software engineering. Kellner et al. [1999] categorises the particular areas of software engineering in which simulation modelling has been applied:

- Strategic management of software processes
- Software project planning

- Control and operational management
- Process improvement and technology adoption
- Understanding of software processes
- Training and learning in software engineering

2.2.1. Strategic management of software process/projects

Simulation can be helpful to inform strategic management for effective decision making. Strategic decisions such as outsourcing, bidding, process adoption and adaptation, and policy analysis have been studied through simulation. Simulation provides software development managers with different scenarios to assist in decision making.

Roehling et al. [2000] report on using simulation to improve software maintenance outsourcing strategies. They studied the dynamics impacting the positive and negative outcomes of outsourcing relationships. Their model benefits the outsourcing decision makers by providing insights into the dynamics and constraints of an outsourcing relationship. Moreover, the model helps outsourcing managers with continuous learning to formulate strategies resulting in successful outsourcing. The model provides managers with a set of generic building blocks to simulate outsourcings decisions under different '*what if*' scenarios.

Kitchenham et al. [2003] describe a bidding model to visualize the uncertainties involved in the software pricing decisions using simulation. Their model aims to provide information to different organization roles about the software bidding process, the uncertainties and risks involved in bidding and fixing appropriate prices and delivery schedule for software under different scenarios. This model is a generic model representing the basic structure of the software bidding process and can be specialized for specific contexts.

Henderson and Howard [2000] report on the effectiveness of simulation for adopting a process strategy for large scale software development. Their model represents software development as a manufacturing activity, consisting of an integrated framework of several independent software development activities producing complex large scale software. They report how using system dynamics modelling helped them understand and predict the benefits of this process strategy.

Williford and Chang [1999] present a system dynamics model for planning the IT strategy at FedEx. This provides a decision aiding tool for funding over a five years period. They modelled the role of IT in cross-organisational processes for supporting new services. Moreover, they studied the effect of courier workloads on software development and maintenance. Their model helped FedEx's IT division allocate resources and decide on a CMM advancement initiative for improved productivity.

2.2.2. Software project planning

Software project planning entails various decisions and tradeoffs on cost, quality, scheduling, staffing, and effort. The risks associated with the tradeoffs made in software project planning can be studied using simulation. Various studies report on the effectiveness of simulation to help the management function for software project planning. Moreover, simulation has been used to adopt a best process from different process alternatives to suit a particular project.

Abdel-Hamid [1989] studied software project staffing using system dynamics. His model helps project managers with managerial and operational aspects of staffing decisions for planning and projection of software projects. This model was used as an experimentation tool to study and predict the implication of different staffing policies on real software project behaviour.

Ruiz et al. [2001] report on developing a system dynamics model for software project cost estimation. They say that their model is particularly useful when there is little historical data available for cost estimation. Their model is also useful for training project managers with cost estimation.

Powell [2004] reports a system dynamics model for studying the dynamics of concurrent software development. He reports on how simulation helped estimate the cost and planning of concurrent activities scheduled in a time constrained environment.

2.2.3. Control and operational management

Simulation has also been used successfully for the control and operational management of software projects and processes. Simulation can aid the operational management of a software project by comparing the current status of a project with forecasted values of a simulation. Then policies on resource allocation, cost and schedule can be reviewed and mechanisms can be devised for the control of the project. Simulation can also help examine the outcome of a process implementation by comparing it against the projected values through simulation.

Raffo et al. [2000] report a discrete event simulation model for a software project management controlling function by coordinating metrics within the model. Their model was used to track project performance and the impact of various managerial decisions. The model helps project managers to evaluate the current status of the project and devise operational decisions to control performance.

Pfahl and Lebsanft [1999] integrate the GQM approach with a system dynamics model for software project planning, control and management. Their model provided Siemens Private Network with an effective tool to understand and control the dynamic relationships between project duration and product quality.

2.2.4. Process improvement and technology adoption

Software process improvement is another area in which simulation has been applied with effective results. Software companies are facing the issue of process improvement and adaptation with fierce competition in the industry. Simulation can be used to analyse and forecast the effect of potential process change and improvement. It can be used to select the best process from different process alternatives. Moreover, simulation can facilitate process evaluation by comparing the outcome of process implementation with the projected outcome.

Christie [1999] reflects on how using simulation can be useful for CMM based process improvement initiatives. He says that the complexities resulting from dynamic feedback loops of software development processes cannot be comprehended mentally or intuitively by managers. Simulation provides a relatively reliable forecasting method to predict and evaluate process change and improvement. He describes how simulation should be implemented to gain process maturity for different CMM levels.

Scacchi [2000] reports on the effectiveness of simulation for software process redesign. He presents an approach to analyse the existing software process and redesign the software process through simulation based on knowledge gained through process analysis. He created a simulator which allows interactively observing and browsing a process model using a graphical user interface; this facilitates analysis of existing process and the redesign of the process model.

Donzelli and Iazoella [2001] report a hybrid simulation model combining discrete event and continuous simulation paradigms for software process improvement. They simulated a waterfall-based software process to study the effects of requirements instability on effort, delivery time, productivity, rework percentage and product quality. The analysis of simulation results gained helped them decide on how to improve the software process to address these issues.

Simulation has also been used to study and manage the impact of technology adoption. Baik et al. [2001] report on using simulation to study and control the effect of COTS (commercial-off-the-shelf) based development process. Simulation helped them adapt the process for COTS integration and manage the risk associated with COTS introduction.

2.2.5. Understanding software processes

Simulation can also benefit the understanding of process and factors affecting the process which is difficult to identify intuitively. Simulation can be particularly helpful in understanding feedback loops in software processes and the complex interrelationship between cost, quality, and time.

Misic et al. [2004] used system dynamics to understand the dynamics of pair programming and task switching in extreme programming practices compared to traditional ones. They modelled factors like, pair personalities, expertise, compatibility, pair switching and task switching to study the effect of these factors on productivity. They highlight what factors make extreme programming advantageous over traditional programming practice.

Wernick and Lehman [1999] simulated the impact of feedback on the long-term evolution of software systems. They modelled a very high level abstraction of factors to understand their effect on long-term software evolution.

2.2.6. Training and education in software engineering

Training and learning about software processes or project management can also be achieved through simulation. Although this objective is similar to understanding, nevertheless, the explicit goal can be teaching and education.

Drappa and Ludewig [1999] developed an interactive animated simulation model aiming to provide a training environment for future project managers. Their model emulates certain aspects of software project development processes providing descriptive and quantitative insights to learners. They tested this training tool with software project management students and found it effective at teaching the dynamics of software development processes.

2.3. Modes of simulation practice

The software process simulation modelling literature does not discuss a classification of simulation models or simulation modelling practice. However, in operational research, Robinson [2002] classifies three modes of simulation on the basis of the characteristics of the simulation model, the modelling process, and the modellers. The three modes of simulation are, simulation as software engineering, simulation as a process of organisational change, and simulation as facilitation. An analysis of the software process simulation literature and discussion with the modellers suggests that the mode of simulation practice in software process simulation resembles very much with the latter two categories. Table 2.1, reproduced from Robinson [2002] summarises the modes of simulation practice with respect to their facets.

2.3.1. Simulation as software engineering

This mode of simulation entails building very large models, built and used for years, and are reusable. They are built using a simulation or programming language. The project may take years to complete, will have many users, and will be highly costly. Client involvement is only for requirements gathering while the model is built in isolation from the customer. The customer is involved only for model experimentation. Validation of the model is conducted by the modeller(s) or by a third party. Many modellers participate in the development of simulation models of this kind. Military combat simulation, flight simulators, video games are the examples of such models.

From the software process simulation literature, I could not find an example of such simulation models.

2.3.2. Simulation as process of organisational change

In this mode of simulation practice, the modeller acts as an agent of organisational process change. The modeller usually builds small or medium size models, which take weeks or months to build. Normally the models are throw-away; however, in some situation they may be used in the longer term. Simulation language or visual interactive tools are typically used to build such models. The models are aimed at answering specific questions; there are many iterations through the modelling process; the customer is highly involved in the modelling process, and validation is done both by the modeller and the customer. Usually only one modeller is involved and the predominant skill required is modelling. Example of such models are supply chain models, assembly line models, health care models. This is the most commonly used mode of simulation in the business domain.

Example of such models in SPSM could be the simulation model developed by Rus et al. [1999] for software reliability management. Similarly, the system dynamics model developed by Williford and Chang [1999] for IT strategy for FedEx IT division may fall into this category.

Table 2.1: Modes of simulation practice [Robinson 2002]

	Simulation as		
Facet	**Software engineering**	**A process of organisational change**	**Facilitation**
1.Simulation model			
Prime motivation	Representation	Intervention in a problem situation	Understanding and provoking debate about a problem situation
Size of the model	Large scale	Small scale	Quick-and-dirty
Longevity of model	Long-term (years)	Short-term (months/weeks)	Short-term (weeks/days)
Model reuse	Reusable	Throw-away, possibly after customer use for experimentation	Throw-away
Software for the model	Programming language/simulation language	Simulation language/visual interactive modelling system	Visual interactive modelling system
2.Modelling process			
Purpose	Many questions could be asked of the model	Specific questions to be answered	Vague questions to be answered
Length of the project	Years	Months/weeks	Weeks/days
Iteration through stages in the project	Limited iteration	Frequent iteration	Highly iterative
Beneficiaries	Users	Customer	Customer
Beneficiaries involvement	Experimentation only	High at times e.g. conceptualisation, validation and experimentation	Very high throughout
Learning	From experimentation with the model	From the modelling process	From the debate surrounding the modelling process
Validating the model	Modeller and independent V&V	Modeller and customer	Modeller and customer
Cost	High	Medium	Low
3.The modellers			
Number of modellers	Many	One	One
Predominant skill	Software development	Modelling	Process management

2.3.3. Simulation as facilitation

Robinson [2002] says that this is a special case of simulation in which the modeller along with the customer develops a model very quickly while the aim is just to understand a problem situation and provoke debate. Such models are throw-away and the modelling process is highly iterative. Questions to be answered are vague, accuracy is not important but the understanding gained through modelling is important. Customer involvement is very high throughout the model development. Such models are comparatively low cost and the predominant skill required of the modeller is process management.

Examples of such models in SPSM can be the system dynamics model developed by Misic et al. [2004] to understand the dynamics of pair programming, and the simulation study reported by Pondar and Mikac [2001] to analyse software maintenance process using discrete event simulation.

2.4. Simulation modelling: A background discussion

This section introduces the simulation modelling process; discusses the role of creativity and discipline in simulation modelling; rationalises the need of a disciplined approach for simulation model development; and presents the issues which may arise due to the weakness in simulation modelling process.

2.4.1. Simulation modelling process

Models are the products that are visible, and modelling is the act of developing a model. The modelling process can potentially affect the quality of the model developed [Eriksson 2003]. Modelling activities in the organizational environment involve people, technology and tools. The question is, in such an environment where tools, technology and people collaborate, what establishes a framework between these entities. Historically, the motivation behind defining a process for any production activity is to establish a framework between these entities so that they should be utilised at the highest possible value and quality [Humphrey and Kellner 1989].

> *"Process is the logical structure of people, technology, and practices that are organized into work activities designed to transform information, materials and energy into specified end result(s)"* [Kellner et al. 1999].

A process defines the set of steps that should be undertaken to accomplish the tasks effectively [Humphrey 2003]. A process categorizes the responsibilities and activities particular to people and tools, also the rules to organising those activities. Therefore, a simulation modelling process suggests a set of activities that should be undertaken to develop a simulation model.

Humphrey [1997] states that a good process brings discipline in human activities and improve the quality of products. It is the process that can effectively help engineers to produce high quality products, with reduced time, and control over cost [Cugola & Ghezzi 1998]. Studies have shown that a standardized process can significantly improve quality and productivity (Herbsleb et al. 1994; Harter et al. 2000; Krishnan et al. 2000). This suggests that a good process for simulation model development may also improve simulation model quality and increase the productivity of modellers.

Several simulation modelling processes has been reported in the literature, which will be discussed in Section 2.5. However, before that it is important to reflect on the debate of discipline vs. creativity in the process of simulation model development.

2.4.2. Simulation and creativity

Shannon [1975] says that simulation modelling is both art and science; producing art needs creativity [Kneller 1965], therefore simulation modelling needs creativity. Many simulation modellers believe that simulation is a creative accomplishment and if it is limited by process constraints, creativity may also be limited [Powell 1995]. A simulation model is considered as a debating vehicle which can elicit knowledge and propose solutions to customers [Robinson 1994]. Paul et al. [2003] say a fixed process of simulation model development may not be applicable in all situations:

> *"One can instantly see that fixed structure to develop simulation models will not be able to cope with all the situations at all times"*

Haworth et al. [2005] suggest that creativity is a process of depicting the personal ideas and imagination of an artist, therefore, creativity is said to be an activity that is an ideas-oriented activity. Paul et al. [2003] says that simulation is aimed at suggesting solutions to the customer problems to facilitate decision making. Merleau-Ponty [1964] says that an artist's style, the he/she imagines the world, is not something that is developed consciously in an order; rather it is developed through a series of personal experiences, observations and chain of perceptions. Therefore many times one artist's view of the world is very different from those of others. Simulation modelling, however, cannot be considered an absolute artistic or creative activity. Simulation modelling is also a solution oriented activity in which a modeller facilitates the client with a range of possible solutions by eliciting knowledge from the client [Paul et al. 2003]. Csikszentmihalyi [1988] says that creativity is the product of three main shaping forces; a set of social institutions or field, a cultural domain, and the individual. In addition to that, a fourth shaping force is added in the production of a simulation model, the client. Therefore a simulation modeller's style not only depends on the personal experiences but also on client intervention. This changes the whole nature of creative endeavour in simulation modelling. The contrast between the nature of simulation modelling and art can be described as:

- Art is ideas oriented [Haworth et al. 2005], simulation is solution/decision oriented [Paul et al. 2003]
- The artist conforms the world to his/her own view [Csikszentmihalyi 1988], the simulation modeller conforms the world to the client's view [Paul et al. 2003]
- The artist is bound by personal intellectual requirements/feelings [Kneller 1965], simulation modeller is bound by customer requirements and commercial pressures [Robinson 1998]

There are situations in which art is to be developed for a client. In this case where the client enters as an intervening force, developing art and developing simulation will have more similarities.

Haworth et al. [2005] describe the nature of creativity

> *"Creativity is not a search for absolute unchanging truths, but ideas and forms in which we can come to rest provisionally, with inter-subjectivity resulting from the communality of the body."*

This is also true for simulation that we are not always looking for absolute truths (solutions) through simulation rather a range of possible solutions. This is one great commonality between art and simulation, which perhaps has convinced a number of simulation modellers of an absolute equivalence between simulation and art. However, taking the previously mentioned difference between simulation and art into account, simulation is said to be a solution oriented creative activity.

2.4.3. Discipline vs. creativity in simulation

In the previous section, I discussed the similarities between simulation and art. In this section I attempt to describe the role of creativity and discipline in simulation to justify the need of process for simulation modelling.

Simonton [2002] suggests that creativity can be considered a constrained stochastic process; that is creativity is not completely random or stochastic, rather loosely bound in the rules of the domain for which creativity is needed. Johnson-Laird [1988] says that there can be many criteria of creative processes on which a creator may rely; some of those criteria will be common to many practitioners while others may depend on individual aptitude and style. Simonton [2002] further states that the multidimensional nature of a creative domain makes it very difficult for a person to decide what is right or which way of doing something is right. However, defining some constraints make it easier for the person to have confidence in the validity of his/her creative process. As Haworth et al. [2005] say:

> *"Random happenings in the process of making art are critical to the creative process, enhancing freedom of choice. In turn, however, choice can be tyrannical, if it is not embedded in constraints, which may originate from the individual, group, and society."*

This suggests that creative process does not consist of only stochastic random activities but there is some structure in the creative process. As Kneller [1965] says:

> *"Creative thinking usually begins with a problematic situation, which is incomplete in some way. The thinker grasps this problem as a whole. Then the dynamics of the problem itself, the forces and tensions within it, set up similar lines of stress within his mind. By following these lines of stress the thinker arrives at as solution which restores the harmony of the whole. Throughout this process he satisfies an inborn urge to grasp a whole pattern and restore it to order... the entire process is one consistent line of thinking"*

It worthwhile noting that the domains where creative endeavour is aimed at providing solutions to the customer and commercial pressures haunt the practitioners; process-based approaches to bring discipline in practices have been suggested to increase productivity and quality. For example, in the early days, software development was also considered a creative activity [Humphrey 1997]. Later researchers proposed process maturity not only at an organisational and team level but even for individual programmers. The personal software process is one example, proposed by Humphrey [1997] to bring discipline in the habits of individual programmers. Ferguson et. al. [1997] suggest why discipline is needed alongside creativity:

> *"In most professions, competent work requires the disciplined use of established practices. It is not a matter of creativity versus discipline, but one of bringing discipline to the work so that creativity can happen. The use of plans and procedures brings order and efficiency to any job and allows workers to concentrate on producing a superior product. A disciplined effort, too, removes waste, error, and inefficiency, freeing financial resources for better uses."*

The software process simulation modelling literature does not provide much debate on the process of developing simulation models. It is not clear whether software process simulation modellers simply do not report on the modelling process because they are using a good process or they are not interested in the modelling process. However, it seems that modellers are more interested in the end product than the process of creating that product. In simulation, where the world is driven by time constraints, commercial pressures, and competition, weakness in the modelling process may bring up many issues as discussed in next section. Therefore, Gass [1987] suggested:

"We need to get away from the crutch that modelling is an art. Guidelines need to be proposed, methodologies for validation and evaluation need to be formalized and applied; and the concept that modelling is a profession with standards must be brought into education and on-the-job training activities of the coming generation of analysts."

As yet, there is not much evidence in the literature that without following a process for model construction a model is of good or bad quality, but it can be argued that a model's quality is questionable if it is constructed without taking the process into account [Eriksson 2003]. As he states:

"Since the quality of the models themselves affects the quality of creation that are guided by these models, it is important to reflect upon the process of model construction in order to understand its basic characteristics and gain insight into how these contributions may successfully be employed."

A process-based approach to simulation model development is similar to process-based development in any engineering discipline and a creative approach has similarities with agile methods for product development. It would be interesting to note that, in most solution based professions where human intellect is involved, such as software development, requirement engineering, simulation modelling, and conceptual modelling, there is a always a debate between process champions and art champions. Lycett et al. [2003] examine the rationale behind process based and agile based approaches. They say that the principles governing process-based approaches are formalism, standardisation to enhance coordination and communication, and economics. On the other hand, the principles governing agile approaches are flexibility, individual excellence, peer-based knowledge capture, and putting minimal effort to get the task done.

Agile approach has some similarity with creative approach because of its heavy reliance on individual excellence and flexibility. While both process-based and agile approaches have shown benefits for quality and productivity [Krishnan et al. 2000, Stark and Crocker 2003] in different contexts, Lycett et al. [2003] show that agile values and principles can be implemented within a process based approach. Similarly in the case of simulation modelling, I argue that the creative principles of simulation modelling can be incorporated in a disciplined framework for simulation model development, as Ferguson et al. [1997] suggest, "*It is not a matter of creativity versus discipline, but one of bringing discipline to the work so that creativity can happen*".

A disciplined simulation modelling process that provides room for creative aspects of simulation is likely to produce good simulation models efficiently. Therefore I aim to develop a simulation modelling process which is likely to bring discipline in simulation modelling and is flexible enough to be tailored to individual needs.

2.4.4. Potential issues arising due to weakness in the modelling process

Weaknesses in the modelling process have raised certain issues to researchers in operational research. Similar issues are likely arise in the simulation modelling of software processes especially as simulation modelling practices increase in software engineering. Many of these problems are similar to the problems that existed and exist even today in software development due to pitfalls in development process. The reported issues are model quality, model confidence, model documentation, inadequate management of simulation projects, poor communication between stakeholders, model reuse both in terms of experience and components, and model implementation.

Model Quality

> *"Nobody solves the problem. Rather, everybody solves the model that he has constructed of the problem."* [Elmaghraby 1968]

Robinson [1998] says that little research has been performed to assess the effect of quality of simulation modelling process on the quality of simulation models. Robinson [2002a] says the quality of the modelling process improves model quality. Many other authors believe that modelling process has a relation with the quality of model produced. Balci [1986] states that there is no precise and agreed means to assess the quality of models at present, however, systemizing the modelling process may improve the quality of the models. Eriksson [2003] and Gass [1987] also reflect on the importance of modelling process in producing high quality models.

Model Confidence

Ramesh [1997] states that the modelling process has an enormous effect on the confidence in the model held by the client. Ramesh [1997] further states that a modelling process must have high customer involvement and documentation should be provided to make the model more credible to the customer. A model used by one individual/decision-maker may appear to be useless or less effective to a new decision-maker unless they are provided with proper material (documentation) to gain confidence in the model [Gass & Joel 1981]. Provision of such material should be part of the modelling process. Model confidence is a property of the person who uses the model rather than the model itself. Users will use the model only if they are certain that the model works according to their criteria.

> *"The materials furnished should enable the decision maker to evaluate the model vis-à-vis any formal or informal criteria used to establish a measure of confidence. Not to produce the materials represents a failure in the model development process."* [Gass & Joel 1981].

Documentation

> *"We do not know of any model assessment or modelling project review that indicates satisfaction with the available documentation."* [Gass 1983]

Foss et al. [1998] say that most simulation models are poorly documented, therefore, rarely reused. The models will evolve and be redefined over the period of time and managers who use the models may change frequently. Foss et al. [1998] further state that poor documentation makes it very hard to maintain the models. Changing objectives and policies may require change in the model many times in its lifecycle [Balci 1986].

Therefore, models should be documented systematically to reflect any changes in the model so that the potential users of the model should be able to understand and use them effectively.

Inadequate management

The U.S. GAO (General Accounting Office) submitted an analysis report of 33 federally funded models of different categories to the US Congress in 1976. The report identifies three main management problems which put modelling projects in difficulties i.e. inadequate management planning (70%), inadequate management coordination (15%) and inadequate management commitment (15%) [Balci 1986, Gass 1987]. Gass [1987] believes that these projects experienced problems due to poor management of the modelling process. In software engineering, process advocates claim that a formal process for software development can be effective to overcome such management difficulties [Humphrey and Kellner 1989]. We need to find out if such problems exist in software process simulation modelling and whether the use of a formal process will overcome them.

Poor communication

> *"All too often, model developers go off by themselves for a year and then proudly drop the 'completed', never to be used model on the sponsor's desk."* [Annino & Russell 1979]

Customer communication is considered very important in simulation model development; Paul et al. [2003] say whole exercise of model development actually revolves around customer communication. Poor communication between modeller and the customer may prove to be a significant problem for simulation project success [Taylor 2000]. Robinson and Pidd [1998] found that communication between modeller and the customer plays key role to the success of a simulation study. Willemain [1994] highlights the importance of communication in a survey of expert modellers. Gass et al. [1978] indicate a strong need of model user and developer communication to improve a model's quality.

Reuse

Robinson et al [2004] note that there is little motivation amongst simulation modellers to adopt procedures to employ reuse in their simulation modelling practice. Professor Ray Paul in [Taylor et al. 2004] says that in order to employ reuse, a modeller needs to adjust his/her simulation modelling process. Not using experience from past modelling projects has been reported as a deficiency in the modelling process [Balci 1986]. Many times a component of some earlier model may be usable in the new one. This is similar to software components reuse in software engineering. Foss et al. [1998] suggests that in a systematic model development process the modeller may take care of reuse in the model design, and produce documentation which enables reuse.

Model Implementation

Another problem reported in the OR literature is that there are too many models developed and too few are practically used by management [David 2001, Little 1970, Gass & Joel 1981]. We need to find out if such a situation exists with software engineering decision models. Reported reasons for this are; good models are hard to find, good parameterization is even harder, managers do not understand the models and many models remain incomplete because of poor quality of modelling process [David 2001].

2.5. Modelling processes reported in the literature

Both in the software process simulation literature and the general simulation literature, authors have reported various proposed and practiced processes for simulation model development. In the following subsections, I will briefly describe some of these processes. The RSMP is compared with these processes in Chapter 7.

2.5.1. Modelling processes in software process simulation

Very little debate is reported about the simulation modelling process in the software process simulation modelling literature. An extensive literature survey revealed only two papers, Pfahl and Ruhe [2002] and Rus et al. [2003] reflecting on the simulation modelling process.

Pfahl and Ruhe [2002] report a framework, "integrated methodology for measurement, modelling and simulation (IMMoS)", for the development of system dynamics models of software engineering problems. The IMMoS is a very rigorous and formal methodology

The process has been described in a linear fashion, however, according to the authors; there would be iteration in the actual model development process. Pfahl and Ruhe's process model takes into account different roles involved in the simulation modelling process such as the customer, the model user, the problem domain expert, and the model developer. IMMoS was evolved by the authors over several years of experience of working with system dynamics modelling in software engineering. IMMoS also takes into account the managerial aspects of simulation modelling. Because of its very formal nature, IMMoS is quite a heavy weight process and may suit only large scale projects; it is also targeted specifically at system dynamics modelling.

Rus at al. [2001] propose a simulation modelling process for the development of discrete event models of software development processes. This process model consists of four phases; this is similar to the classic waterfall model although validation and verification is conducted concurrently with model development. Rus et al. [2003] mention that the process is iterative in nature, however, the reader naturally gets an impression that it is a linear process by the way it is represented.

2.5.2. Modelling processes in operational research simulation

In contrast to software engineering, operational research (OR) has a long history of simulation modelling practices. Pidd [1999] considers modelling as the technical heart of OR. A relatively extensive debate can be found about the importance of the modelling process in the OR literature. Balci [1986] suggest that the process of model development is an iterative activity in nature, bouncing back and forth during its life cycle. Gass [1987] proposes that we need to adopt a lifecycle view of model development to show the model developers, users and management the importance of each modelling activity. Several authors have proposed simulation modelling processes in the OR simulation literature.

Robinson [2004] describes an iterative process for the development of discrete event simulation models in operational research. The process consists of 4 phases; conceptual modelling, model coding, experimentation, and implementation.

Law and Kelton [2000], one of the most-used text-books for discrete event simulation, proposes a process for the development of simulation models which includes problem formulation, defining the model, model building, validation, and experimentation.

Shannon [1998] and Nordgren [1995] propose processes for discrete event simulation consisting of similar steps as those of Law and Kelton [2000].

2.5.3. Limitations in the reported modelling processes

Several limitations can be identified in the above-presented modelling processes. These limitations provide a rationale for my study. Following I summarise these limitations as following:

1. *Not targeted for novices*: Although novices SPSM can benefit from the process frameworks proposed by Pfahl and Ruhe [2002] and Rus et al. [2003], they are not specifically targeted at novices. While the process frameworks reported in textbooks [e.g. Law and Kelton 2000, Robinson 2004] can be considered for novices, nevertheless, their applicability has been questioned in practical contexts [Paul et al. 2003].

2. *Based on individual experience*: They are based on the individual experiences of the author(s). A simulation process model based on the collective perceptions of experienced simulation modellers, developed through an empirical investigation is likely to reveal a more practical approach for simulation model development which is close to real world simulation practice.

3. *Targeted for particular modelling technique*: Modelling process reported in the literature are targeted for a specific modelling paradigm i.e. either system dynamics or discrete event. My study aims to provide a broader view of

simulation modelling heuristics and process rather than discussing the internal mechanisms of simulation techniques.

4. *Higher degree of formalism*: Simulation modelling is considered an artistic and largely an individual activity [Powell 1995]. There should be a balance between theoretical formalities and practicalities in a simulation modelling process [Paul et al. 2003]. A simulation modelling process should take into account not only the formalities to a feasible level but also allow the modeller to exercise his/her creative abilities. Law and Kelton [2000] is the most popular text for teaching discrete event simulation. Paul et al. [2003] are very critical of the applicability of Law and Kelton's 10 step simulation modelling process in real world simulation practice. The process framework, IMMoS, proposed by Pfahl and Ruhe [2002] also emphasises a very high degree of formalism; binding the simulation modellers too tightly with the process rules and steps. Also Rus et al.'s [2003] process model also suffers with a high level of formalism which may not be appropriate for novices.

2.6. Simulation modelling process for novice software process simulation modellers

Simulation modelling has come into research and practice very recently in software engineering. Therefore, a large number of software process simulation modellers are said to be novices. This section discusses the process of cognitive skills acquisition for a novice to become expert simulation modeller from being a novice. Newell [1980] says that problem-solving is cognitive activity; similarly modelling is aimed at problem solving, therefore it is also a cognitive activity [Wallace and Willemain 1999, Atolagbe et al. 1997]. This section compares the difference of performance between novices and experts and justifies why a disciplined approach for novices in SPSM is particularly needed.

It would be worthwhile to define novice in the context of this research. The Cambridge Advanced Learner's Dictionary [Camb. 2005] defines a novice as "a person who is not experienced in a job or situation". Dictionary.com [Dict. 2005] defines a novice as "a person new to a field or activity; a beginner". Therefore, in our case a novice software process simulation modeller is one who is a beginner or is new to software process simulation whether in an academic situation or in practice.

2.6.1. Anderson's theory of cognitive skills acquisition

Anderson [1982] developed a theory that represents the process of acquisition of cognitive skill in three stages; the declarative stage, the knowledge-compilation stage, and the procedural stage. In the declarative stage, the learner gains information and facts about a skill and develops an understanding to execute certain behaviour. The knowledge-compilation stage is a transitional stage between the declarative and procedural stage that compiles declarative knowledge much like a computer program compilation. In the procedural stage the process of performing tasks based on compiled knowledge become relatively automatic. In the compilation stage; the knowledge acquired in the declarative stage, which is dumped into long-term memory, is needed to be brought into working memory repeatedly in order to reach the procedural stage. The process of bringing information from long-term memory to working memory is slow and most errors in problem solving occur due to working memory errors. Anderson [1982] suggests that this compilation process should be disciplined in order to gain efficiency in human learning and therefore producing high quality solutions efficiently.

2.6.2. Novices vs. Experts

The simulation modelling literature generally does not address the difference between the performance and quality of models produced by novice and expert simulation modellers. However, closely related domains such as conceptual data modelling and computer science report that novices perform badly compared to experts [Batra and Davis 1992, Chaiyasut and Shanks 1994, He et al. 1994]. Venable [1996] says that the data models produced by experts are better quality models with fewer errors, and are more maintainable and cost-effective. Venable [1996] suggests that there is a strong motivation to train novices with the skills of expert modellers so that they can produce models of high quality.

Prince and Hoyt [2002] say that novices in any field go through a long learning curve before they become experts. They produce bad solutions with more errors because of their lack of practical experience and poor skills [Venable 1996, He et al. 1994, Fiebig and Hayes 1996]. Hong and Liu [2003] show that the performance of problem solvers depends on the depth of their thinking. Hong and Liu [2003] conclude from their study that experts think more strategically and deeply while novices tend to use a trial-and-error thinking approach. Kavakli et al. [2001] provide evidence that experts are highly focussed and think in a structured manner; that is why experts show higher productivity and performance as compared to novices whose thinking process is unfocused and unstructured.

2.6.3. Why a simulation modelling process for novices?

Anderson's [1982] theory of acquisition of cognitive skill serves as an input to justify the need of a disciplined framework for novice software process simulation modellers. Novices essentially go through the knowledge-compilation stage (learning curve) to become experts during which they make mistakes and learn from them. Waisel et al. [1999] say that modellers become experts by an intuitive process developed after a long period of trial and error. It can be argued that one of the reasons simulation modellers produce bad models is the skills gap that occurs in the process of becoming an expert from a novice [Willemain 1995]. Atolagbe et al. [1997] say that one of the reason novice simulation modellers produce bad models is that they cannot define and establish the structure of a problem.

Sadowski and Grabau [2000] identify the most common pitfalls in simulation practice due to a lack of understanding and training in simulation methodology. Gass and Joel [1981] say that most models can be considered bad models on the basis that their users do not have confidence in them; the prime reason for this is that the modellers do not provide essential material to make the model credible to their users, which is a weakness of the modelling process. As stated earlier, Landry et al. [1996] say that there are too many simulation models produced but too few used. David [2001] reflects that not having a broader view of model development and implementation, i.e. modelling process for that matter, is one of the reasons that models are not used.

It is very important that novices in SPSM should have essential training and guidelines that are close to real world simulation modelling practice. While there is active research going in general simulation literature aimed at enhancing simulation education and training [Taylor and Siemer 1996, Paul and Taylor 1997, Atolagbe 1999] the software process simulation modelling community lacks in such research and is generally isolated from mainstream simulation community. No research seems to be reported in the software process simulation modelling literature that provides a process framework for novices, synthesised through an empirical investigation of real world simulation practice. One possible solution to decrease the learning curve is to provide them with a disciplined process framework for simulation modelling. Willemain [1995] says that while developing simulation models, experts think beyond what they have been taught in textbooks. In case of novices, Willemain [1995] says:

> *"Most courses focus on the internal plumbing of models much more than on the process of modelling, especially the critical first stages of model development. Once students become practitioners, the same bias makes them less reflective of their own practice, thereby limiting both the range of responses they can generate and their ability to practice continuous improvement."*

Willemain [1995] suggests that developing guidelines for the model development process will help novice software process simulation modellers produce better quality models. As Wallace and Willemain [1999] say:

> *"In order for potential modellers to make the most efficient and effective use of these new technologies, they need to be provided with guidance on how to construct model. This guidance presupposes some formalisation of the process of modelling. Without this formalisation, modelling remains solely an art. Art is traditionally taught in studio like settings, which is not feasible for the number of potential modellers. Therefore we need to understand the process well enough to*

provide, at the very least simple guidelines and easy-to-understand aids for building models."

This is a major shortcoming in the simulation modelling literature that it does not provide novices in SPSM with a disciplined framework that is close to real-world simulation modelling practice. The discussion in this chapter leads me to suggest the objectives of developing a process for novice software process simulation modellers that:

I. is close to real-world simulation practice

II. is independent of a particular simulation technique (i.e. discrete event and system dynamics)

2.7. Conclusion

This chapter has presented an account of the literature reviewed during this research. Abdel-Hamid [1989] developed the first simulation model of software processes in order to understand the dynamics of cost and quality of the software. Since then simulation modelling has been widely applied in various areas of software engineering including strategic management, planning, control and operational management, process improvement, understanding, and training. Discrete event and continuous simulation techniques are the commonly used paradigms in software process simulation modelling.

Despite increasing interest in the simulation modelling of software processes, very little can be found in the SPSM literature about the simulation modelling process itself. Simulation researchers in operational research have reported concerns such as model quality, model confidence, communication, inadequate management and model evaluation, which arise due to the weakness of simulation modelling process. Although the software process simulation modelling literature has not yet reflected on such issues, similar issues are likely to arise in software process simulation modelling.

Simulation modelling is considered largely an individual and artistic activity. The problem with the simulation modelling processes reported in the simulation modelling literature is that they are very formal and are based on personal experiences of the author(s). Secondly, they are mostly aimed for one particular modelling technique.

Simulation modelling has come into research and practice very recently in software engineering. Therefore, a number of software process simulation modellers are said to be novices. The simulation modelling literature in general and the software process simulation modelling literature in particular lacks studies focused towards novice simulation modellers. Research in closely related areas such as conceptual data modelling and computer science show that novices perform significantly worse compared to experts. Studies in psychology and conceptual modelling domains show that novices go through a long and slow learning curve to become experts during which they produce weak solution; however, systemising the learning process for novices may improve efficiency and enable better solutions. Therefore, a disciplined process, developed through an empirical investigation of the practices of expert simulation modellers is likely to help novice simulation modellers to produce better models.

PART II: METHODOLOGY

3. Chapter three: Background to research methodology

3.1. Introduction

This chapter discusses the background to the research methodology employed in this project. The chapter aims to provide a thorough background to my research methods and a justification for employing these methods.

The chapter consists of seven sections. In Section 3.2, I summarise empirical methods in software engineering, a brief discussion on qualitative and quantitative research methods and combining these methods; it also provide a justification as to how these research methods suit for my research problem. Section 3.3 presents a detailed overview of grounded theory, which is the prime research approach used in this project. Section 3.4 reflects on the data collection methods used in this research and their relevance to grounded theory. Section 3.5 reflects on the data analysis methods used in this study. Section 3.6 discusses the importance of piloting the research instrument and why I have piloted the various research instruments used in this project. Finally Section 3.7 concludes the chapter.

3.2. Empirical research

I use empirical research methods in this project to answer my research questions and test the hypothesis. Empirical research is a research activity that uses direct data collection methods to test or explore a real situation. Empirical research derives knowledge from actual events, processes, and objects in order to explain a particular phenomenon or test a hypothesis. Lauer and Asher [1988] define empirical research as:

> *"...the process of developing systematized knowledge gained from observations that are formulated to support insights and generalizations about the phenomena under study"*

Bausell [1986] says that typically empirical research consists of following five steps:

1. Identifying and composing a research question
2. Selecting the participants to answer the research question
3. Deciding on how to use the participants to answer the research question
4. Analysing the results
5. Interpreting and communicating the results

Bausell [1986] emphasises three differentiating characteristics of empirical research:

1. Its verifiable nature
2. Its cumulative nature
3. The finite nature of the resulting product

Empirical research methods have gained increasing interest in software engineering in the last three decades [Jeffery and Scott 2002]. Jeffery and Scott [2002] say that empirical research can be useful for developing sound and practical approaches in software engineering if conducted carefully. Lehman and Belady [1976] say that empirical research methods allow researchers to study, build and verify theories on the basis of observation and understanding obtained through direct data collection. Jeffery and Scott [2002] suggest that empirical research falls into three categories in software engineering:

1. To invent new phenomena
2. To understand existing phenomena
3. To facilitate inspirational education

Jeffery and Scott [2002] say that the empirical research is relevant to develop new phenomena and provide the evidence of their benefits so that the new phenomenon will be adopted in practice; the second category is focused towards industry needs and the third category facilitates advances in software engineering education.

> My research project falls in all three categories as I aim to develop a simulation modelling process by understanding existing practices of expert simulation modellers to facilitate the training of novice software process simulation modellers. For this purpose my research questions aim to explore the contexts and practices of expert simulation in order to develop a simulation modelling process and test the hypothesis that a simulation modelling process can be helpful to novices in SPSM to improve their simulation modelling.

I employ direct data collection techniques which include a survey, interviews and experiments to answer my research questions described in Chapter 1. Black [1999] reflects on the benefit of direct data collection:

> *"Information, knowledge and understanding are gathered through experience and direct data collection."*

Robson [2002] says that direct data collection methods are useful when the researcher wants to find out what people do, feel, and/or believe; to measure their abilities or intelligence. The research methods employed in this project has been used widely and are matured in the social science [Bernard 2000]. Although empirical research is relatively new to software engineering [Jeffery and Scott 2002], it has gained significant recognition because of the complexity of the socio-technical problems in software engineering [Seaman 1999]. Fenton et al. [1994] call for the development of software engineering phenomena backed by evidence of their effectiveness through direct data collection and observations.

3.2.1. Qualitative and quantitative research methods

It is very difficult to draw a clear distinction between qualitative and quantitative research methods, as the nature of the data collected and the way data is interpreted determines whether a research method can be termed as qualitative or quantitative. However, the different objectives of qualitative and quantitative paradigms mean that different data collection and analysis are used. Table 3.1 summarizes the differences between two sets of methods.

Table 3.1: Difference between Qualitative and Quantitative Paradigms [Blaxter 2001]

Qualitative Paradigm	Quantitative Paradigm
1. Concerned with understanding behaviour from actors' own frame of reference	1. Seek the facts/causes of some phenomena
2. Naturalistic and uncontrolled observations	2. Obtrusive and controlled measurement
3. Subjective	3. Objective
4. Grounded, discovery-oriented, exploratory, expansionist, descriptive, inductive	4. Ungrounded, verification-oriented, reductionist, hypothetico-deductive
5. Process Oriented	5. Outcome-oriented
6. Valid: real, rich, deep data	6. Reliable: hard and replicable data
7. Ungeneralisable: single case studies	7. Generalisable: multiple case studies
8. Assume a dynamic reality	8. Assume a stable reality

Blaxter [2001] says that quantitative research aims to seek facts and cause-effect relationships between different factors contributing to some phenomenon. They are typically based on numeric data. However, qualitative data can also be interpreted in a quantitative way [Bryman 1988]. For example, correlating word frequencies in content analysis of text, where the text is qualitative data.

Gilgun [1992] describes qualitative data as data represented in words and figures, while Seaman [1999] says quantitative data is the data represented by numbers or discrete categories.

The following definitions by Punch [1998]] explain the two sets of methods more clearly:

> *"Quantitative research is empirical research where the data are in the form of numbers. Qualitative research is empirical research where the data are not in the form of numbers."*

> *"'Qualitative implies a direct concern with the experience as it is 'lived' or 'felt' or 'undergone'. (In contrast 'quantitative' research, often taken to be the opposite idea, is indirect and abstracts and treats experiences as similar, adding or multiplying them or 'quantifying' them)."*

Seaman [1999] says that qualitative research methods are designed to study human behaviour and perceptions like understanding and communication. The motivation behind qualitative research methods is to study the complexities of human behaviour, a phenomenon that cannot be studied and represented in depth by quantities effectively.

Qualitative researchers are interested in processes, meanings, experiences and structures of the world [Creswell 1994]. Therefore, qualitative research is descriptive and interpretive in the sense that it explores the process, meaning and understanding of the world and explains them [Maxwell 1998].

Creswell [1994] proposes the following characteristics of a qualitative research problem:

- The concept is immature due to a conspicuous lack of theory and previous research
- A need exists to explore and describe the phenomenon and to develop a theory
- The nature of the phenomenon may not be suited to quantitative measurement

My research problem satisfies all three of these criteria. The concept of a modelling process is immature in software process simulation as the available literature does not report the modelling process of the modellers. Rus et al. [2003] say there is a need to migrate software process simulation modelling from craft to engineering and hence models should be developed under a systematic process. For this purpose, I explore the practices of simulation modellers and propose a modelling process on the basis of findings. Moreover, this research aims to explore the habits, behaviour and practices of humans for which quantitative measure are not suitable [Seaman 1999].

Klein and Myers [1999] says that the commonly used qualitative research methods are action research, case study research, ethnography, and grounded theory. I use grounded theory as a core research method in this project. Section 3.2 gives a detailed overview of grounded theory.

3.2.2. Combining the research methods

Seaman [1999] says that qualitative and quantitative research methods are both equally appropriate in the process of providing evidence to answer research questions.

> *Software engineering is intrinsically multidisciplinary and combining qualitative and quantitative research methods in software engineering takes advantage of the strengths of both sets of research methods* [Seaman1999].

Webb et al. [1996] say that scientists may have greater confidence in their conclusions about a research problem if multiple methods of investigation have been employed. Denzin and Lincoln [2003] says that multiple data collection methods, data analysis methods and data sources are combined to gain *triangulation*. In software engineering, a combination of quantitative and qualitative research method has been used in a number of empirical studies [Beecham 2003, Dyba 2000].

Bryman [1988] states that qualitative and quantitative methods can be complimentary to each other. If the researcher does not have in-depth information about the particular domain to formulate a hypothesis, qualitative research methods can be used to derive a hypothesis by studying information-rich data sources [Creswell 1994]. The hypothesis can be then tested using quantitative methods. Qualitative research can also help construct attitude scales and indices for use in quantitative research [Sieber 1973]. Qualitative research can be helpful in validating a quantitative research instrument by intensive interviewing [Belson 1986]. Moreover the availability of qualitative information alongside quantitative data can make it easier to understand and interpret quantitative data [Smith and Robbins 1982].

Similarly quantitative methods can also be used in a complimentary fashion for qualitative research. For example, quantitative data could show interesting trends or discrepancies in a population. A qualitative researcher may use that information to set out an in-depth investigation with the information rich participants of the quantitative study to explore those interesting trends or discrepancies. Kahl [1953] and Reicher and Emler [1986] used such an approach in social science.

A combination of both qualitative and quantitative methods suits the nature of inquiry in software engineering because of its interdisciplinary and socio-technical nature. Although my study is predominantly qualitative, I use some quantitative data collection methods to strengthen the qualitative results. However, my small sample sizes do not allow rigorous statistical analysis. A preliminary survey with software process simulation modellers highlighted the trends within software process simulation community. The results from this preliminary survey indicated that there was a need for an in-depth study of the practices of simulation modellers. The evaluation of the formulated simulation modelling process included both quantitative and qualitative data collection.

3.3. Grounded theory (GT)

> *"A distinction in research is between that which is concerned with verification and that which is concerned with discovery. In the former type, theory serves as a framework to guide verification. In the latter, theory is the 'jottings in margins of ongoing research', a kind of research in which the conclusions are not known before the investigations are carried out."* [Gherardi and Turner 1987, p. 12]

Grounded theory (GT) emerged as a paradigm in the wake of a long-standing debate on the relative reliability and appropriateness of quantitative and qualitative methods. Glaser and Straus [1967] note that quantitative methods were predominantly the methods of choice in social science research and qualitative methods were given low status in the area. A particular issue in social science research at that time was a preoccupation with the quantitative testing of hypothesis/propositions derived from abstract theories whose own basis could be questioned [Locke 2000]. The distinguishing characteristic of GT as against other research approaches is that it is explicitly emergent i.e. it does not test a hypothesis rather the purpose is to develop a theory or hypothesis from the data in the context of a research situation [Glaser and Straus 1967].

Since 1967, GT has been established as one of the core qualitative research methods in the social sciences and there is an increasing interest in grounded theory in management science [Locke 2000] and information systems [Baskerville and Pries-Heje 1999]. Haig [1995] says, "*It is currently the most comprehensive qualitative research methodology available*".

Strauss and Corbin [1990] say that a GT research project does not begin with a theory to seek proof; rather it begins with a certain study area to discover a theory relevant to that area. This means that qualitative data is obtained systematically through different data sources and analysed in a way that theory emerges from any kind of qualitative data such as talk, text, video, fieldwork notes, etc.

Glaser and Straus [1967] say that theory is generated by an iterative process involving the theoretical sampling of data gathered through various sources, establishing a category system and a method of constant comparison of data sets. In GT, the boundaries between data collection and data analysis are not defined. Data is collected and analysed simultaneously in an iterative fashion. As Pidgeon [1996] says:

> *"Taken together, the commitments of constant comparison and theoretical sampling involve the researcher in a highly interactive and iterative process in which the traditional distinction between the data collection phase and the data analysis phase of a project often breaks down."*

Haig [1995] says that a grounded theory is one that is:

1. Inductively derived from data
2. Subjected to theoretical elaboration
3. Judged adequate to its domain with respect to a number of evaluative criteria

Pidgeon [1996] says that:

> *"This leads to a model of research that that is flexible, that is carried out in everyday contexts and that has as its goal the (co-)construction of participants' symbolic worlds and social realities."*

Since the first elaboration of grounded theory, Glaser and Strauss have developed two different approaches to the methodology. Strauss and Corbin [1990] developed very detailed procedural guidelines for novice GT researchers to implement GT in practice. Whereas Glaser [1978] further expanded on the original work and claims to be true to the original approach of GT [Bryant 2002]. Glaser [1992] criticises Straus and Corbin [1990] that by setting out concrete procedures for grounded theory, their approach is said be forcing the theory from data and is therefore not a true grounded theory approach. However, in the second edition of Strauss and Corbin [1998], Strauss and Corbin react to Glaser's criticism and warn the reader that these procedures should be taken just as heuristics rather than rigid implementation guidelines. Babchuk [1997] believes that the researcher may decide on one approach between Glaser or Strauss to follow. Heath and Cowley [2004] say that Strauss and Corbin's [1998] approach is more feasible for a novice GT researcher because of the more detailed procedures for conducting the grounded theory research. This project follows Strauss and Corbin's [1998] version of GT.

3.3.1. Theoretical sampling

The sampling strategy to be employed in a research project is affected by many factors such as, the nature of the study, type of data a researcher is looking to collect, accessibility of the population, and time and resources constraints.

The selection of sampling method depends on the aim and nature of the investigation. Sampling decisions are affected by the objective of covering the *width* and/or *depth* of a certain field [Flick 2002]. Theoretical sampling is the core principle of GT research. Theoretical sampling works as a driving factor to the progress of a GT research project.

This is to access the data relevant to the research question. Glaser and Straus [1967] define theoretical sampling as following:

> *"Theoretical sampling is the process of data collection for generating theory whereby the analyst jointly collects, codes and analyse his data and decides what data to collect next and where to find them, in order to his theory as it emerges."*

Initially the researcher starts with a problem area and looks for relevant concepts possibly through different data sources. The researcher identifies data sources depending on his/her knowledge and understanding of the problem area. These initial data sources can be literature, information databases, interviewing, or observations [Strauss and Corbin 1998]. As Glaser and Straus [1967] put it:

> *"The initial decisions for theoretical collection of data are based only on general sociological perspective and on a general subject or problem area."*

The researcher gains an abstract understanding of the problem area and develops a loosely defined framework of relevant concepts to progress the research. This process corresponds to 'open coding', where the researcher looks for concepts with an open mind; open coding will be discussed later in this chapter. Therefore, initial data analysis shapes the continuing data collection. Glaser and Strauss [1967] say that:

> *"The sociologist may begin the research with a partial framework of local concepts, designating a few principles or gross features of the structure and processes in the situation that he will study."*

Because the process of data collection and data analysis overlap in grounded theory research, the researcher's decision to collect data is driven by the emergent framework of ideas. Glaser and Strauss [1967] say:

> *"The process of data collection is controlled by the emerging theory, whether substantive or formal."*

The emergent theoretical framework allows the researcher to decide on the data sources to get in-depth insights into the problem area. The researcher will select information-rich data sources which can help further explain the emergent theoretical framework. As Strauss and Corbin [1998] state:

> *"Data gathering driven by concepts derived from the evolving theory and based on the concept of making comparison, whose purpose is to go to places, people, or events that will maximise opportunities to discover variations among concepts and to densify categories in terms of their properties and dimensions."*

As a qualitative paradigm, grounded theory uses non-random sampling. Theoretical sampling defines the selection process of sources (interview participants in this case) for data collection and sampling continues until a theoretical framework emerges and categories are saturated due to repetitions of concepts. Therefore, Baker et al. [1992] say that the selection of participants is driven by emerging theory/hypothesis and the sample size is driven by theoretical completeness (saturation of concepts). Cutcliffe [2000], however, says that establishing a distinction between theoretical sampling and purposeful sampling is difficult. Cutcliffe [2000] says, 'purposeful sampling involves the calculated decision to sample a specific locale according to a preconceived but reasonable set of dimensions. In contrast, theoretical sampling has no such calculated initial decisions. The grounded theory researcher seeks further interviewees/sources of data in order to add to the fullness of the understanding of the concept'. However, even if sampling is driven by the emerging concepts, the sampling can still be termed as purposeful i.e. *purpose* is to select the participant/data source which can provide deep insights in order to saturate the concept. Therefore, Patton [1990] argues that all non-random sampling methods can be considered purposeful. Considering this my sampling method for interview participants can be viewed as either purposeful or theoretical, however, I prefer to use the term 'theoretical sampling' in order to maintain grounded theory tradition.

Cutcliffe [2000] says that an issue in sampling that deserves attention is the decision as to whether a sample should be a broad and diverse sample or a focused and narrow sample. Glaser and Straus [1967] note that there are three basic questions a researcher must consider during theoretical sampling to select data sources:

1. What groups or sub-groups does one turn to next in data collection?

2. For what purpose are groups or sub-groups to be selected?

3. How should one select the participants?

As grounded theory method emphasises choosing comparative groups for data collection in order to discover a theory or hypothesis general to the problem area and cover a wider context; I have studied two closely related but diverse groups of simulation modellers.

3.3.2. Place of literature in grounded theory

There are varying notions as to the way the literature should be used in grounded theory research. Various researchers have argued that a literature review prior to data collection should be not be conducted in order to avoid pre-conceptions so that the theory should emerge from the data rather than pre-conceived ideas of the researchers [Hickey 1997, Lincoln and Guba 1985, Stern 1980]. Hutchinson [1993] takes a different view, arguing that a literature review prior to data collection is perfectly feasible; however, the aim of such a literature review should be to identify current gaps in the knowledge and rationalise the proposed research.

Cutcliffe [2000] says that these two differing points of views, perhaps, can be explained by noting that first view is taken by those people who are in a position to say, "*We already recognise that there is a distinct dearth or even absence of knowledge concerning the phenomenon, and therefore have already decided that a grounded theory method would be suitable*"; while the second view can be explained by noting that they are the people in a position to say, "*What do we know about this phenomenon?*". Therefore, Cutcliffe [2000] argues that under these considerations both arguments are valid, because the first view fits the people who already have obtained necessary knowledge through prior experience or background; whereas the second view fits the people who are on a learning curve to understand the phenomenon and then further explore it. Cutcliffe [2000] further argues that many proposed research questions, especially in doctoral studies, require conceptual clarity; reading closely relevant literature is likely to induce conceptual clarity and help decide upon the key research areas to be explored. Therefore I conducted an initial literature analysis to construct an objective conceptual framework within which I further explored the phenomenon. Heath and Cowley [2004] follow a similar approach for their grounded theory project in nursing research. Pandit [1996] also uses a similar approach in a grounded theory project to devise strategies for corporate turn-around.

3.3.3. Evaluating the outcome of grounded theory research

Originally Glaser and Strauss [1967] describe two aspects of evaluating the theory generated through this approach. One aspect is said to be internal validity, which is relevant to the internal process of validating outcome of GT research; and the other aspect serves to conduct external validity, which relates to evaluating the outcome of GT research project as a whole.

Internal validity is conveyed through a rigorous reflection on the theory generation process; Glaser and Strauss [1967] do not discuss in detail how to assess the internal validity of the theory. However, Strauss and Corbin [1998] detail more rigorous guidelines for this purpose. Strauss and Corbin [1998] say that these criteria should not be treated as rigid procedures to evaluate the grounded theory because they may not be applicable to every research project. Strauss and Corbin's [1998] criteria to evaluate the research process include how the sample was selected, what categories emerged, evidence supporting the categories, how the categories guided the theoretical sampling, and how the categories emerged.

External validity can be assessed by following four criteria as discussed in Glaser and Strauss [1967]:

Fitness: The generated theory should be carefully derived from the diverse data and should fit the phenomenon. The categories within the theory must directly relate to the data. The question to be asked is; does the theory fit the substantive area in which it will be used?

Understanding: The generated theory should provide understanding, and it should be understandable to the expert and the layman[1] in that particular area. The theory should be able to explain and interpret what is taking place within the context of the theory. The question to be asked is; is the theory readily understandable by laymen concerned with the area?

Generality: The theory should provide generality of scope; it should be abstract enough to be applicable to a wide variety of contexts. The question to be asked is; is the theory sufficiently general to be applicable to a multitude of diverse everyday situations within the area?

Control (modifiability): It should provide control to its audience; it should state under which condition the theory applies and how it can be modified for a new situation. Given that the social world is constantly changing, the theory must be adaptable and modifiable. The question to be asked is; does the theory allow the user partial control over the structure and process of daily situations as they change through time?

3.4. Data collection methods

I have employed a number of direct data collection techniques, which include a survey, interviews and experiments. Grounded theory allows a wide range of data collection methods. However, interviews are the most predominant and discussed data collection tool in grounded theory literature. This section presents a background to each of these methods.

3.4.1. Survey

I conducted a preliminary survey to investigate the practices of software process simulation modellers. The aim of this survey was to further conceptualise the problem area. This survey was built upon the themes identified from simulation modelling literature.

[1] Someone who does not have much knowledge of the field or is new to the field.

Questionnaire surveys are a well known data collection technique. They are most appropriate when the researcher wants to collect objective data from a large sample and generalise the results to a population [Bryman 1988].

> *Survey research is the method of collecting information by asking a set of pre-formulated questions in predetermined sequence in a structured questionnaire to a sample of individuals drawn so as to be representative of a defined population* [Hutton1990].

Researchers identify various advantages and disadvantages of survey research. The advantages of survey research are:

- All participants are presented with same set of questions; therefore, homogeneity in response is possible [Oppenheim 1992].
- Survey research allows the generalisation of the results to the wider population [Oppenheim 1992].
- Questionnaire surveys are impersonal in nature; therefore, the respondent is not directly affected by researcher's attitude or vice versa as it happens in interviews [Bernard 2000].
- A large sample can be accessed with relatively low resources [Hague 1993].
- They can be administered from a remote location using mail, email or telephone [Fowler 1993].

The disadvantages of survey research are:

- The data provides snapshots of points in time rather than a focus on the underlying processes and changes. Therefore, it is difficult to find out the *how* and *why* aspects of events and processes [Blaxter 2001].

- The researcher is often not in a position to check first-hand the understanding of the respondent to the questions asked. Issues of truthfulness and accuracy are thereby raised [Blaxter 2001].

- The survey relies on breadth rather than depth for its validity. This is a crucial issue for small-scale surveys because rigorous statistical analysis is not possible on the results [Blaxter 2001].

- Survey research is inflexible in terms of design. The design has to be same throughout the study in order to ensure reliability [Oppenheim 1992].

- The ways in which questions are framed and answers classified can be subjective and introduce biases [Oppenheim 1992]

Sampling is perhaps the most critical issue in survey research. Belson [1986] says that random sampling is required for data collection in surveys where the aim of study is to generalise results to a population. Bernard [2000] says that if a sampling frame is not available, non-random sampling can also be used in surveys; this limits the generalisability of results to the population, however, it can be useful to understand trends and attitude within the population.

Reponses rate is another critical issue in survey research. Hague [1993] says that the generalisability of survey results depends on the representativeness of the sample which in turn depends on the appropriateness of the response rate. However, there seems to be no agreement between researchers about the appropriateness of response rate [Bernard 2000]. Hague [1993] says that a response rate between 60 to 80 percent should be considered appropriate. Oppenheim [1992] says typical response rate in surveys is between 30 to 40 percent. However, Fowler [1992] says that a high response rate is no guarantee to the reliability of results; he says that studies even with 70 percent response rates may have errors. Punch [2003] says that response rate in a survey can be increased by administrative procedures and good questionnaire design.

3.4.2. Interviews

Interviewing is a powerful tool to find out people's opinions about certain issues. Qualitative interviews explore specific topics, events, cultures, meaning, processes, social interactions and behaviour, personal habits and political or social phenomena [Rubin & Rubin 1995]. There are two basic types of interviews; informal and formal interviews [Oppenheim 1992].

3.4.2.1. Informal Interviews

There can be certain situations where informal interviewing is the only way to gather data. Informal interviews do not have structure or control and cannot be recorded in most situations [Bernard 2000]. The researcher just goes into the field and asks questions informally, and relies on his/her memory for the analysis. Informal interviewing is the method most common in ethnography [Bernard 2000]. For example Connolly [1990] studied street children's behaviour in Guatemala by living and hanging out with them and asking them questions informally. Although grounded theory allows a wide range of data collection methods [Glaser and Strauss 1967], informal interviewing is not suitable for my research because I needed to have a rich data set consisting of interview transcripts and notes. Moreover, my research situation allowed formal interviewing.

3.4.2.2. Formal Interviews

Where a researcher wants to have a certain level of control, formal interviewing is the method of choice. In a formal interview both researcher and participant know that they are going through an interview process. They agree a time and place in advance and the interviews can be conducted face-to-face, by telephone or in a group. There are three broad categories of formal interviews unstructured, semi-structured and structured interviews [Bernard 2000]. Each type of interview has its own advantages and disadvantages.

Unstructured Interviews

In an unstructured interviews, the interviewer has a clear plan in mind but controls the conversation less [Bernard 2000]. The interviewer lets the interviewee lead the conversation. The basic idea behind this is to let the interviewee express himself/herself. Seaman [1999] considers the interviewee as source of both questions and answers in an unstructured interview. Unstructured interviews are conducted when researchers have quite a lot of time and there is a possibility of interviewing the same person again [Bernard 2000]. Questions in this type of interview are mostly open-ended [Seaman 1999]. This type of interview may be used to develop formal guides for semi-structured and structured interviews [Bernard 2000]. Unstructured interviews are also effective at building an initial rapport with the interviewee [Maxwell 1998]. This approach is not feasible for my study, as I have specific, though open ended research questions. I am not 'particularly' looking for new ideas rather I want to find out more about some existing ideas.

Structured Interviews

In a structured interview all interviewees are asked the same questions [Bernard 2000]. Seaman [1999] says that in a real structured interview no qualitative information is taken at all. However, in a qualitative study researchers are interested in collecting unanticipated information. A structured interview does not allow the interviewer to ask for explanation or further questions [Belson 1986].

Answers in structured interviews are quantifiable (e.g. yes, no, agree, disagree etc.) [Seaman 1999]. This interviewing approach is not feasible for my study as I want to explore the *what, why* and *how* aspects of the practices of simulation modellers.

Semi-Structured interviews

Semi-structured interviews are a mix of structured and unstructured interviews. Normally such interviews are conducted when there is less opportunity to interview the same person again [Bernard 2000]. In semi-structured interviews, the interviewer has a clear plan in mind along with a list of questions and topics that are to be covered [Bernard

2000]. Either the interviewer or interviewee can take the lead depending on the type of question being asked [Rubin and Rubin 1995]. However, the interviewer needs to be cautious as the lead may be taken totally by the interviewee and the interview may take an inappropriate direction [Rubin and Rubin 1995].

Semi-structured interviews are the most common qualitative interviewing approach [Bernard 2000]. In semi-structured interviews, interviewers can ask predefined questions and the discussion may lead to new questions relevant to the topic. This approach is helpful in avoiding pre-judgements [Walsh 2001] and hence minimizes the researcher's own bias to lead the interview in the wrong direction. Semi-structured interviews are most suited to my research because I have a clear framework of ideas to explore and investigate relevant concepts.

3.4.2.3. Interviewing administration

Commonly used administration techniques are:

1. Face-to-face interviews
2. Telephone interviews

In social science research, telephone interviewing has historically been considered a poor technique [Bernard 2000]. However, Taylor [1997] showed that telephone interviewing can be used effectively to conduct surveys of the general public, whether for commercial clients or for public opinion research. Dillman [1978] shows that the data collected in a telephone interview can be as valid as the data collected in a face-to-face interview. However, within software engineering research, I could find no examples of qualitative interviews by telephone. There are advantages and disadvantages to both techniques. Table 3.2 summarises the advantages and disadvantages of face-to-face interviews. Table 3.3 summarises the relevant advantages and disadvantages of telephone interviews.

Table 3.2: Advantages and disadvantages of face-to-face interviews (Bernard [2000])

Advantages	Disadvantages
1. A question can be clarified more effectively	1. Requires good skills to administrate
2. Other data collection techniques can be used, like visual aids, graphs, cue cards can be used.	2. Costly both in terms of time and money
3. Provides sufficient time to interview.	3. Less number of people is accessible
4. More effectively communication like use of body language and gestures.	4. Face-to-face interviews are very time consuming.

Table 3.3: Advantages and disadvantages of telephone interviews (Bernard [2000])

Advantages	Disadvantages
1. Impersonal quality of self administered questionnaire and personal quality of face-to-face interview	1. Interviewer does not know who she is talking to.
2. Inexpensive and convenient to conduct	2. Some interviewee may not feel comfortable with long conversation on phone.
3. Less administration overheads and saves time.	3. In long interview, interviewee may tend to do other things while on the phone and loose concentration.
	4. Both interviewer and interviewee cannot see the gestures and body language.

3.4.3. Experiments

Grounded theory proposes that the results of a GT project should be understandable to the layman in the field and that it should fit the phenomenon. I have conducted controlled experiments with novice software process simulation modellers to evaluate the RSMP; this provides indication whether the RSMP is understandable by the laymen in the field and it fits in the domain of software process simulation modelling.

In controlled experiments the subjects are divided into two (or more) groups; one group, which is given some treatment, such as some training, enhanced exposure, or knowledge, is called the treatment group; and the other group, which is not given any treatment is called the control group [Bernard 2000]. The two groups are then exposed to the same experimental conditions and their performance is observed and later compared.

Tichy [1998] complains that Computer Scientists usually avoid experimentation for testing their theories. He argues that experimentation is a good tool for providing evidence in support of a theory and making it acceptable to the community. Kitchenham et al. [2002] emphasise the importance of rigorous experimentation for empirical software engineering research.

Bernard [2000] classifies experiments into laboratory experiments and field experiments in terms of where they are conducted. Patton [1990] says that laboratory experiments can test and clarify theories about how things work in the real world. Laboratory experiments provide greater control on the experimental parameters and protocol, whereas, field experiments are said to provide greater realism [Creswell 1994].

The aim of my experiments is to answer the research question relevant to the evaluation of the RSMP. I have conducted laboratory experiments to gain a greater control; because the performance of the subjects had to be measured under certain experimental conditions and compared so as to identify difference in their performances.

Threats to the validity of experiments

Campbell and Stanley [1963] identify some common threats to experimental validity in controlled experiments as following.

- All subjects, in both control and treatment groups should be exposed to the same experimental setting. A change in the experimental setting e.g. some external disturbance, power cuts, or technical problems may affect the responses of the subjects.

- Selection of subjects is a major threat to the validity of experiments. If the results from the experimental study are to be generalised to a population, the selection of subjects must be random.

- There is a possibility that subjects in a control group or treatment group may get more experienced over a period of time. This may introduce an imbalance between the characteristics of the two groups.

- Diffusion of treatment is a threat to validity when there is a chance that the control group may also get the treatment which was actually intended for the treatment group.

3.4.4. Expert panel questionnaire

Another dimension to validating a theory generated through the grounded theory approach is that it should be understandable and verifiable by the experts in that field. I conducted an expert panel evaluation of the RSMP to satisfy the validity requirements of grounded theory.

The basic motivation behind using experts for the evaluation and improvement of the RSMP is that they have relevant in-depth experience of and insights into the simulation modelling process. According to Kelly [1955], the way humans look at things, answer a question or anticipate future events depends on their personal mental constructs developed through previous experiences. In other words they act on a mental model of a phenomenon which has been developed based on their past experiences [Rosqvist 2003]. Kelly suggests that based on these mental models humans can approach reality in a hypothetical manner. Kenny [1984] suggests that having a mental model of past experiences, we are in a position to predict future events when provided with hypothetical conditions. Burke [1966] argues that mental constructs based on past experiences and observations influence our perceptions of reality. Therefore, it can be argued that expert simulation modellers, based on their experience are in a position to evaluate the RSMP and recommend improvements.

In software engineering, expert panel evaluation has been used very successfully in the past. Very recently, Beecham et al. (2005) used a panel of 20 experts to conduct an evaluation of a requirements process improvement model. Rosqvist [2003] presents and discusses the effectiveness of expert judgement for software quality evaluation. Dyba [2000] used 11 experts to conduct a review of the key success factors in software process improvement. El Emam and Madhavji [1996] used 30 experts to evaluate the success of a requirements engineering process in information systems development. Lauesen and Vinter [2001] report on the usefulness of subjective judgements by a group of 3 experts for defect prevention. A study of software project effort estimation by Kitchenham et al. [2002] shows the effectiveness of a human-centred estimation process over function point based estimation models. The above mentioned studies show the effectiveness of expert based evaluation and estimation.

3.4.5. Questionnaire design

Various questionnaires have been designed and distributed to the participants in this study. Therefore, it is important to reflect on the questionnaire design. The questionnaire is a popular and useful data collection tool used in surveys, interviews and experiments. Questions in a questionnaire can be asked in different modes, such as face-to-face, telephone, mail, or email, depending on the study design.

Researchers believe that questionnaire design not only affects reliability of the study but also response rate.

Hague [1993] says that the first step in questionnaire design is to decide the types of questions to be asked. Hague [1993] divides questions into three type; behavioural, attitudinal and classification. Behavioural questions uncover factual information from the respondents such as what they do, what they have etc. Attitudinal questions discover people's perceptions about something or some phenomenon. Classification questions provide information that helps classify respondent into groups based on different characteristics such as age, gender, experience, location etc.

Questionnaires may have closed or open questions depending on the type of data to be collected. If the aim is find out trends in a population and generalise the results, closed questions are appropriate [De Vaus 1996]. If the aim is to get deep insights into some event, phenomenon or process, open questions are most appropriate [Bernard 2000]. Closed questions are most commonly used in quantitative studies and open questions are most popular in qualitative studies [Walsh 2001].

The type of data to be collected is a crucial decision. Open questions normally provide qualitative data; and data is analysed by identifying themes and interpreting and relating them with each other. Closed questions give data which are quantifiable. The researcher may provide the respondents with a variety of ways the questions can be answered, such as scales, yes or no option, multiple choices, etc. the choices of analysis methods for quantitative data largely depend on the type of collected data e.g. ordinal, interval or continuous data. For example, parametric analysis can be performed on interval or continuous data, while non-parametric analysis can be performed on ordinal data [Field 2000].

The wording of the questions is believed to have effect on the reliability of response and also the response rate [Fowler 1992]. Belson [1986] suggests that question wording should be understandable to the respondents and should relate to their cultural and linguistic domain; moreover careful wording is very important to remove biases of the researchers.

Consistency and coherence in the questions arrangement and wording is another aspect to be taken care of in a questionnaire design. Oppenheim [1992] stresses that questions should be arranged in a logical order and wording should be consistent, so that the respondents can have a coherent view of the questionnaire.

3.5. Data analysis

3.5.1. Qualitative data analysis in grounded theory

Grounded theory defines a rigorous approach for analysing qualitative data based on a constant comparative method. This section describes the constant comparison method, coding principles, and steps for category building.

3.5.1.1. Constant comparative method

Pidgeon [1996] says that throughout a GT research project life, a principal analytical task of the researcher is the continuous comparison of data elements, such as basic data instances, emergent categories and theoretical propositions. Each subsequent data collection is readily analysed and categorised to compare with the earlier categorised data. This task of constant comparison during GT research enables the researcher to select the future data sources.

Glaser and Strauss [1967] say that the discovery of the grounded theory in the data is accomplished with a comparative analysis of categorical data collected from two or more comparative groups of data sources. The selection of comparative groups is based on similarities and differences between them. They should have enough in common as well as vital differences that make them distinct [Glaser and Strauss 1967]. However, their differences should not be so large that the data collected from them cannot be analysed comparatively. Glaser and Strauss [1967] give a number of reasons to collect data from comparative groups:

- Comparative groups allow the generalisation of categories of collected data
- Different data can be collected under the same category or issue
- Similarities and differences of data under the same category can be studied
- The scope of the results is broadened

Once the data has been collected from comparative groups and categorised accordingly, both qualitative and quantitative analysis can be performed on it.

Glaser and Straus [1967] say that with this constant comparison of data

> *"[the constant comparison method] starts to generate theoretical properties of the category. The analyst starts thinking in terms of the full range of type or continua of the category, its dimensions, the conditions under which it is pronounced or minimised, its major consequences, its relation to other categories, and its other properties."*

3.5.1.2. Coding

Straus and Corbin [1998] say that in GT research, analysis is conducted by developing a theoretical framework in a category system in which categories (themes or concepts) are interrelated through well-defined statements of relationship; where this theoretical framework explains some relevant social, psychological, educational, or other phenomenon. Coding is the analytical process by which data are broken down, conceptualised and put together in an integrated manner to formulate theory.

Denzin and Lincoln [2003] define themes as abstract or fuzzy constructs which are identified before, during and after data collection. In qualitative research, themes can be identified inductively or deductively depending on the nature of the study [Bernard 1990].

Grounded theory aims to generate theory and so the emphasis is to identify themes using an inductive procedure [Bernard 1990]. Grounded theorists suggest a careful line by line reading of text and marking important concepts and putting similar concepts together. In Content analysis on the other hand, where the aim is to test an existing hypothesis, a deductive procedure is used for themes identification [Bernard 2000, Kripendorff 1980]. Patton [1990] says that in content analysis, the focus of analysis and hence themes come from the research hypothesis identified at the beginning of the study.

Grounded theorists look for concepts with an open mind and every new theme identified is noted down and establishes a category system i.e. an inductive approach is employed for themes identification. In other approaches such as content analysis or correspondence analysis, the researcher looks for themes helpful to proving or disproving hypothesis and establishing a category system i.e. a deductive approach to theme identification. Pidgeon [1996] stresses this fundamental difference between content analysis and grounded theory; otherwise grounded theory research will become merely a hypothetico-deductive endeavour like content analysis.

Once the themes have been identified from textual data, the next step is to develop a codebook. A codebook is an organised list of codes associated with a particular theme [Denzin and Lincoln 2003]. A codebook contains a description of each code, the word or phrase, and examples of typical real text occurring in the textual data [Bernard 2000, Weber 1990, Krippendorff 1990]. The codes can be numerical or abbreviations of a particular theme [Bernard 2000]. Bernard [2000] suggests that the number of codes for a particular analysis should be within feasible boundaries so that analysis of the data can be performed conveniently and effectively

Once the codebook has been constructed, the next step is to mark units of text with particular codes [Denzin and Lincoln 2003]. Codes can be associated or tagged with words, phrases, paragraphs, documents, persons, events, and/or processes etc. in data [Bernard 2000]. These codes act as values associated with particular themes occurring in the text and make it easier for the researcher to refer to them when needed [Denzin and Lincoln 2003].

Strauss and Corbin [1998] define three different types of coding procedures; open coding, axial coding, and selective coding.

I. Open coding

Strauss and Corbin [1998] say that open coding is the process of applying the analytical strength of a researcher to the data to identify the thoughts, ideas and meanings contained in their properties and dimensions. These concepts are abstract constructs which represent some event, object or action.

Open coding is an inductive process in which the researcher looks for concepts with an open mind. Every 'new' identified concept forms a new category. The emphasis is on the breadth of categories. As Strauss and Corbin [1998] say:

> *"We want to see new possibilities in phenomenon and classify them in ways that others might not have thought of before (or, if considered previously, were not systematically developed in terms of their properties and dimensions)."*

The categories should be named or given codes and described what is represented by each category [Strauss and Corbin 1998]. Similar concepts are gathered under one category. For this purpose, identified concepts are compared and therefore the concepts having similar properties are brought together under one category.

Goed and De Villiers [2003] say that categories can also be identified from literature; however, they should be treated as temporary until they can be verified from the data.

Goed and De Villiers [2003] also say that the dimension of a concept represent the location of property along a continuum or range. For example, the dimension for height property can be between short and tall. Categories can be broken down into sub-categories on the basis of properties and dimensions.

II. Axial coding

Axial coding is the process of interrelating categories to their sub-categories. Axial coding puts together the data fractured in open coding establishing connections between categories and sub-categories. Therefore axial coding is actually a process of developing a structure of main categories and sub-categories [Pidgeon 1996].

III. Selective coding

Selective coding is the process of integrating the categories and sub-categories which were established in open coding and axial coding. Strauss and Corbin [1998] say that following the constant comparison method, the researcher breaks down the data through open coding and then assembles the data through axial coding; during this process a core category should emerge with high frequency of mention (explicitly or implicitly), and will be connected to other categories. This is the core category.

Strauss and Corbin [1998] give guidelines to selecting a core category:

- It must be central; that is, all other major categories can be related to it.
- It must appear frequently in the data. This means that within all or almost all cases, there are indicators pointing to that concept.
- The explanation that evolves by relating the categories is logical and consistent. There is no forcing of data.
- The name or phrase used to describe the central category should be sufficiently abstract that it can be used to do research in other substantive areas, leading to the development of a more general theory.
- As the concept is refined analytically through integration with other concepts, the theory grows in depth and explanatory power.
- The concept is able to explain variation as well as the main point made by the data; that is, when conditions vary, the explanations still holds, although the way in which a phenomenon is expressed might look somewhat different. One also should be able to explain contradictory or alternative cases in terms of the core category.

3.5.2. Quantitative data analysis

3.5.2.1. Cohen's kappa measurement of agreement

I use Cohen's kappa measurement of agreement to test the reliability of coding system established for the interview data. An Inter-coder reliability test is used to gain a level of confidence as to whether the coding scheme for qualitative data established by one researcher matches with another researcher's results [Burnard 1991]. Cohen's Kappa statistic is commonly used to check this inter-coder reliability. The *"Kappa statistic measures how much better than chance the agreement is between a pair of coders on the presence or absence of binary (yes/no) themes in texts"* [Bernard 2000].

Landis and Koch [1977] outline the strength of agreement depending on the k value obtained from a Cohen's kappa test as shown in Table 3.4.

Table 3.4: Cohen's kappa agreement benchmarks

'*k*' value	*Strength of agreement*
0.00	Poor
0.01 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost perfect

A kappa value of 0.7 is acceptable to most researchers [Bernard 2000]. However, some researchers such as Krippendorrf [1980] consider 0.80 a reliable value for Kappa agreement. Researchers therefore have differing notions as to the value to Cohen's kappa agreement for inter-coder reliability; Dunn [1989] says that any k value to assess inter-coder reliability is subjective. However, Cohen kappa statistics can be used to strengthen the confidence to the reliability of a coding scheme.

3.5.2.2. Spearman's Rho test for correlation

I use Spearman's Rho test to determine correlation between variables in my survey. Spearman's Rho test for correlation is a non-parametric test, used to determine the correlation between two variables. If the scales are ordinal, Spearman's test provides proper measures of correlation between two variables [De Vaus 1996]. The relationship between two variable will be statistically significant if correlation value is less than 0.05 [Field 2000].

3.5.2.3. *t*-test for statistical significance

I use a *t*-test to compare the performance of different subjects in the experiments. The *t*-test is a parametric test used to determine the significance of difference between means of two data sets [Field 2000]. It is used to determine whether the difference of performance between two groups or observation is by chance. An independent *t*-test is used when the researcher wants to compare means from two independent groups of subjects [Brace et al. 2003]. In contrast to that, the paired t-test is used if a researcher wants to compare means of two sets of observation coming from the same groups of subjects. If the significance value of the t-test is less than 0.05, this indicates that the difference between two sets of observations is statistically significant; which implies that difference of performance between two groups or two observations is not by chance.

3.6. Piloting the research instrument

I have conducted pilot studies of all the research instruments used in this project. Piloting a research instrument is very important; because in any study, it is hard to be sure that the research instruments prepared to conduct the study are appropriate. Moreover it is hard to say with confidence that the participants in a survey or interview will give the intended information unless the questions are fully tested. Similarly, in experiments, the researchers may collect unnecessary or inappropriate data if the research instrument has not been tested adequately. Piloting is a commonly used tool to enhance the reliability of research instruments. A pilot study is defined as, "*A small scale version of the real thing, a try-out of what you propose so its feasibility can be checked*" [Robson 2002].

Piloting is important in all area of research for instrument validation. Researchers emphasise that conducting a pilot study prior to the real study avoids ambiguities and technical errors. It is very easy for a participant to misunderstand or misinterpret the interview questions [Belson 1986]. Moreover, a researcher's bias, lack of training and experience, unfamiliarity with participants' background and many other factors may introduce erroneous, badly structured, poorly worded and ambiguous questions [Oppenheim 1992]. Piloting helps to avoid such a situation. Berry and Jeffery [2000] discuss the piloting that helped them improve the validity of their research instrument for assessing software measurement programs. Dyba [2000] also reports the usefulness of piloting his instrument for measuring the key factors of success in software process improvement. Piloting is also helpful in estimating the time and budget required for the actual study [Bourque & Fielder 2003].

3.7. Conclusion

In this chapter I have given a background description to the methods employed in this research. I have discussed the importance of empirical research and its use in software engineering. I have also given a brief discussion of qualitative and quantitative methods and their relevance to my research. I have discussed the principles of grounded theory in detail and how it is implemented. Moreover, I have presented a background to the data collection and analysis methods and their relevance to grounded theory methods.

In the Chapter 4, I describe my research strategy; and how I have executed my research strategy in the context of research methods discussed in this chapter.

4. Chapter four: Research strategy and execution

4.1. Introduction

This chapter reports on the strategy and implementation of the research in the context of the research methodology discussed in chapter 3. As Glaser and Strauss [1967] say, the goal of a grounded theory project is to develop a hypothesis from systematically collected data rather than to collect data in order to test a hypothesis; the goal of this research project is to develop a simulation modelling process that closely matches the practices of simulation modellers and is grounded in the data collected from them. A grounded theory approach is suited for my research.

In this chapter I present my research strategy and how I have executed it. I also report on each of the research instruments used during different phases of this research.

Section 4.2 gives an overview of the research strategy. Section 4.3 discusses the conceptualisation phase of the research strategy, which is the first phase. Section 4.4 discusses the formulation of the RSMP, which is the second phase of the research strategy. Section 4.5 discusses evaluation of the RSMP, which is the third phase of the research strategy. Finally Section 4.6 presents an overall summary of the research strategy and implementation.

4.2. Research strategy

To understand the research process, this project can be divided into three phases; namely 'conceptualisation', 'formulating the RSMP', and 'evaluating the RSMP'. Figure 4.1 graphically represents each phase. Table 4.1 summarises each phase, its activities and the rationale to those activities.

The first phase, 'conceptualisation', encompasses the activities employed to determine the research questions and hence define the areas of interest to be explored in the subsequent research phase. The conceptualisation phase largely consists of literature analysis and a questionnaire survey.

Figure 4.1: Three phases of research strategy

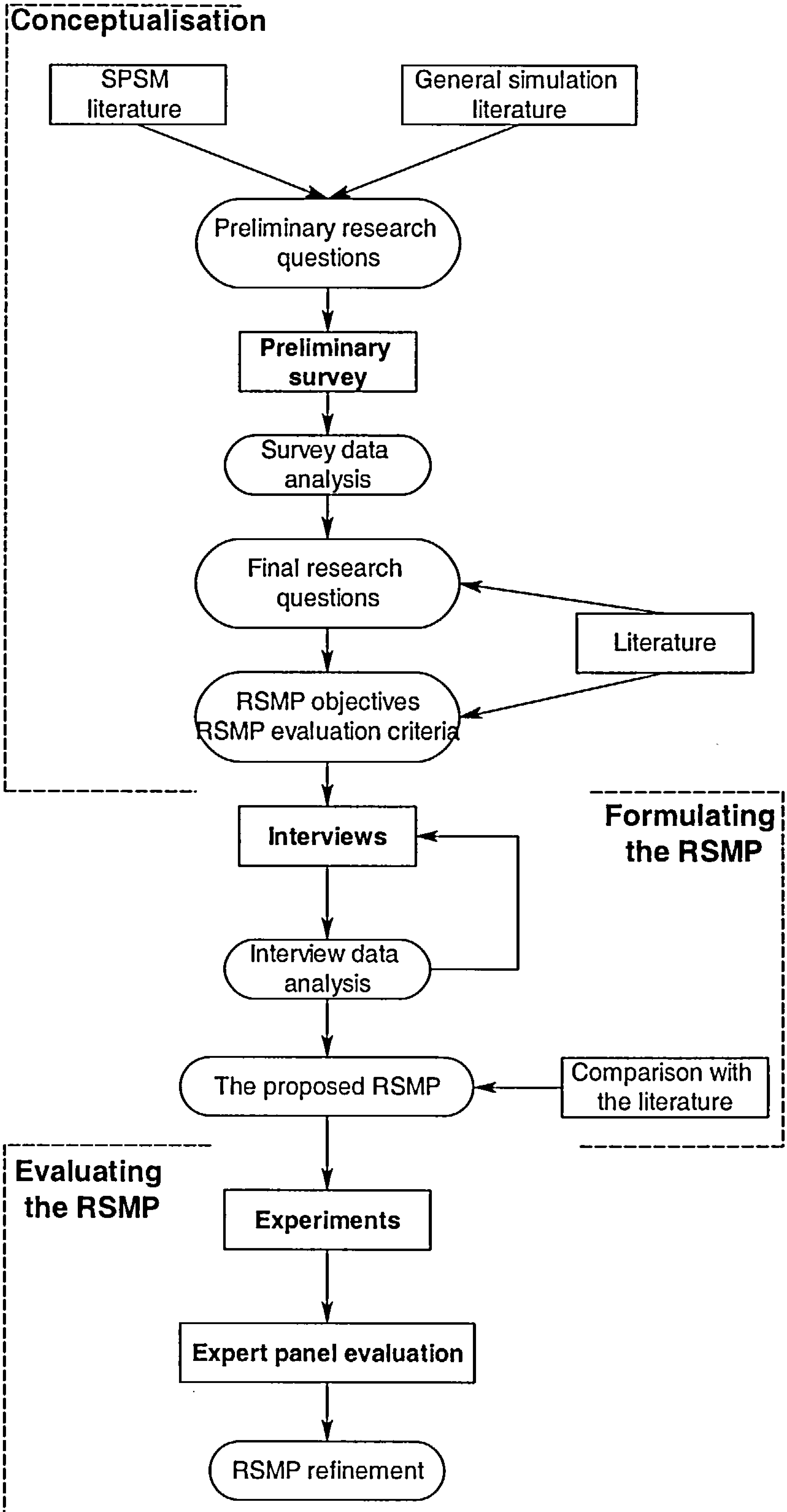


Table 4.1: Phase-activity-rationale matrix of the research process

Phase	Activity	Rationale
Conceptualisation		
Literature review	Themes/concepts identification Initial research question	Clarity of focus
Questionnaire survey	Definition of final research questions and hypothesis Definition of conceptual framework of ideas to explore	Determine the relevant concepts to be explored further
Define project success criteria	Definition of objectives of the RSMP	Help steer the RSMP development
	Definition of the evaluation criteria	Test the external validity of the RSMP
Formulating the RSMP		
Data collection	Theoretical sampling (Participants selection)	Helps identifying participants which are useful to explore, connect and integrate an emerging conceptual framework
Data analysis (coding and constant comparison)	Conduct semi-structured interviews	Evidence of lived experience of the participants
	Open coding	Develop concepts, categories and properties
	Axial coding	Identify related categories and and sub-categories
	Selective coding	Integrate categories in an emergent framework
		* *Using these three forms of coding and reporting rigorously on the coding process enhances internal validity*
Closure of data collection	Identify data saturation (otherwise go to theoretical sampling again). Write up results.	Further data collection only gives marginal insights, therefore end process.
Comparison with literature	Comparison with other frameworks to identify similarities and differences	Improves internal validity by construct definition and comparison. Also improves external validity by relating to the domain for which study is to be generalised
Evaluating the RSMP		
Test the RSMP framework	Conduct experiments with novices	Justify fitness in the domain and novices understanding of the RSMP by evaluating usability and usefulness
	Expert evaluation	Justify fitness in the domain, expert understanding, generality and modifiability of the RSMP. Also improves the RSMP constructs.

* Format adapted from Pandit [1996}

The second phase, 'formulating the RSMP', consists of the activities related to data collection through an interview instrument and data analysis following a grounded theory approach. The second phase has been informed by the outcome of the conceptualisation phase.

The third phase, 'evaluating the RSMP', phase aims at evaluating the RSMP for its fitness, understanding, generality and modifiability as suggested by grounded theory evaluation guidelines. This phase consists of an experimental study with novices and an expert panel evaluation. The evaluation phase helped in revising and improving the RSMP as suggested by the results of this phase.

4.3. Conceptualisation

The aim of the conceptualisation phase is to understand the software process simulation modelling, develop concepts from the literature and decide upon the issues to be explored in depth. It explores what is happening in software process simulation and what might be the issues to be addressed.

Conceptualisation phase consists of three major activities; the literature review, a preliminary survey with expert software process simulation modellers, and establishing success criteria against which the RSMP has been tested.

4.3.1. Literature review

For the purpose of conceptualising the problem area, the software process simulation literature was analysed alongside the general simulation literature. A thorough discussion on background literature has been presented in Chapter 2. The literature was reviewed to answer an initial research question:

"What is happening in software process simulation?"

4.3.2. Preliminary survey

I conducted a preliminary survey to investigate the practices of software process simulation modellers. The aim of this survey was to further conceptualise the problem area. This survey was built upon the themes identified from the literature review. This survey is a partial replication of a survey conducted by Willemain [1994] with simulation modellers in operational research.

Based on the initial research question and the themes identified from the literature a questionnaire was constructed to explore what is happening in software process simulation research and practice. Appendix A2 shows the questionnaire used in this survey. A similar approach is used by Baskerville and Pries-Heje [1999] to understand IT in practice in a grounded theory based project. Baskerville and Pries-Heje [1999] used an interview survey approach and identified various issues to be explored in depth.

The results from this survey and further analysis of relevant literature helped in determining the final research questions and hypothesis as described in Chapter 1. It also identified that focussing only on software process simulation modellers will not be a viable option and that also studying a closely related group of people will be helpful useful. For this purpose I decided that a group of simulation modellers from operational research should also be studied, where simulation is long established in practice. The survey results, along with further literature analysis, also underpinned the decision upon the areas of interest to be explored in the subsequent phase. The results of the preliminary survey are presented in detail in Chapter 5.

4.3.2.1. The survey respondents[2]

The population for this survey is software process simulation modelling practitioners and researchers. It is a *difficult-to-find* and *difficult-to-access* population because no sampling frame exists for it and the population is dispersed across the world. This questionnaire survey was conducted at the ProSim workshop May, 2003, which is major event of the simulation modellers of software processes The ProSim03 workshop attracts simulation

[2] The term 'respondent(s)' is used hereafter to refer to the modellers participated in preliminary survey

modellers (both from industry and academia) from all over the world each year, and they are leading authors in SPSM. One can argue that these active researchers are not necessarily a representative sample of software process simulation modellers. There is no way to guarantee the representativeness of a non-random sample [Oppenheim 1992]. However, these are amongst the people who are defining the future of SPSM.

4.3.2.2. Questionnaire design

Most of the questions in the questionnaire are closed and required specific information from the respondents. The questionnaire consists of three types of questions; classification, behavioural, and attitudinal.

Classification questions aim to discover demographic information of the respondents such as their nature of job, experience, and types of simulation model they develop.

The behavioural part of the questionnaire is constructed on six point likert scales. The original questionnaire of Willemain [1995] consists of 7 point likert scales. The respondents in Willemain's [1995] survey tend to choose a middle value. Therefore, I convert this into a 6 point scale with the idea to stop the respondent choose a middle value. There is a counter-argument that if we do not give a middle value choice, it means we are pushing the respondents to give their opinion while someone may have a neutral perception. Researchers have varying opinions about the number of choices for likert scales. Likert himself, in his original paper, do not consider the number of choices to be an important issue [Likert 1932]. However, Dyba [2000] claims that reliability is increased when going from 2 to 5 likert scale choices and starts deteriorating beyond 5 scales.

The attitudinal part of the questionnaire provides the respondents with multiple choices to answer the questions. These multiple choices were identified from the simulation literature. Moreover, the option is provided if the respondent want to specify some choice other than the given ones.

4.3.3. Success criteria

The preliminary survey results and literature review helped in finalising the research questions and deciding that a simulation modelling process should be developed for novice software process simulation modellers. The next step was to devise success criteria against which the formulated simulation modelling process (RSMP) has been tested. This step entails two activities; establishing the objectives of the simulation modelling process and a criteria against which the potential process would be tested.

The two objectives of the RSMP as described in Chapter 1 were established at this stage. The evaluation criteria were then established following which the RSMP was developed and subsequently evaluated. The evaluation criteria have been described in Section 4.5 of this Chapter along with the detail of the evaluation phase.

4.4. Formulating the RSMP

This phase answers first three research questions. The aim of this phase was to collect data from simulation modellers and analyse it to discover the simulation modelling processes of the participants[3] to develop a simulation modelling process empirically. The results of this phase are reported in Chapters 6 and 7. Having decided on the final research questions and hypothesis and constructed an objective conceptual framework of ideas within which data was to be collected and analysed, an interview instrument was devised. This section discusses the data collection, sample selection, and data analysis procedures which led to developing the RSMP.

4.4.1. Data collection

4.4.1.1. Semi-structured interviews

To explore the context and practices of two groups of simulation modellers i.e. software process simulation modellers and operational research modellers, I conducted semi-structured interviews with them. The semi-structured interviewing technique is the most appropriate for my research, because the preliminary survey results suggested that an in-

[3] The term 'participant(s)' is used hereafter to refer to the modellers participated in the interview study

depth study should be conducted to explore various areas related to the simulation modelling process. This required interviewing experienced simulation modellers to explore their practices. The interview questions focus on 10 main areas of interest to explore the modelling context and practices of the modellers.

I chose a combination of both face-to-face and telephone interviewing. The prime reason for choosing this combination is that the sample in this study is geographically spread across three continents. The available resources both in terms of time and money did not allow for travelling and conducting face-to-face interviews with all the participants.

An interview questionnaire was prepared, consisting of 10 open ended questions and sent to the participants a week prior to conducting the interviews. The interview questionnaire sent to the participants is shown in Appendix B1. I also prepared an interview script document, as shown in Appendix B2, which I used during the interview to ensure a generally uniform way of conducting interviews with all participants.

4.4.1.2. Theoretical sampling

As discussed in Chapter 3, Glaser and Straus [1967] note that there are three basic questions a researcher must consider during theoretical sampling to select data sources:

1. What groups or sub-groups should be included in data collection?
2. For what purpose groups or sub-groups are to be selected?
3. How to select participants?

There are two main participant groups in this study i.e. software process simulation modellers and operational research simulation modellers. In each groups there are three sub-groups i.e. researchers, consultants, and researchers cum consultants.

The purpose of including operational research simulation modellers was that simulation modelling is a long established practice in operational research, and the application areas of simulation (such as project management, process improvement) of simulation models developed in OR are quite close to software process simulation modelling. Therefore, I anticipated that studying the practices of simulation modellers in a closely-related domain will help identify the deficiencies and enable knowledge transfer.

Within each groups there are three sub-groups; researchers, consultants, and researchers cum consultants; they have different intents to simulation modelling of software processes. For example, researchers come from different background, their objectives for simulation model development is normally innovation. Whereas consultants' intents to simulation model development are commercial. Modellers' objectives in model development may affect the way they develop simulation models. Hence inclusion of both groups gives an insight of what is happening in the industry and academia. Therefore, the inclusion of researchers and consultants is aimed to discover state-of-art in simulation practice and develop a simulation modelling process which is based both on the practices of researchers and consultants.

The criteria for the selection of participants intended to the participants who are experienced, knowledgeable, thoughtful and reflective. As far as researchers are concerned, I judged them subjectively based on their publications and credentials from their web pages. This approach may not work as effectively on the consultants. Therefore, the consultants have been selected on the basis of their experience. Moreover, in both groups, participants have been selected who have quite low level of experience and those who are highly experienced.

The sampling process was driven by the conceptual framework established before data collection. First a pilot study was conducted which helped in validating the interview instrument and deciding upon the participant selection for the main set of interviews. Data collected in each interview was analysed and the emerging concepts helped to decide subsequent participant selection. The first 10 interviews were aimed to explore and understand the concepts i.e. open coding was performed and concepts saturated. The next 10 interviews were intended to confirm the relationships between these concepts in order to establish categories and sub-categories, and confirm the relationships between categories, sub-categories and inter-categories relationships.

Most studies do not discuss how the sample size for a qualitative investigation has been decided. There is no magic number or criteria to decide on a satisfactory sample size. Anschuetz and Rosenbaum [2003] conducted 10 interviews to improve the website design of Ford Vehicles. Pape et al. [2003] conducted 8 semi-structured interviews from a population of 300 hundred students to investigate the process of e-community building at the University of Hamburg. Niederman et al. [1993] conducted a study of facilitation issues in distributed meeting using communication technologies. They conducted 37 semi-structured interviews when the size of the population was undefined and the interviewer team consisted of three members. Jennings [2001] conducted a study of best practices in corporate training interviewing 8 experts in the field. As stated above, a general criterion in grounded theory, as suggested by Glaser and Strauss [1967], is to stop collecting further data when the researcher feels that a level of saturation in the data has been achieved i.e. collecting more data is of minimal value because similar concepts are being discussed by the participants. In my study, having conducted and analysed 4 pilot interviews and the first 10 interviews of main study, it was clear that no new concepts were being discussed by the participants. Therefore, the next 10 interviews were focussed on establishing and confirming the relationships between the concepts being discussed by the participants.

4.4.1.3. Pilot study

I conducted an extensive pilot study to evaluate the interviewing instrument. The objectives of this pilot study were to evaluate:

I. The validity of questions.

II. The understandability of questions.

III. The appropriateness of the structure and flow of the questions.

IV. My interviewing skills.

V. The appropriateness of the equipment to be used during the study.

VI. The interview duration

This pilot study was conducted in two phases. The first phase consists of pre-testing the interview questions validity using skirmish test method [Berry and Jeffery 2000] and intensive interviewing method [Beslon 1986]. The pre-test was conducted with four participants on an initial draft of the interview questions and questions were improved on the basis of feedback by participants and discussion within the research team. The second phase of piloting consisted of pilot interview sessions with four participants to evaluate the research instrument.

Pre-testing the interview questions

I used a two dimensional approach to pre-testing the interview questions; skirmish test Berry and Jeffery 2000] and intensive interviewing method [Beslon 1986]. Berry and Jeffery [2000] used an approach called a *skirmish test* to do a systematic assessment of participants' perceptions of questions in their survey. They report that the skirmish test helped them effectively improve their questions and avoid difficulties faced by the participants. They asked four questions, providing a rating on a seven point ordinal scale against every question in the survey to judge its validity. Table 4.2 shows an example of applying the skirmish test on an interview question. Appendix B3 shows the skirmish test questionnaire.

The skirmish test method tests questions validity in three dimensions i.e. understandability, participant's knowledge and relevance. Based on these three questions (*a*, *b*, and *c*), the criteria to validate a question is that response of participants for each skirmish test question should be positive. Response to a question is positive if it lies on left side of the middle value i.e. 1, 2 or 3 and negative if it lies right side of the middle value i.e. 4, 5 or 6. Berry and Jeffery [2000] used a skirmish test for their questionnaire survey consisting of closed questions, whereas in my study I used it for open ended questions. Therefore, I asked the pre-test participants to suggest improvements in the questions.

Table 4.2: Sample skirmish test questions

Q# 1	What kind of simulation models do you develop?	High						Low
a.	How confident are you that you ***understand*** this question.	1	2	3	4	5	6	7
b.	To what extent do you have ***knowledge*** to answer this question	1	2	3	4	5	6	7
c.	How ***relevant*** is this question to the subject of software process simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied with the way the question is asked, please suggest how this question could be improved							

To increase confidence in the skirmish test results I used intensive interviewing. Belson [1986] proposes intensive interviewing as a way to avoid possibility of inaccurate replies from respondents. Belson [1986] argues that the intensive interviewing method overcomes error which a participant may introduce. Each participant completed the questionnaire while being interviewed. I asked each participant about their thinking process when answering each question and they provided a reason for choosing any choice. This increased confidence in the responses validity of the participants.

Pre-testing of the validity of interview questions provides confidence in the appropriateness of questions. One question was replaced as a result of the skirmish test. Improvements in wording of questions were also suggested.

Piloting the interview session

Piloting the interview sessions helped in assessing and improving the instrument in various dimensions. It helped assess the appropriateness of the structure and flow of the interview questions. It also helped testing my interviewing skills and provided valuable practice for the main set of interviews. The use of audio recording equipment was also evaluated. Moreover, it helped determine the time necessary for interviews. At the end of each pilot interview, the participant was asked various questions to evaluate the session from their point of view. It also helped improving my approach for main set of interviews.

4.4.2. Data analysis

After each interview, interview audio data was transcribed and chunks of text were indexed in a chronological fashion as shown in Appendix B5. After indexing the data in chronological order, grounded theory coding methods were employed in order to analyse the data. Open coding, axial coding and selective coding are analytical; it is not necessary for a researcher to move from open to axial and then selective coding mode in a strict orderly manner.

In the open coding, data was broken down by identifying various concepts which appeared in the data in order to formulate categories. Data were initially broken down by asking simple questions like what, where, how, when etc. Concepts on the basis of similar properties were put together in order to establish and then saturate the categories. Appendix B6 shows an example of open coding.

In axial coding, the data broken down during open coding was assembled together by making connection between categories and their sub-categories. Appendix B7 shows an example of axial coding.

In selective coding all the categories were integrated from the initial theoretical framework in a coherent way. For this purpose various concepts identified during open and axial coding were tabulated and relationships defined between them on the basis of the contextual information. Moreover a graphical sketch of each participant's practices was formulated by the information inferred from data analysis. This helped provide a global coherent view of the contextual information and processes of all the participants. Chapter 6 and 7 report on this in detail.

4.4.3. Closure of data collection

Following the principle of theoretical saturation, I decided to stop further data collection when I felt that the value of further data collection was minimal. Then I formulated the proposed RSMP. The formulation of the RSMP will be described in Chapter 7 in detail.

4.4.4. Comparison with the literature

The final step in grounded theory research is comparison with the extant literature to validate and identify the similarities and differences of the results with the literature. Eisnhardt [1989] says:

> *"Overall, tying the emergent theory to existing literature enhances the internal validity, generalisability, and theoretical level of the theory building. Because [in grounded theory] the findings often rest on a very limited number of cases."*

The RSMP was compared with existing simulation modelling processes reported both in software process simulation literature and general simulation literature. This revealed the distinguishing characteristics of the RSMP; generalisability and hence internal validity of the RSMP in the simulation modelling domain.

4.5. Evaluating the RSMP

The third and final phase of this research aims to evaluate the RSMP. The results of this phase are reported in Chapters 8 and 9.

I followed the grounded theory approach for the development of the RSMP, therefore, my evaluation strategy conforms to the evaluation guidelines suggested in the grounded theory literature [Glaser and Strauss 1967, Strauss and Corbin's 1998, Baskerville and Pries-Heje 1999]. As described in Chapter 3, in grounded theory research, evaluation consists of judging the internal and external validity on various criteria. To ensure internal validity the researcher should rigorously report on the research process, sampling, coding procedures, and compare the results with extant frameworks. Therefore the research process has been thoroughly and rigorously discussed in this thesis. This part of my thesis aims to address the external validity of the RSMP.

External validity aims to assess the results' fitness in the domain, understanding by audiences, generalisability, and control and modify the emergent framework as necessary. Following the grounded theory guidelines, the RSMP has been evaluated in four aspects:

- Generality; how general the RSMP is? What is the scope under which it can be used?
- Understanding; is RSMP understandable to novice and expert software process simulation modellers
- Fitness; does the RSMP fit in the domain of software process simulation modelling? Is it usable and useful?
- Control; does the RSMP provide control so that it could be tailored to individual needs?

Table 4.3 lists the evaluation aspects, criteria used, rationale and the evaluation instrument by which the RSMP has been evaluated. These evaluation criteria were established prior to developing the RSMP.

The grounded theory literature is generally focussed on philosophical discussions and procedural guidelines for theory formulation. Less has been discussed about methodology for evaluating the outcomes of grounded theory research [Pace 2004]. Glaser [1992] suggests that to evaluate the outcome of grounded theory, other methods should be used which are suited for that. Although the grounded theory literature does not specify methods to be used to evaluate the theory, some action research projects such as [Pandit 1996, Baskerville and Pries-Heje 1999] have evaluated the results of a grounded theory based project by applying the results in practice. Unfortunately it was not possible to test the RSMP in industrial practice due to non-availability of subjects. Therefore, I decided to evaluate the RSMP through controlled experiments and expert panel judgements; a two-staged evaluation instrument.

A two-staged study was designed to evaluate the RSMP's generality, understanding, fitness, and control. In first stage, the RSMP is evaluated through two sets of controlled experiments with novices i.e. with students, to evaluate RSMP's fitness, and understanding as shown in Table 4.3. The results from the experiments are assessed in terms of evaluation criteria, which provide evidence of fitness of the RSMP to the field. The experiments results also give some evidence of generality of the RSMP.

Table 4.3: Evaluation criteria for the RSMP

Evaluation aspect	Criteria	Rationale	Evaluation instrument
Generality	Scope	The RSMP should provide generality; it should be abstract enough to be applicable to a variety of contexts. For this purpose the scope should be clearly defined and evaluated under which the RSMP could be used.	Expert panel
Understanding	Understandable	The RSMP should be understandable to the expert and the novices in the area of software process simulation modelling.	Experiments Expert panel
Fitness	Usability Usefulness	The RSMP should fit in the domain of software process simulation modelling. For this purpose the RSMP should be evaluated for its usability and usefulness.	Experiments Expert panel
Control	Tailorable	Does the RSMP allow its user partial control over the structure? The RSMP should provide control to its audience; it should state under which condition the RSMP applies and how it can be tailored for individual needs. The RSMP must be adaptable and modifiable.	Expert panel

In the second stage, RSMP is assessed by a panel of expert software process simulation modellers. This aims to evaluate the RSMP for its generality, understanding, fitness to the field, and control as shown in Table 4.3.

Based on the results of the experiments and expert panel judgments, the RSMP has been further refined. Chapters 8 reports on the results of experiments and Chapter 9 reports on the results on expert panel evaluation.

4.5.1. Controlled experiments

The aim of these experiments is to answer my fourth research question that was based on evaluating the RSMP. I conducted laboratory experiments to gain greater control; because the performance of the subjects[4] had to be measured under controlled experimental conditions and compared so as to identify difference in their performances.

The first phase of the controlled experiments was conducted with MSc. Software Engineering student at University of Hertfordshire. The first phase of experiments is referred to as the SE experiments as they were conducted with software engineering students. The second phase of the experiments was conducted with MSc. Operational Research students at Warwick Business School. Therefore, the second phase of experiments is referred to as the OR experiments.

4.5.1.1. Experiments design

The experiment design in both SE and OR experiment was the same. The subjects were given a case study to develop system dynamics simulation models. In each phase, there were two groups of subjects; one group called the RSMP group and the other group called Non-RSMP. Such an experiment design is called a Two Groups Post-Test only design.

Bernard [2000] discusses eight different experimental designs based on sample availability, time and reliability requirements. Bernard [2000] suggests that a Two-Group pre-test post-test (TGPP) design with random assignments of subjects in two groups is a

[4] The term 'subject(s)' is used hereafter to refer to the students participated in the experiments

classic experimental design. In a TGPP design with random assignments, two groups, a control group and a treatment group, are formed in which subjects are assigned randomly from a sample of a defined population. In the pre-test, the two groups are exposed to the experimental conditions and observations are made. Then the treatment is applied to the treatment group e.g. some training or exposure to enhanced knowledge. Then a post-test is conducted by exposing both groups to the experimental conditions and observations are made. The performance of two groups in the pre-test and post-test are analysed and compared, and conclusions drawn. A 'pre-test and post-test' design enhances the reliability of the experiments' results. However, Bernard [2000] says that Four Group pre-test post-test (FGPP) design with random assignments of subjects tends to be the most reliable design. This involves four groups, two control and two treatment groups formed from a defined population. In the most limited circumstances a Two Groups post-test (TGP) only design with non-random assignments is viable [Bernard 2000]. In a TGP-only design with non-random assignments, two groups, a control group and a treatment group, are formed and subjects for both groups are selected on defined selection criteria. The treatment group is provided with certain treatments and the two groups are exposed to the experimental conditions only once and observations are made.

In an ideal world, I should have adopted a FGPP design with random assignments, however, the availability of subjects, time constraints and resource constraints forced me to choose a TGP only design.

4.5.1.2. Experiment subjects

In the SE experiment, subjects were selected from the MSc. Software Engineering module, Models and Measures in Software Engineering (MMSE) at the School of Computer Science, University of Hertfordshire.

The MMSE class, consisting of 45 students, was given three lectures, 6 hours of class contact, in system dynamics modelling as part of the module teaching. After these three lectures a class test was held to assess students' ability to work with system dynamics modelling. Based on the scores obtained in the test, the top 10 students were invited to participate in the experiments; this is 22% of the class population. The reason to choose the top 10 students was that we wanted subjects in the experiments who are sufficiently proficient with simulation modelling that they can perform, given the limited time of the experiments. None of the invited subjects had any prior experience in simulation modelling. Inducements are believed to be useful to increase response rate in a study [Oppenheim 1992]. Therefore each subject was offered a £10 incentive to take part in the experiments. All 10 of them agreed to participate; however, one subject did not turn up on the day of the experiment.

All 10 students had similar training in system dynamics modelling via the MMSE module. The subjects were divided into a control group named the Non-RSMP group and a treatment group named the RSMP group. To ensure that that both groups have a balanced skill level, subjects were assigned to the groups on the basis of the marks they obtained in the class test.

Both groups were given a system dynamics case study to work on, as shown in appendix C2. In the first set of experiments, the Non-RSMP group used their own modelling process for simulation model development based on their learning from class lectures. In the second set of experiments, the RSMP group used the RSMP to develop the simulation model for the given case study. The performance of the two groups was compared to evaluate the RSMP.

Five students participated in the Non-RSMP experiments and four students participated in the RSMP experiments. However, one subject of the Non-RSMP group could not work properly because of some technical problems. This leaves four subjects in each group for the analysis.

In the OR experiments, subjects were selected from the MSc. Management Science and Operational Research module, Methodology of Operational Research (MOR), at Warwick Business School.

The MOR class, consisting of 60 students, had 12 hours class contact for discrete event simulation and 6 hours of class contact in system dynamics modelling as part of the module. Therefore subjects of the OR experiments had relatively more training than those of SE experiments. Students were invited to volunteer for the experiments; each subject was offered a £10 incentive to take part in the experiments. Seven students agreed to participate voluntarily. However, one student withdrew from the experiments immediately after having agreed to participate. The remaining six students were divided into a control group named Non-RSMP group and a treatment group name the RSMP group. To ensure that that both groups have a balanced skill level, subjects were assigned to the groups on the basis of their past performance in other modules; this way each group had one strong subject and 2 weak subjects. However, the strong subject of the RSMP group and one weak subject of the Non-RSMP group withdrew from the experiment just a few days before the experiments were scheduled. This left two subjects in each group and an imbalance of skills between the two groups.

The case study for OR experiments was more of a managerial nature compared to that of SE experiments which was technical in nature. Appendix C2 shows the problem statement for the OR experiments.

In both phases of the experiment, each RSMP subject group was tutored in the RSMP individually (see appendix C1 for tutorial). Care was taken to ensure that tutoring the RSMP should not increase their skills in system dynamics modelling so as to keep skill level between the groups balanced. For this purpose, the discussion in the RSMP tutorial was focused on general process steps without referring to system dynamics modelling.

After tutoring in the RSMP, each subject was given an evaluation questionnaire to complete. The purpose of this questionnaire was to evaluate RSMP from the subjects' perspective prior to the experiment. See appendix C4 for the RSMP pre evaluation questionnaire.

4.5.1.3. Representativeness of the experiment sample

The representativeness of the chosen sample is limiting. In case of the SE experiments, I could have chosen subjects randomly from the population of MMSE students, making the sample representative of the population in statistical terms. However, given that the purpose of experiments was to evaluate the understandability, usability, and usefulness of the RSMP, the subjects of the experiments were needed to be capable of doing simulation modelling. Moreover, choosing the best students was aimed to get a sample as close to novice simulation practitioners as possible in terms of skills. Therefore the sample is representative of the best skills in the population of MMSE students.

In the OR experiments, however, the subjects participated in the experiments on voluntary basis.

There is always a trade off between sample size and time and cost. Patton [1990] says that qualitative research is aimed to get in depth insights into the problem under study, therefore, making it difficult to study a big sample. In the available time and limited resources, this size of the sample was most feasible. In an ideal world, the sample size is too small for these experiments; however, there are some benefits from having a small sample. Langdridge [2004] says that small samples are most appropriate when there is homogeneity in the population in terms of characteristics. The population in these experiments was quite homogeneous in terms of their experience and training in simulation. The aim of these experiments was to evaluate the RSMP by comparing the performances of the two groups of modellers drawn from a homogeneous population. Hakim [1987] suggests that small samples can be useful to develop and test hypothesis. Rubin and Rubin [1995] say that studying a few information rich subjects in a population to gain insights into the population characteristics can provide much more information than conducting a large scale study. The given sample size was most feasible for an in-depth evaluation of the RSMP given limited time and resources.

4.5.1.4. Experimental setting

RSMP is based on heavy client contact. To emulate the real environment of modeller and client, one person from the research team acted as a client. The client was briefed about the problem in advance. Following the discussion with the client, improvements were made in the problem statement. Subjects had free access to the client for as much time as required during the experiment to emulate a modeller-client relationship.

The duration of each experiment was 2 hours. Given that students had other personal and study commitments and pressures, this duration was short enough to keep subjects' interest but realistic enough to allow use the RSMP.

The experiments were held in a quiet room. Each subject was provided with a computer installed with the Vensim tool for system dynamics modelling [Vensim 2004]. There are a variety of tools available for system dynamics modelling. Vensim is one of the most commonly used tools and it is freely available for educational purposes. Moreover, the subjects were taught system dynamics using this tool and hence used the same tool in the experiments. Moreover, Vensim has been reported to be useful for novices [Eberlein and Peterson 1994]. Each subject was provided with pen, paper, and a written statement of the case study which they were required to model using Vensim. Each subject's activities on the computer were recorded using 'Screen Movie' software [ScreenMovie 2004] to measure the effort spent on different tasks and find out the pattern of the performed activities.

The subjects were given the problem statement at least two days prior to the experiments to allow them sufficient time to understand the problem. The experiments with the Non-RSMP group were conducted prior to tutoring the RSMP to the RSMP group. This is to mitigate the risk that the RSMP group might discuss the process with the Non-RSMP group prior to conducting the experiments. Non-RSMP group having the knowledge of RSMP could compromise the experiment protocol, as they were expected to develop a simulation model with their own process.

The start of the experiment for each subject was staggered to allow him/her to discuss the problem with the client individually. The client was easily accessible to the subjects to allow effective communication between the client and the modeller.

At the end of the experiment, the subjects were given a questionnaire to evaluate the experiments from their perspective. See appendix C5 for the experiment evaluation questionnaire. Moreover, the RSMP subjects were given a questionnaire to evaluate their experience of using the RSMP; see appendix C6 for the RSMP post evaluation questionnaire. Each of the RSMP subjects was given a model produced by one of the

Non-RSMP subjects to evaluate. The Non- RSMP subjects were then called back to evaluate the model produced by the RSMP subjects. See appendix C7 for peer evaluation questionnaire.

4.5.1.5. The model assessment criteria

The models produced by the experiment subjects have been assessed using the assessment criteria shown in Appendix C9. These assessment criteria were devised earlier in the research program and aimed to evaluate the usefulness of the RSMP. Devising the assessment criteria prior to developing a simulation modelling process and conducting the experiments minimises bias. If the assessment criteria were established after proposing the simulation modelling process, there was a fair chance that it might influenced to show the effectiveness of the potential modelling process. Therefore, the model assessment criteria were established in advance. The criteria have been established based on the recommendations from simulation modelling literature.

The assessment criteria have some elements which can be measured objectively while others need subjective judgement. The models produced during the experiments have been assessed by three different assessors. Criteria that can be measured objectively were assessed by me. To minimise self bias, subjective criteria have been performed by the client and peer groups. Appendix C9 reports in detail on how the evaluation criteria have been established.

The models' syntactic correctness, which is objective judgement, was assessed by me.

To ensure the reliability of subjective judgements, the client was invited to assess the models' semantic quality and the documentation using the established criteria. The client was provided with a questionnaire, as shown in appendix C8, to assess the simulation models produced during the experiments.

The maintainability of the simulation models was assessed by peer review. The models were swapped across the Non-RSMP and the RSMP groups in each set of experiments, and the subjects were given a questionnaire asking questions to assess the models in terms of their maintainability. See Appendix C7 for the peer evaluation questionnaire.

4.5.1.6. Questionnaire design

Several questionnaires have been designed and distributed to the subjects in these experiments. The aim of these questionnaires was to obtain subjects' perceptions to evaluate the experiments, the RSMP, and the models produced during the experiments.

All the questions in these questionnaires are attitudinal. Most of the questions are closed; however, some are open-ended aiming to explore subjects' feelings and perceptions about the experiments and the RSMP. All the closed questions have been constructed on five point likert scales.

Care was taken to keep the questions wording simple and clear. The flow of the questions was organised with great care, as Belson [1986] believes that questions structure and flow may also have effect on the accuracy of questionnaire responses. Moreover, the length of the questionnaires was kept short enough so as to ensure that subjects finish them in time. These properties of the questionnaire were validated through a pilot of the experiments.

4.5.1.7. Pilot experiment

Each phase of the experiments was piloted prior to conducting the main set of experiments. The objectives of this pilot study are to evaluate:

I. Appropriateness of the problem statement

II. Appropriateness of the experimental setting

III. Validation of the questionnaires

Both pilot experiments were conducted with a pilot subject prior to the main set of experiments. The pilot subject was a recent MSc. Software Engineering graduate. The pilot subject was given similar training for system dynamics through MMSE class sessions and later tutored in using the RSMP. This helped me test the experimental setting and brought confidence to the experimental protocols.

Originally the plan was to hand out the problem statement as subjects arrive for the experiments. However, the pilot experiment revealed that it is would take a long time for them to read through the problem and develop an understanding. The pilot subject took half hour to develop an understanding of the problem before deciding to see the client, which is ¼ of the experiment duration. This led me to decide that the subjects should be given sufficient time to develop an understanding of the case study problem prior to coming for the experiments. Therefore, in the main set of experiments, the subjects were provided with the problem statement two days prior to the experiments.

The pilot subject could not produce a complete working model. Discussion with the pilot subject suggested that a lack of experience with system dynamics modelling and the modelling tool hindered the production of a working model. However, the client was satisfied with the simulation model for its semantic quality. The pilot subject could not do experimentation, however, he did follow all the other steps required by the RSMP. This suggested that without a sufficient level of expertise with system dynamics and the modelling tool, the subjects would not be able to produce a complete working model. Therefore, I base the evaluation on as is level of goodness in models they produced.

To gain confidence in the various questionnaires designed for these experiments, they were validated in the pilot experiment. The pilot evaluation suggested minor wording changes in the questionnaires.

The pilot experiment also helped test the appropriateness of the equipment used in the experiments. This included testing the computer setup, modelling tool and the screen capture software for recording the subjects' activities on the computer. The pilot experiment provided confidence in the appropriateness of the experimental equipment.

4.5.1.8. Threats to the validity of experiments

Several measures have been taken to make these experiments as reliable as possible; however, there are several threats to the validity of the experiment results as discussed in Chapter 3.

Experimental setting

It was ensured that both groups should have a similar experimental setting. In both SE and OR experiments, both groups were provided with a quiet room with no external disturbance, similar computers, operating system and tools. Each subject in both groups was given an introduction to the experiments upon arrival and their consent was taken. During the experimental session no external disturbance was caused which could distract the subjects.

Selection of subjects

A random selection of novice software process simulation practitioners would have been an ideal sampling method for this. However, a number of constraints forced me to choose these experiments. Software process simulation modelling is a relatively new field and both the research and practitioners' community is small. I could only identify 6 software process simulation researchers with in the UK. Moreover, the software process simulation modelling community is geographically dispersed across Europe, North America and South America. Furthermore, no sampling frame exists to identify the software process simulation modelling community. The results from these experiments would be much more generalisable if practitioners had participated.

In the SE experiments, the selection of subjects method was purposeful i.e. subjects have been selected on certain criteria rather than being randomly selected. The criterion used was performance in the MMSE class test for system dynamics modelling. Students with the top 10 scores were invited to participate in the experiments to get a sample as skilled as possible. This was necessary, as this was the only feasible way to be confident that they would be able to produce simulation models. However, obtaining high scores in a paper based test is no guarantee of a capability to produce a physical system dynamics model. It would be interesting to repeat these experiments with low scorers of the MMSE system dynamics test to see what effect the RSMP may have on weaker students.

In the OR experiments, students were invited to participate in the experiments rather than being selected using criteria. The volunteers were then divided into groups on the basis of their previous performance in the MSc. to create balanced groups.

I do not attempt to generalise the results from these experiments. However, these experiments provide an indication of the performance difference of two groups following different approaches, where the RSMP group performed generally better than the Non-RSMP group in a variety of aspects of simulation modelling.

Maturation

There was a two week lag between the Non-RSMP^{SE} and the RSMP^{SE} experiments sessions. There are two ways that the RSMP subjects could mature over the Non-RSMP subject. First, the RSMP subjects could in theory access the simulation problem statement from the Non-RSMP subjects and work on the problem for two weeks. To mitigate this risk, Non-RSMP subjects were instructed not to show the problem statement to the RSMP subjects. Second, the RSMP subjects could-self study system dynamics and improve their skills over the Non-RSMP subjects. This was an unavoidable risk, as we had no control over their activities. However, considering subjects' other commitments this seems unlikely. Both Non-RSMP^{OR} and the RSMP^{OR} experiments were conducted on the same day, therefore, the threat of maturation is not valid for OR experiments.

Diffusion of treatments

The treatment in these experiments was tutoring the RSMP to the RSMP (treatment) groups in both SE and OR experiments. It was possible that the RSMP subjects could possibly discuss the RSMP with the Non-RSMP subjects.

In the SE experiments, Non-RSMP experiments were conducted prior to tutoring the RSMP to the RSMP group to mitigate this risk. In the OR experiments this strategy could not be adopted because the experiments with both groups were conducted on the same day. However, the RSMP^{OR} subjects were instructed not to discuss the RSMP with the Non-RSMP^{OR} subjects.

Validity of assessment criteria

There are no standard assessment criteria in practice to evaluate a simulation model. The evaluation criteria were established through an analysis of the simulation modelling literature. The validity of the criteria used for the evaluation of the simulation models may be another potential threat to validity.

Duration of experiments

The short duration of the experiments may be another potential threat to the validity of the conclusions drawn from these experiments. A field study of the RSMP with practitioners, where a simulation study may last for weeks or months, would add to the validity of the conclusions from these experiments.

4.5.2. Expert panel evaluation

As a second stage of evaluating the RSMP, I constructed a questionnaire and invited a panel of seven expert software process simulation modellers to evaluate the RSMP. Five of the seven invited experts participated in the expert panel evaluation. The questionnaire was sent to the subjects by email and received back by the same method. Appendix D1 shows the expert panel questionnaire.

4.5.2.1. The expert panel

The number of experts in this panel is very small; however, varying size of expert panel has been used successfully in the past in software engineering studies. This is a small sample size. This sample size is justified on two grounds. First, the type of data to be collected in the study; and second, the availability of the sample. Rubin and Rubin [1995] says that studying a few information rich participants in a population to gain insights into the population characteristics can provide much more information than conducting a large scale quantitative study. The aim of this phase of the study is to evaluate the RSMP and improve it by expert judgement and recommendations. The sample size is feasible for an in-depth evaluation of the RSMP and its improvement, aiming to collect both quantitative and qualitative data.

In previous uses of expert panel evaluations, quantitative data was collected via objective questions. Although most studies used relatively larger samples, Lauesen and Vinter [2001] report on the effectiveness of expert judgements for software defect prevention with only 3 experts and Dyba [2000] used only 11 experts. It can be anticipated that a small sample size will not significantly affect the reliability of this evaluation.

Another reason for using such a small sample is that most of the expert software process simulation modellers had already participated in the interview phase of this research project. This left a very small number of knowledgeable and insightful people in the area to participate in expert panel evaluation.

4.5.2.2. Questionnaire design

A goal question metrics (GQM) based approach [Basili and Rombach 1988] has been adapted to design the expert panel questionnaire. The GQM approach is based on the assessment of goals by answering one or more questions associated with a particular goal. The answers to these questions act as metrics for the assessment. The resulting metrics and their interpretations reflect the values or viewpoints of the people involved in the assessment [Basili and Weiss 1984]. The GQM assessment model has three levels as described by Basili and Rombach [1988]:

- Conceptual level (goal): A goal is defined for an object, for a variety of reasons, which is relative to a particular environment.
- Operational level (question): A set of questions associated with each goal which focuses to characterize the assessment or achievement of a specific goal.
- Quantitative level (metric): A set of metrics, is associated with every question in order to answer it in a measurable way. These measurements can be objective or subjective.

A GQM approach is a hierarchical structure for assessment, starting with a goal (specifying the purpose of measurement), the object to be measured (i.e. characteristics of the attribute associated with the purpose) and viewpoint (i.e. the answer to the question).

In our case following are the goals:

1. Evaluate scope of the RSMP

2. Evaluate the understandability of the RSMP

3. Evaluate the usability of the RSMP

4. Evaluate the usefulness of the RSMP

5. Evaluate tailorability of the RSMP

6. Improve the RSMP

The RSMP has been evaluated for first goals by asking closed questions. However, the sixth goal needs open ended questions, as it is aimed at gaining insights from the experts to improve the RSMP.

Table 4.4 summarises the goals and the associated attributes to be assessed using a GQM approach. Each goal has been characterised by associating it with certain attributes to be assessed. There is a set of question associated with each goal to assess each attribute indexing it to the questionnaire shown in Appendix D1. The expert panel questionnaire, as shown in Appendix D1, has been organised in 5 parts. Experts were provided with the documents describing the RSMP as shown in Appendix C1.

Section 1 of Table 4.4 shows the attributes to be assessed to achieve the goal of evaluating the scope of the RSMP. All questions in Part-I of the questionnaire are aimed at achieving this goal.

Section 2 of Table 4.4 shows the attributes to be assessed to achieve the goal of evaluating the understandability of the RSMP. All the closed questions in Part-II of the questionnaire are aimed at achieving this goal.

All the closed questions of Part-III of the questionnaire are aimed at achieving the goal of evaluating the usability of the RSMP. Section 3 of Table 4.4 shows the attributes to be assessed to evaluate the usability of the RSMP.

All the closed questions of Part-IV of the questionnaire are aimed at achieving the goal of evaluating the usefulness of the RSMP. Section 4 of Table 4.4 shows the attributes to be assessed to evaluate the usability of the RSMP.

Table 4.4: Goal and attributes to be assessed

Goal	Attributes (Question to asses the attribute)
1. Evaluate scope	*All closed questions of Part-I of the questionnaire* 1. Generality (Q: 1) 2. Applicability of the RSMP w.r.t. modelling technique (Q: 2) 3. Applicability of the RSMP w.r.t. model size and complexity (Q: 3)
2. Evaluate understandability	*All closed questions in Part-II of the questionnaire* 1. Clarity (Q: 1) 2. Level of detail (Q: 2) 3. Consistency (Q: 3)
3. Evaluate usability	*All closed questions in Part-III of the questionnaire* 1. Relevance to simulation practice (Q: 1) 2. Logical set of steps (Q: 2) 3. Level of client contact (Q: 3) 4. Rigour of documentation (Q: 4) 5. Ease of following the RSMP (Q: 5) 6. Ease of following the documentation guidelines (Q: 6)
4. Evaluate usefulness	*All closed questions of Part-IV of the questionnaire* 1. Usefulness of process view (Q: 1) 2. Discipline (Q: 2) 3. Problem definition (Q: 3) 4. Model scope capturing (Q: 4) 5. Model design (Q: 5, 7) 6. Experiments design (Q: 6, 9) 7. Model validity (Q: 8) 8. Quality of documentation (Q: 110) 9. Model maintenance (Q: 11, 12) 10. Cost and effort (Q: 13, 14)
5. Evaluate tailoraibility	*All closed questions of Part-V of the questionnaire* 1. Tailorability (Q: 1) 2. Adaptability (Q: 2) 3. Extensibility (Q: 3)
6. Improving the RSMP	*Questions in all three parts of the questionnaire* 1. Improving understandability (Part-II Q: 4) 2. Improving usability (Part-III Q: 7) 3. Improving the RSMP for its usefulness (Part-IVI Q: 15)

Section 5 of Table 4.4 shows the attributes to be assessed to achieve the goal of evaluating the scope of the RSMP. All questions in Part-V of the questionnaire are aimed at achieving this goal.

To achieve the goal of improving the RSMP, open ended questions have been asked in all three sections of the questionnaire. Section 6 of Table 4.4 indexes the relevant questions in the questionnaire.

4.6. Conclusion

This chapter has provided a clear overview of my research strategy and execution. I have described my research strategy and execution in the context of the research methods discussed in Chapter 3. I divide my research into three phases, conceptualisation, formulating the RSMP, and evaluating the RSMP. I have discussed sub-phases and activities in each phase and provided rationale for each activity. I have also justified my approach by making reference to similar studies as appropriate. I have thoroughly reflected on each of the research instrument used in this study.

The conceptualisation phase consists of literature review and a preliminary survey with software process simulation modellers. The conceptualisation phase helped clarifying the focus and to devise the final research question. The second phase, formulating the RSMP, is underpinned by findings from the conceptualisation phase.

The second phase consists of data collection from expert simulation modellers in software engineering and the operational research. Analysis of collected data in this phase leads to the development of the RSMP.

The third evaluates the RSMP. The RSMP has been evaluated in a two staged procedure. In the first stage two sets of experiments is conducted with novice software process simulation modellers in order to assess the understanding, and fitness of the RSMP to the field. The second stage of the evaluation uses experts from the field to assess the RSMP for its understanding, fitness in the field, generality and modifiability.

PART III: RESULTS, ANALYSIS, and INTERPRETATIONS

5. Chapter five: Preliminary survey

5.1. Introduction

This chapter reports on the results of a preliminary survey of software process simulation modellers, which is a part of the first phase of my research. The objective of the survey is to identify the current state-of-the-art in SPSM. An initial research question was formed to investigate current state-of-the-art in SPSM:

What is happening in software process simulation modelling?

I present quantitative data collected from the respondents of this study. The results from this study focus and conceptualise the problem area for the rest of the study. The conceptualisation phase is aimed at establishing an understanding of current simulation practice in software engineering. The main outcome of this phase is the hypothesis and the final research questions. The results from this phase provide the rationale for exploring various concepts in more depth for developing a simulation modelling process for novices in SPSM.

The simulation literature was reviewed to find out current state-of-the-art in software process simulation modelling as described in Chapter 2. Various themes and concepts of interest were identified from the literature as shown in Appendix A1. As a second step, a preliminary survey was then conducted with software process simulation modellers in order to refine the themes to be explored in-depth and potentially identify additional themes of interest. The simulation literature review, preliminary survey and further literature review determined the research questions. This also allowed the construction of a logical framework of ideas to be explored around the research questions in the subsequent phase of study. The results of this survey identify the characteristics of software process simulation modellers, the kind of problems they work on, the kind of models they develop and their simulation practices.

The chapter has been organised in four sections. Section 5.2 introduces the respondents and reports the results of the survey. Section 5.3 presents a discussion of the results and the final outcome of this phase of the research and Section 5.4 concludes the chapter.

5.2. The preliminary survey

Here, I report results from the preliminary questionnaire survey of seventeen expert modellers in the field of software process simulation modelling. The objectives of this preliminary survey are to:

1. Understand how modellers see themselves
2. Explore how modellers view their problems, models, and practices
3. Explore the critical issues in software process simulation modelling

The survey is a partial replication of Willemain's [1994] survey. Willemain conducted his study of 12 OR expert modellers to gain insight into how they make models, the models and problems they solve, the qualities of effective modellers and their modelling processes. I replicate part of Willemain's [1994] survey to identify whether similar problems exist in software process simulation modelling as they do in operational research.

The questionnaire consists of 6 sections, addressing the following questions:

1. Describe yourself as a modeller
2. Describe the models you develop
3. Describe the problems you model
4. Describe the most typical way you develop your models
5. Describe your modelling process
6. Describe the critical issues in software process simulation modelling.

The first four sections of the questionnaire largely replicate the questionnaire survey conducted by Willemain [1994] with expert modellers in the field of operational research. I have added a fifth section to discover what process simulation modellers use for developing models of software processes and a sixth section to identify the most critical issues. Appendix A2 shows the questionnaire used in the preliminary survey.

5.2.1. The respondents

The target sample for this survey is the delegates of the ProSim03 workshop. Questionnaires were distributed to all delegates 30 of the workshop and 17 responses were collected. To ensure a higher response rate the questionnaire was distributed and collected by hand. This also helped avoiding the time and money costs of sending the questionnaire by post. A normal response rate is considered between 30-40% [Oppenheim 1992]. I obtained a better than average response rate of 57%. This increases confidence in the study results.

Figure 5.1 shows the divide between respondents; 9 of the 17 respondents are academics (including 1 research student), 8 respondents are from industry. Hence, the sample is a good mix of academics and practitioners. Figure 5.2 shows the experience profile of the respondents in simulation modelling. The average simulation modelling experience of the sample is 6.5 years.

Figure 5.1: Survey respondents

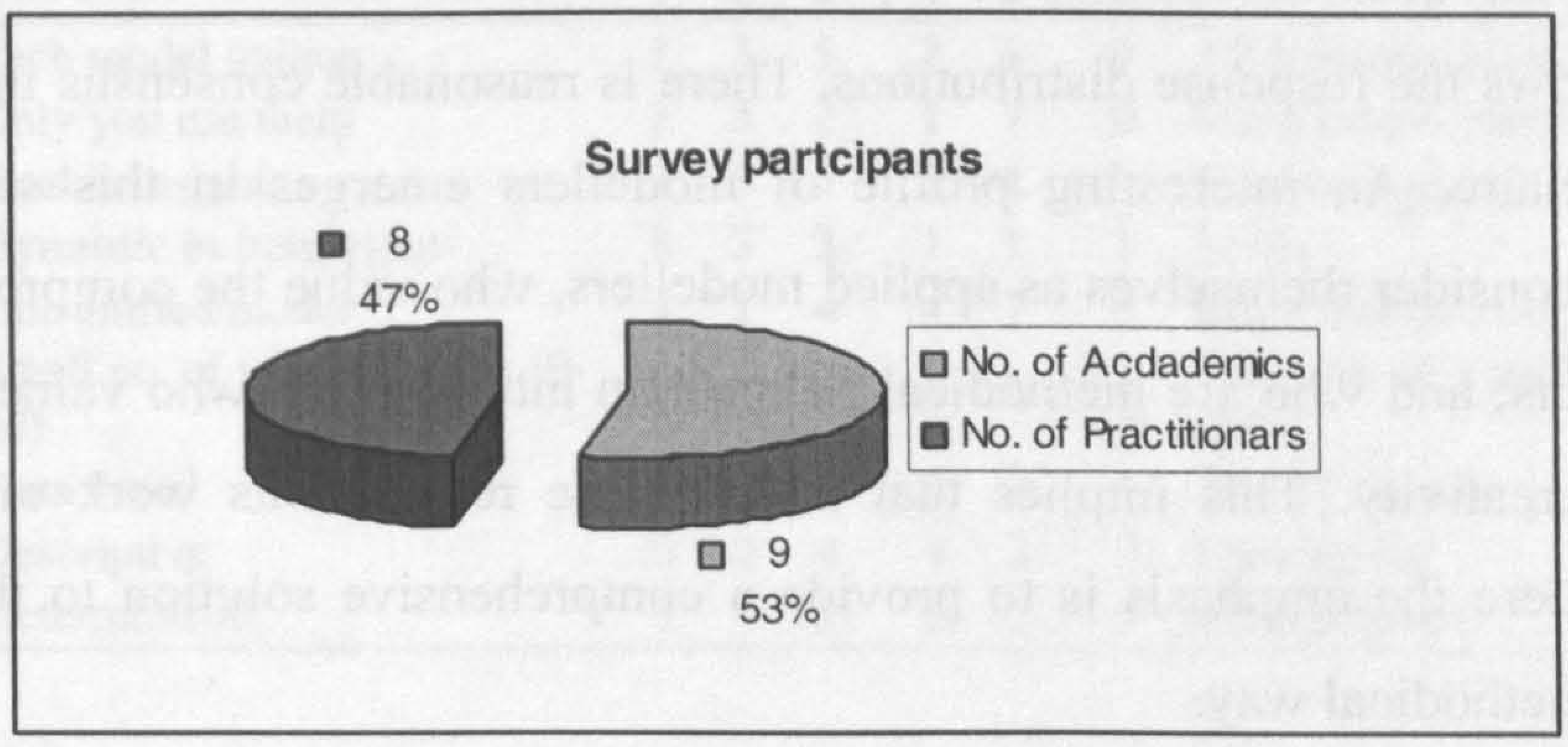
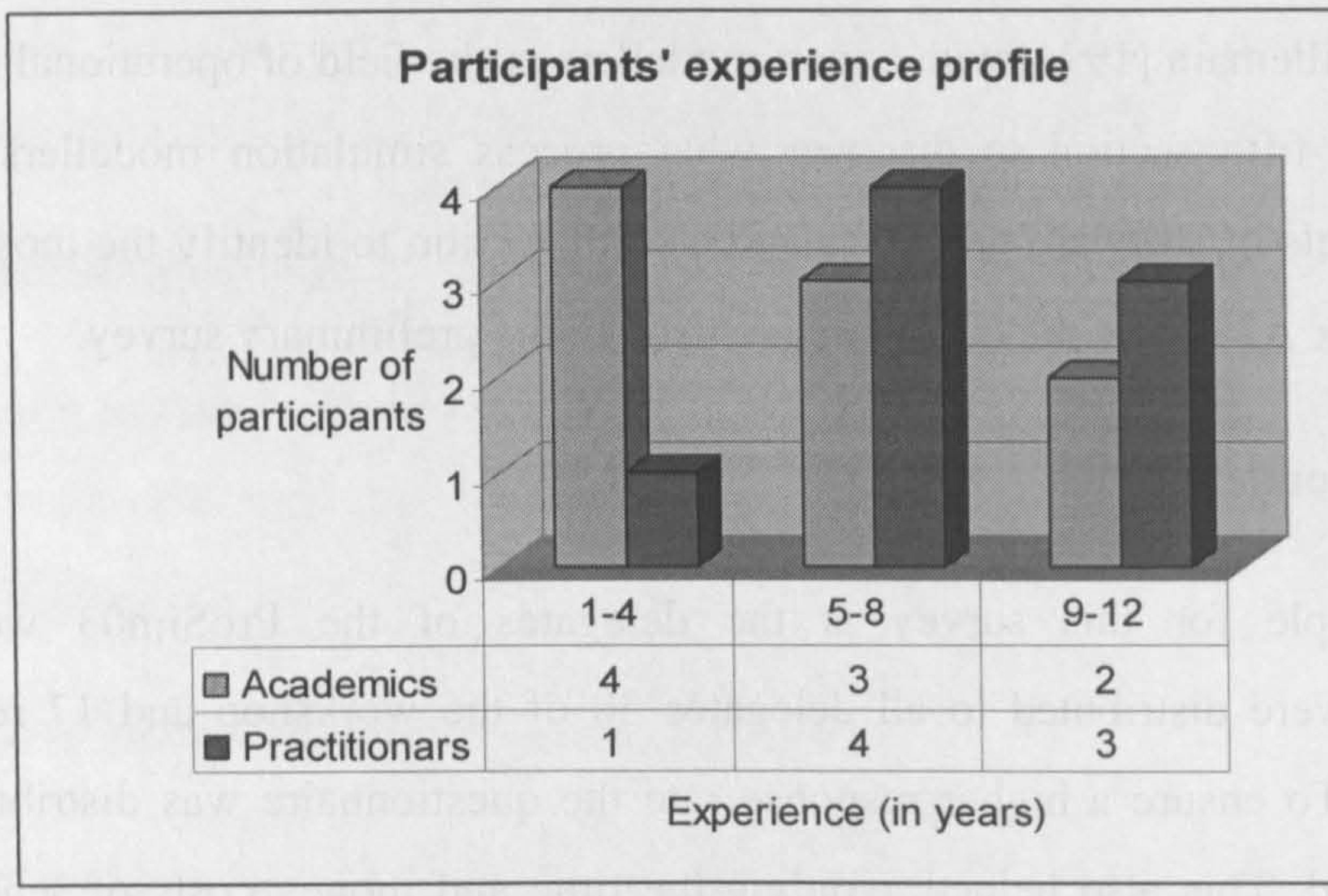


Figure 5.2: Respondents' experience profile in simulation modelling



5.2.2. Questionnaire results

Here I discuss the results of the questionnaire. The discussion has been divided into 6 subsections corresponding to the 6 sections of the questionnaire. The response distributions have been shown in the tables for each part separately. Following Willemain [1994], I consider a consensus in response if 75% of the responses lie on one side of the Likert scale. I do not attempt to generalise the results to a population by showing a consensus, rather highlight general trends in response of the respondents. The items with consensus have been marked in bold face.

<u>I. Describe yourself as a modeller</u>

This part of the questionnaire asks respondents about the kind of modeller they are? Table 5.1 shows the response distributions. There is reasonable consensus in this part of the questionnaire. An interesting profile of modellers emerges in this section; most respondents consider themselves as applied modellers, who value the comprehensiveness of their models; and who are methodical rather than intuitive and who value practicality rather than creativity. This implies that most of the respondents work on real-world problems, where the emphasis is to provide a comprehensive solution to the customer following a methodical way.

Willemain's [1994] survey of 12 modelling experts in the field of operational research did not generate such a consensus. This might be because in [Willemain 1944] most respondents chose middle values for this part. Observing Table 5.1 suggests that a similar tendency of choosing the middle values is also evident in my results. If I had provided a middle value choice, my results may have been more similar to Willemain's. Secondly the sample size in my survey is slightly bigger than that of Willemain's [1994]

Table 5.1: Describe yourself as a modeller

Q#		1	2	3	4	5	6	
1.1	Theoretical	0	0	3	7	7	0	**Applied**
1.2	Value Elegance	1	0	2	9	5	0	**Value Comprehensiveness**
1.3	Intuitive	0	0	3	4	9	1	**Methodical**
1.4	Value Creativity	1	1	1	8	5	1	**Value Practicality**
1.5	Generalist WRT subject area	1	1	3	8	2	2	Specialist

II. Describe the models you develop

In this part of the questionnaire respondents are asked about the models they develop. Table 5.2 shows the response distributions. This part generates a mixed response. Consensus has been obtained only on two questions i.e. the models they develop are dynamic in behaviour (Q2.4). Secondly, most of them develop probabilistic models (Q2.9) that involve prediction of situations in advance; this may be related to Q.2.7 where most of the respondents develop simulation models which are data based.

Table 5.2: Describe the models you develop

Q #		1	2	3	4	5	6	
2.1	Each model unique	1	3	5	7	1	0	All basically identical
2.2	Only you use them	2	5	2	1	7	0	Many others use them
2.3	Goal is insight	3	3	5	5	1	0	Goal is quantities
2.4	**Dynamic in behaviour**	8	3	3	1	1	1	Static
2.5	One unified model	4	1	4	4	1	3	Many linked sub-models
2.6	Small no. of variables (say 10-30)	1	2	3	5	4	2	Large no. of variables (say 100+)
2.7	Data based	3	1	7	3	2	1	Theory based
2.8	Descriptive	5	2	4	4	2	0	Prescriptive
2.9	Deterministic	1	1	2	6	2	5	**Probabilistic**

More than half of the respondents use their models themselves which includes 6 respondents from academia and 3 respondents from industry. Responses to the rest of the questions are mixed and distributed across the 6 scales. However, a tendency of choosing middle values is observable. Q2.6 shows that more than half of the respondents develop large models. This may be related to the fact that most modellers consider themselves to be very methodical and they work on large models. Question is, are they methodical because they develop large models?

III. Describe the problems you model

Table 5.3 summarises the results for this part of the questionnaire. This part presents the kind of problems respondents set out to model. I found consensus on every question in this part of the questionnaire. Table 5.3 shows that most of the respondents model a system that exists. Table 5.3 shows that sixteen respondents have specific objectives for the problem in hand, while, one respondent (who is a student) does not have specific objectives. Table 5.3 shows that most of the respondents model complex systems and most also model large problems. This can be related to respondents' response in Table 5.2 where most of the respondents indicate that they develop large models. Most of the respondents solve problems that have immediate relevance. Finally, most of the respondents model process related problems.

Table 5.3: Describe the problems you model

Q #		1	2	3	4	5	6	
3.1	**System that exist**	5	8	2	1	1	0	System only imagined
3.2	Vague objectives	1	0	0	0	11	5	**Specific objectives**
3.3	Simple systems	0	1	2	3	8	3	**Complex systems**
3.4	**Large problems**	2	5	9	0	1	0	small problems
3.5	**Immediate relevance**	2	4	7	0	3	1	Long-term relevance
3.6	Model a product	1	0	1	3	5	7	**Model a process**

The tendency to choose middle values is very low in this part of the survey. Willemain [1994] got consensus only on the first 3 questions in this part. I am unable to give a definite explanation as to the difference in my responses. One potential answer may be that the respondents in my survey are software engineering while the respondents in

Willemain [1994] survey are from operational research; therefore, perhaps the difference in responses in the two surveys is because the respondents are from two different disciplines.

IV. Describe the most typical way you develop your models

This part examines if respondents follow most recommended modelling heuristics in operational research [Powell 1995, Pidd 1999]; the results are shown in Table 5.4. In this part I get consensus on the first 3 questions, whereas Willemain [1994] gets consensus on all questions except for Q4.6. Table 5.4 shows that most of the respondents look for analogies to solve the problem, start with a small amount of content and then add while developing the model. Also they work over extended periods of time rather than developing the model in one burst. Responses in Table 5.4 show that most of the respondents have heavy client contact, however, a consensus could not be found. Most of the respondents develop a single rather than developing many alternative models and compare results as shown in Table 5.4; this is contrary to the practice recommended in the simulation literature [Powell 1995, Pidd 1999].

Table 5.4: Describe the typical way you model

Q #		1	2	3	4	5	6	
4.1	**Look for analogies**	3	8	3	2	1	0	Start from scratch
4.2	**Start small and add content**	6	8	2	0	1	0	Start big and subtract content
4.3	Work in one short burst	0	2	2	5	7	1	**Work over extended time**
4.4	No client contact	0	2	4	4	4	4	Heavy client contact
4.5	Make single model	3	4	3	3	2	2	Make alternative models and compare results
4.6	Work alone	5	2	3	2	3	2	Work collaboratively with others

Responses to Q4.6 in Table 5.4 indicate that some respondents do not collaborate with others while working on a modelling problem. It is difficult to explain the reason for low collaboration. One potential reason may be that simulation modelling is a new discipline in software engineering and organisations do not provide very many resources, hence there are very few people working on simulation modelling. Another potential answer can be that the nature (size & complexity) of problems/models or nature of simulation modelling itself does not need many people to work together. This will be further explored in subsequent phase of this research.

V. Describe your modelling process

This part of the questionnaire explores the underlying process that respondents employ in their modelling practices. Table 5.5 shows the summary of results. Most of the questions show strong consensus. This is different to what the literature suggests in that the software process simulation modelling literature does not report the use of a formal process for model development. The majority of the respondents indicate that they have a systematic process for model development. Other consensus items are that they assess feasibility as a first step, define the problem sufficiently, always document formally, value a modular structure, value usability, review the model at each step.

As responses from most of the respondents in Table 5.5 suggest that they have a strong modelling process in use for simulation model development. An in-depth exploration of their modelling processes would be helpful to devise a simulation modelling process which is close to real world simulation practice.

Table 5.5: Describe your modelling process

Q #		1	2	3	4	5	6	
5.1	**Systematic process**	4	7	2	1	3	0	Ad hoc process
5.2	**Assess feasibility as first step**	1	9	2	3	1	1	Don't assess feasibility
5.3	Define model scope at all levels	4	6	1	3	2	1	Scoping isn't a big concern
5.4	**Define problem sufficiently**	5	9	1	0	1	1	Insufficient problem definition
5.5	**Always document formally**	3	4	7	1	2	0	Never document formally
5.6	Follow a life cycle approach	3	7	1	3	2	1	No life cycle approach
5.7	**Value modular structure**	8	8	0	1	0	0	Develop model in one view
5.8	**Concern usability**	4	7	3	2	0	1	Usability isn't of much concern
5.9	**Review model at each step**	4	5	4	1	2	1	Review at the end
5.10	Evaluate formally	3	4	4	3	1	2	No formal evaluation
5.11	Concerned with model maintainability	3	6	1	1	3	3	Maintainability is not an issue

Documentation is an issue that the OR simulation literature has shown concern for. I expected to observe a similar tendency in software process simulation modelling as well, while the result is that the majority of the respondents document their models formally.

This raises the question of what simulation modellers consider to be formal documentation and what the value of documentation is to model developers and users. I aim to explore the issues related to model documentation in a subsequent phase of my research.

Response for Q5.6 shows that more than half of the sample thinks that they have a life cycle approach to their model development practices. More than half of the respondents say that they conduct formal evaluation for their simulation models. This raises the question, what does evaluation mean?

A majority of the respondents indicate that they work on large and complex problems as shown in Table 5.3; one can question the importance of maintainability if in case the models are to be used for long-term. My literature review suggests that maintainability of models has not been given much attention in simulation; however, in this survey more than half of the sample considers maintainability as an important aspect. This raises the question as to how the simulation modellers take care of maintainability of their models.

The responses from the respondents in this section of the questionnaire raise many important and interesting questions related to simulation modelling process, documentation, evaluation, and maintenance. These questions need an in-depth study to explore and understand the simulation modelling practice of software process simulation modellers.

VI. Critical Issues

The sixth part of this questionnaire attempts to identify the most critical issues to be addressed by the software process simulation modelling community. I show the questions and their responses in Tables 5.6 and 5.7. Respondents have selected multiple answers for these questions.

Table 5.6 shows that the modelling process and the evaluation of simulation models of software processes are the most urgent issues to be addressed. Validation is also indicated to be another urgent issue that needs attention. It is interesting that most of the respondents claim that they have a systematic modelling process but still consider the modelling process as being the most important issue. Only one respondent is concerned about modelling notations. This suggests that most of the respondents find modelling notations satisfactory for their work. None of the respondents consider modelling tools and the model development environment as an important issue to be addressed. This also implies that respondents are happy with the available tool support for their kind of work. Education and training is another aspect that respondents do not consider important. This is an interesting observation; while a significant debate can be found about simulation education and teaching in general simulation literature, the respondents in this survey do not even consider it an issue.

Table 5.6: Most urgent issues to be addressed in software process simulation modelling (SPSM)

Issues in SPSM	Responses
a. Modelling process	6
b. Evaluation	6
c. Validation	5
d. Modelling notations	1
e. Modelling tools or model development environments	0
f. Formal education and training (for model developers)	0
g. Other (please specify)	3 (Model confidence, data sources and data collection.)

Table 5.7: The area of modelling process needs more attention

Area of simulation modelling process	Responses
a. Model requirements analysis (scope, problem definition, inputs and outputs definition etc)	3
b. Model design	7
c. Formal documentation	3
d. Maintenance	3
e. Other (please specify)	6 (Marketing, Making simulation modelling accessible and useful, Verification, Reuse, Model understanding, Application and Use)

Table 5.7 shows that modellers are most concerned about model design in the modelling process. It is interesting that Willemain's [1995] experiments with expert respondents show that they spent 59% of effort on model structure. This suggests that within the modelling process the model design issue is the most in need of attention. Model requirements, maintenance and formal documentation are lower priority issues. I need to find out why maintenance and documentation are low priority to modellers. One reason for this might be that the respondents do take care of the documentation and maintainability of their models and hence do not consider it an issue. Another potential reason could be that simulation models developed so far in software engineering are too small (though they say they build large models; also we do not know as yet how to determine the size and complexity of models) or large but conceptually too simple to be documented and maintained. Another reason could be that most simulation models may not be used for long-term, therefore documentation and maintenance is not an issue.

5.2.3. Further analysis of the results

Part 1 to 3 of the questionnaire explores the contextual information; part 4 and 5 explore the practices and part 6 explores the critical issues in software process simulation modelling. A rigorous statistical analysis on the survey results is not possible due to small data set, however, correlating contextual and practice variables may provide interesting insights. The generalisation cannot be said to be statistically valid; nevertheless, they provide indicators for further in depth exploration.

I have conducted a Spearman's correlation test on each contextual variable against each practices variable. Table 5.8 shows the variables that correlate with each other. Appendix A3 shows results of conducting the Spearman's test. Correlating Q1.3 with practices variables reveals that a respondent who perceives themselves as methodical looks for analogies (Q.4.1), has a systematic process (Q.5.1), documents formally (Q5.5), values a modular structure of the model (Q5.7), and concerned with the usability of the model (Q5.8). As the respondents who claim to be methodical and hence have a systematic process, it would be useful to understand their systematic process.

Correlating Q2.2 with practices variables suggests that respondents whose models are used by others, first assess feasibility of the model (Q5.2), and tend to follow a life cycle approach to model (5.6).

Table 5.8: Correlation matrix of variables

Variable – I	Variable - II
Q1.3 Methodical	Q4.1 Looks for analogies Q5.1 Systematic process Q5.5 documents formally Q5.7 Values modular structure Q5.8 Concerned with usability
Q2.2 Models used by others	Q5.2 Assess feasibility Q5.6 Follow a lifecycle approach
Q2.6 Develop large model	Q4.3 Work over extended period of time Q4.4. Heavy client contact Q5.4 Define problem sufficiently
Q3.2 Specific objectives	Q5.3 Define model scope Q5.10 Formally evaluate
Q4.4 Heavy client contact	Q5.2 Assess feasibility Q5.3 Define model scope Q5.4 Define problem sufficiently Q5.9 Review model at each step Q5.10 Formally evaluate

* The tables shows only the variables which correlate to each other. Where variable-I correlates with variable-II

The correlation of Q2.6 reveals that respondents who say they develop large models tend to work over extended period of time (Q4.3), have heavy client contact (4.4), and define the problem sufficiently (5.4). However, the results do not suggest any connection between model size and the modelling process. Similarly there seemed to be no connection between the size and complexity of the problem with the modelling process. This raises the question why the size and complexity of a model/problem does not have connection with the modelling process?

Correlation of Q3.2 with practice variables suggests that when the respondents have specific objectives of the model, they define scope of the model at each level (Q5.3) and formally evaluate the model (Q5.10).

Correlating Q4.4 with practice variables reveals that respondents, who have heavy client contact, tend to assess feasibility as a first step (Q5.2), define problem scope (Q5.3), define the problem sufficiently (5.4), review the model at each step (Q5.9), formally evaluate the model (Q5.10).

It is very difficult to draw concrete conclusions from this small survey; however, it has highlighted various areas of interest for further exploration; this will be discussed in the next section. There are a few issues which were not included in this survey. The survey did not ask about respondents' background, the kind of modelling techniques (e.g. discrete event, system dynamics) they use and their problem domains. The subsequent phase of my research also takes these aspects into account.

5.3. Discussion of the results and future research

My empirical findings from the survey do not support my initial hypothesis that software process simulation modellers do not use a systematic process for simulation model development; this hypothesis was based on the fact that the software process simulation literature does not report the use of a formal process. However, the majority of respondents in this survey indicate the use of a systematic process for model development. The question of my future research is, what systematic modelling process do they use? Most of the respondents document their models formally, though it is not clear, what formal documentation is to them and what the value of documentation is to model developers and model users?

Most of the respondents assess feasibility as a first step, define the problem sufficiently, value a modular structure, value usability, and review the model at each step. However, model evaluation is not much practiced. About half of the respondents consider maintainability as an important aspect. Most of the respondents show that they work on large and complex problems, and we would expect maintainability to be a potential issue for such large and complex models. Many respondents do not have a life cycle perspective of the simulation modelling process. This may be a reason for not giving importance to maintainability. The majority of the respondents consider modelling process and evaluation as the most urgent issues to be addressed in software process simulation modelling. Moreover, model design is considered to be the most urgent issue in the modelling process.

The majority of the respondents report using a systematic process for simulation model development. As discussed in Chapter 2, a simulation modelling process developed through an empirical study which is close to real world simulation practice would have a potential for novices in SPSM to improve their simulation modelling. By the end of survey results analysis, the prime aim of the research was clear i.e. to develop a simulation modelling process for novice software process simulation modellers through an empirical study of simulation modellers' practices.

The analysis of the survey results have raised many questions, and suggested particular areas of simulation modelling to be explored further. The results helped determine the research questions and the concepts which are to be explored through an in-depth study of simulation modellers to develop the simulation modelling process. Four research questions were identified:

1. What are the modelling contexts of simulation modellers?

2. What are the practices of simulation modellers?

3. What process emerges by investigating the contexts and practices of simulation modellers?

4. Will a simulation modelling process help novice software process simulation modellers to improve their simulation modelling?

Two broad areas of interest augmented by the first two research questions, the contexts and the practices of simulation modellers, have been decided to be explored to answer the research questions. The third research question aim aims to investigate whether it is possible to consolidate a simulation modelling process by studying the contexts and practices of simulation modellers. The fourth research question aims to evaluate the simulation modelling process which is developed by studying the contexts and practices of expert simulation modellers.

The context of the simulation modellers means the circumstance or the parameters within which simulation modellers develop their models. This includes the background information such as their education, experience and training. The type of modelling techniques they use. The kind of models they develop (e.g. aims of the models, problem domains etc). Size and complexity of the models they develop. And their typical work environment (e.g. team working, client contact etc). I also aim to explore what connection might the simulation problem domain, simulation technique, and simulation tools have with the modelling process. An in-depth study of expert simulation modellers will further explore these issues. The survey results do not suggest a relationship between the size and complexity of problem/model with the simulation modelling process of the respondents. The subsequent phase of my study will explore the perceptions of expert simulation modellers about model size and complexity and their relationship with the simulation modelling process. Moreover, it is also not clear what the relationship might be between simulation teams and the modelling process. The possible connection of teamwork with the simulation modelling process will also be explored in the subsequent phase of my research.

The survey results have given rise to many interesting questions about the practices of the respondents. Exploring the practices of simulation modellers is meant to find out the typical way they develop their models and its relation to their contexts. This included finding out their modelling process and its relationship with their contexts. How and to what extent the simulation modellers document their models; what factors affect the way they document their models? Do they have to maintain their models? How they take care of maintainability of their simulation models and what contextual factors affect their decision to maintain the models? What maintenance principles do they employ in their simulation modelling process? What does formal evaluation mean to the simulation modellers and how do they evaluate their models? Moreover, what deficiencies they feel in the way they develop their models and how they can be overcome.

As discussed above, the results for the part of the survey which was a replication of Willemain [1994] were very different from those of Willemain. While there could be several reasons for these differences, this motivates me to explore whether such differences can be found in a comparative group of OR simulation modellers and what is the significance of the potential differences. Simulation is a long established practice in OR, therefore, a study of comparative groups would help identify deficiencies in software process simulation modelling and transfer best practice knowledge from OR. Therefore this survey also underpins my decision that a comparative group of simulation modellers from OR should also be studied to develop a simulation modelling process which is close to real world simulation practice.

5.4. Conclusion

In this chapter, I have presented the results of my preliminary survey conducted with software process simulation modellers which was aimed to investigate current-state-of-the-art in SPSM. This preliminary survey along with the literature analysis as reported in Chapter 2 formed the first phase of my study i.e. conceptualisation. Seventeen expert simulation modellers, both from industry and academia took part in this survey. This survey investigates current practices and issues in software process simulation modelling. A part of the survey questionnaire replicates earlier work by Willemain [1994].

The survey results suggest that the majority of the respondents say that they have a systematic process for model development. The most highlighted issue in software process simulation modelling is the modelling process. The survey results also show that most of the respondents are very methodical, work on large problems, build big models, and document their models formally. However, to most of the respondents the maintainability of models is not an issue. Evaluation is another highlighted issue by the respondents. Question arises as to what systematic process they use, what formal documentation is to them, why maintainability is not an issue and how do they view evaluation. To find out answers to these questions it is important to understand the contextual environment of the simulation modellers.

I do not intend to generalise the results, as the sample size is very small and chosen with a non-random sampling method. However, this preliminary survey highlights areas of interest for further exploration and has helps to establish an objective framework of concepts in order to develop a simulation modelling process. The survey provides a clear focus to my study and helps determine the research questions. For the purpose of developing a simulation modelling process, the contexts and practices of two groups of simulation modellers from software engineering and operational research are studied in the subsequent phase 'formulating the RSMP'.

6. Chapter six: The Contexts and practices of simulation modellers

6.1. Introduction

This chapter presents the results of the semi-structured interviews conducted with expert simulation modellers in Software Engineering and Operational Research. These interviews were conducted to find answers to my first two research questions:

RQ1: What are the modelling contexts of simulation modellers?

RQ2: What are the modelling practices of simulation modellers?

These interviews were conducted with face-to-face with expert simulation modellers or by telephone. A detailed description of the interview instrument has been provided in Chapter 4. Appendix B1 shows the interview questionnaire sent to the participants of this study and Appendix B2 shows the general interview script used during the interviews.

I present the results of qualitative data collected from 20 expert simulation modellers about their modelling contexts and practices. The data have been analysed following a grounded theory approach as described in Chapter 4 and descriptive statistics have been used to present a coherent view of the data. The research findings reported in this chapter feed into developing the detail of the RSMP, which would be presented in Chapter 7.

The chapter has been organised in 5 sections. Section 6.2 introduces the participants of the study and their demographics. Section 6.3 presents the participants' contextual information including the type of models, modelling techniques, modelling tools, size and complexity of the models and teamwork of the participants. Section 6.4 presents the modelling practices of participants, which includes their documentation, maintenance and evaluation practices. Section 6.5 describes a summary of the results and how they are going to be used in developing the RSMP.

6.2. The Participants

In this study, two groups of simulation modellers have participated; these are

- Software process simulation modellers group (SPSM group)
- Operational research simulation modellers (OR group)

The aim was to explore both participant groups' model development processes and practices in order to propose a simulation modelling process for novice software process simulation modellers. The study of two groups allowed comparison and identification of deficiencies in the modelling practices of software process simulation modellers.

Table 6.1: Participants background

Participant	Education	Experience in years	Professional role
SPSM group			
S1	Bachelor	2	Researcher
S2	PhD	2	Researcher
S3	PhD	3	Consultant
S4	PhD	9	Consultant/Researcher
S5	PhD	9	Consultant/Researcher
S6	Masters	4	Consultant
S7	PhD	6	Researcher
S8	PhD	16	Consultant
S9	PhD	11	Consultant
S10	PhD	20	Consultant/Researcher
OR group			
R1	PhD	13	Consultant
R2	Masters	2	Consultant/Researcher
R3	Bachelor	7	Consultant
R4	PhD	6	Consultant
R5	PhD	14	Consultant
R6	Bachelor	8	Consultant/Researcher
R7	PhD	10	Researcher
R8	PhD	1	Consultant/Researcher
R9	PhD	9	Researcher
R10	Masters	6	Consultant

The sample in this study consists of both simulation practitioners and researchers. Both groups consist of both researchers and practitioners and have varying degrees of education and experience. There are 20 participants in total, 10 of which are software process simulation modellers and the other 10 are simulation modellers from OR. Table 6.1 presents each participant's education, experience in simulation and professional role. The participants from S1 to S10 show the SPSM group and the participants from R1 to R10 show the OR group.

Table 6.2: Group wise profile of the participants

	Education			Professional role			Avg. Experience
	PhD	Masters	Bachelor	Consultant	Researcher	Researcher/ Consultant	
SPSM	8	1	1	5	2	3	8.2 years
OR	6	2	2	4	3	3	8.9 years
Total	14	3	3	9	5	6	8.5 years

Figure 6.1: Participants' educational profile

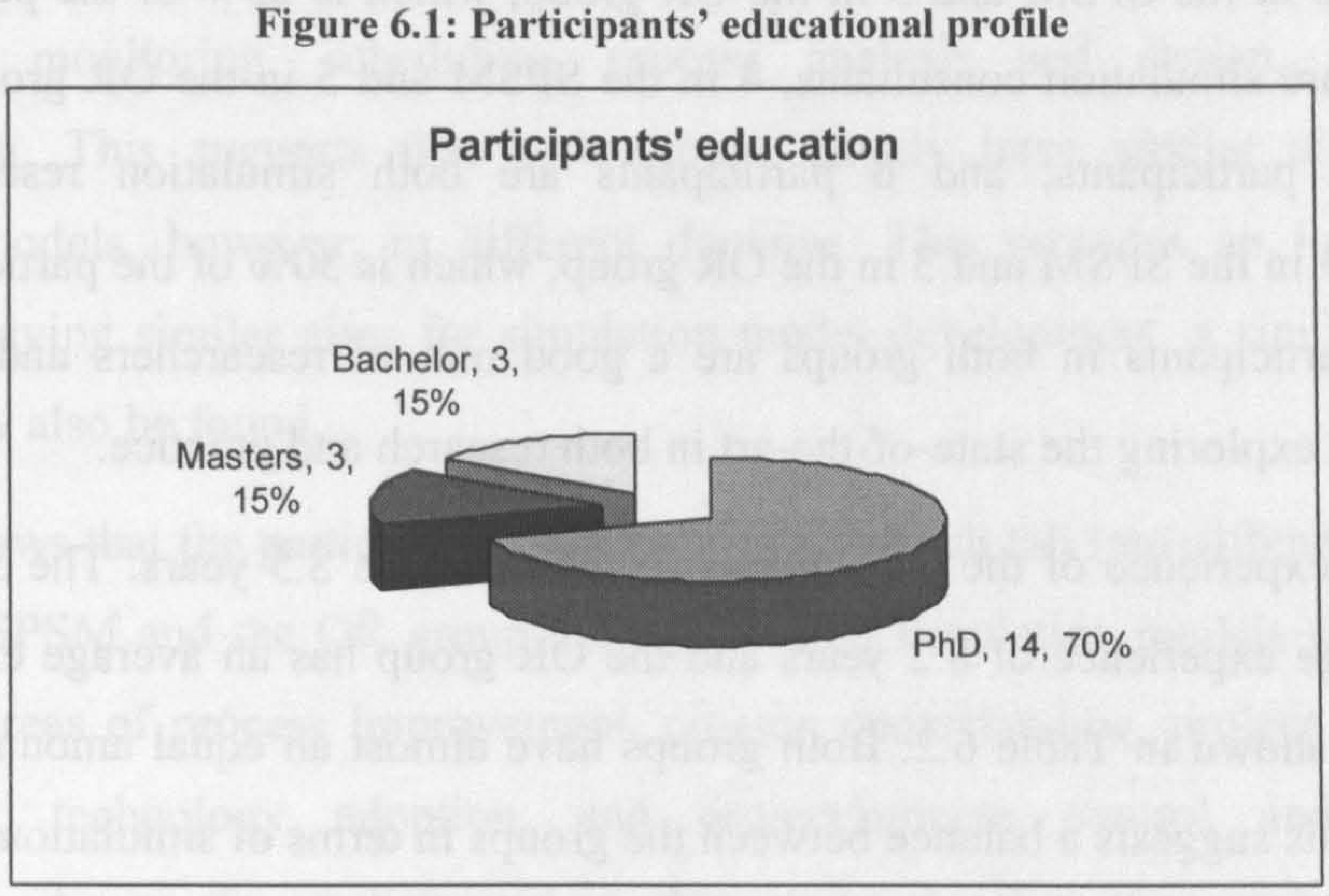


Table 6.2 summarises participants' demographics with respect to the group. Figure 6.1 shows educational demographics of the participants. There are 14 participants with a PhD, 8 in the SPSM and 6 in the OR group, which is 70% of the participants; 3 participants with Master degrees, 1 in the SPSM and 2 in the OR group, which is15% of the participants; and 3 participants hold Bachelor degree, 1 in the SPSM and 2 in the OR group, which is 15% of the total participants. This suggests that the participants in this study are highly educated and most of them had some simulation education in their professional or research degrees.

Figure 6.2: Participants' professional roles

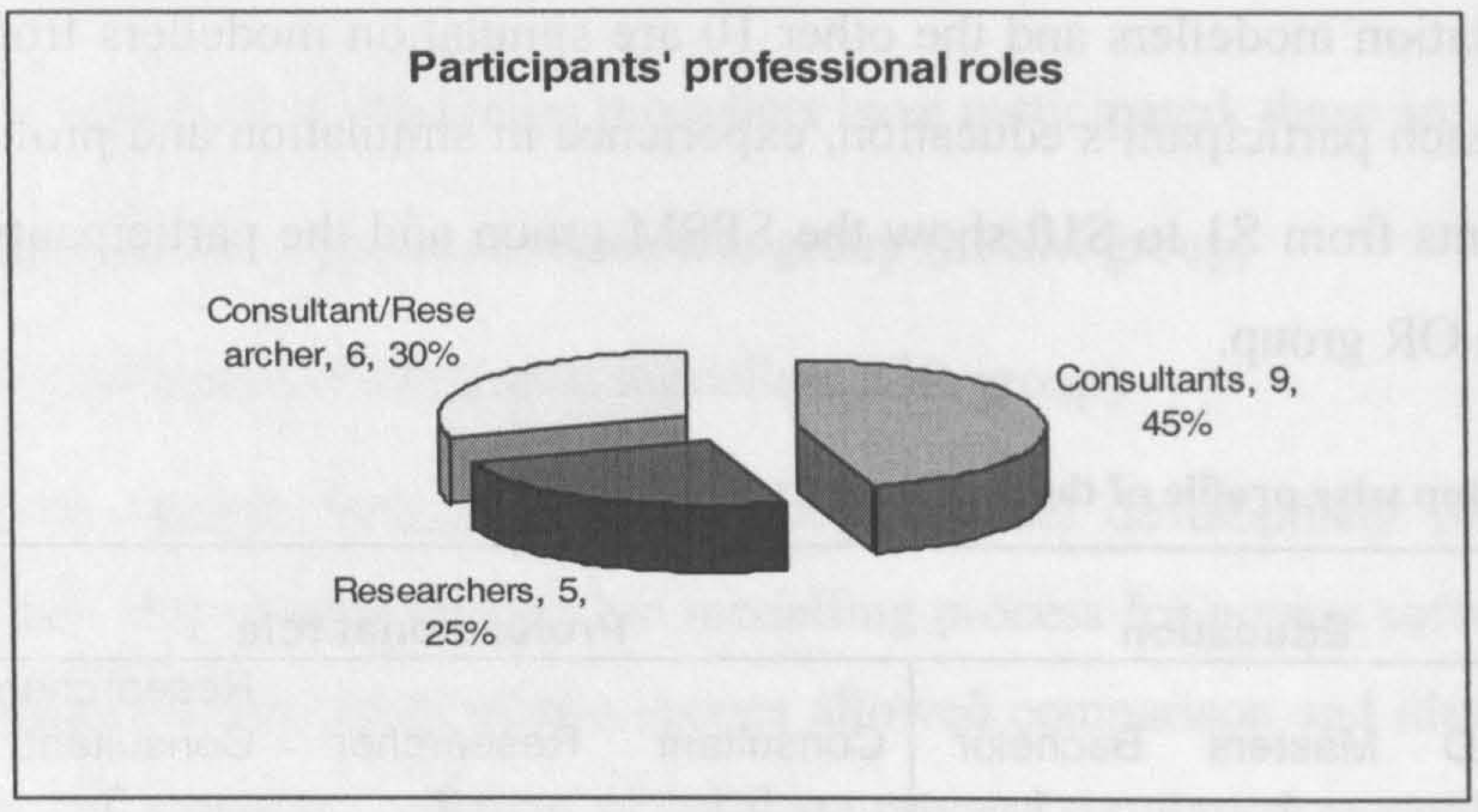


Figure 6.2 summarises participants' professional backgrounds. There are 5 simulation researchers, 2 in the SPSM and 3 in the OR group, which is 25% of the participants; 9 participants are simulation consultants, 4 in the SPSM and 5 in the OR group, which is 45% of the participants; and 6 participants are both simulation researchers and consultants, 3 in the SPSM and 3 in the OR group, which is 30% of the participants. This shows the participants in both groups are a good mix of researchers and consultants which helped exploring the state-of-the-art in both research and practice.

The average experience of the participants in simulation is 8.5 years. The SPSM group has an average experience of 8.2 years and the OR group has an average experience of 8.9 years, as shown in Table 6.2. Both groups have almost an equal amount of average experience; this suggests a balance between the groups in terms of simulation experience.

6.3. Context of the participants

The data presented in this section aims to answer the first research question of my thesis.

RQ1: What are the contexts of simulation modellers?

These results include the type of simulation models developed by the participants, the modelling tools used by them, the modelling techniques used, the size and complexity of the models produced by them and the kind of teams they work in. This contextual data provides information about important factors which in turn affects the practices of the simulation modellers and their modelling process. The modelling process of the participants is discussed in the next chapter.

6.3.1. Type of models

Participants in this study develop various kinds of models. The models have been classified with respect to their aims, application area, problem domain, and term of use. Table 6.3 summarises the types of model developed by each participant.

Table 6.3 shows that the simulation models developed by the participants have several aims. The SPSM group mainly develop models which aim at getting insights into the software process, process understanding, studying the effect of different factors on cost, quality and schedule, process representation, resource planning, and studying the performance of the software process. The OR group develop models which are aimed at performance monitoring, scheduling, process analysis and design, and process representation. This suggests that both groups largely have similar aims for their simulation models, however, in different domains. This provides an indication that because of having similar aims for simulation model development, a similarity in their practices may also be found.

Table 6.3 shows that the participants develop models which fall into different application areas. Both SPSM and the OR group mainly develop simulation models that fall in the application areas of process improvement, process understanding, project planning and management, technology adoption, and project/process control and operational management. Again the participants in this study develop the models in similar application areas.

Table 6.3 also shows that the participants in this study develop simulation models of various problems. Simulation modellers in software engineering have developed models to study, understand, manage, and control various software engineering problems such as software inspections, software evolution, the Rational Unified Process (RUP), supporting CMM initiatives, software reliability engineering, and software testing processes. The participants in the OR group have experiences of working with problems relevant to airport processes, passenger flow, cargo, logistics, supply chain management, mining, oil and gas pipelines, call centres, manufacturing, telecom business processes, financial sector, banks, healthcare policy planning, defence and scientific phenomena.

An important consideration in this study, as described in Chapter 4, was that the two participant groups should have a feasible level of similarities and differences in their characteristics so that it should be possible to compare them. The data suggests that the two groups largely have similar aims and similar application areas for their simulation models, showing a level of similarity between the groups; however, their domains of work are quite different, which shows a level of difference between the two groups.

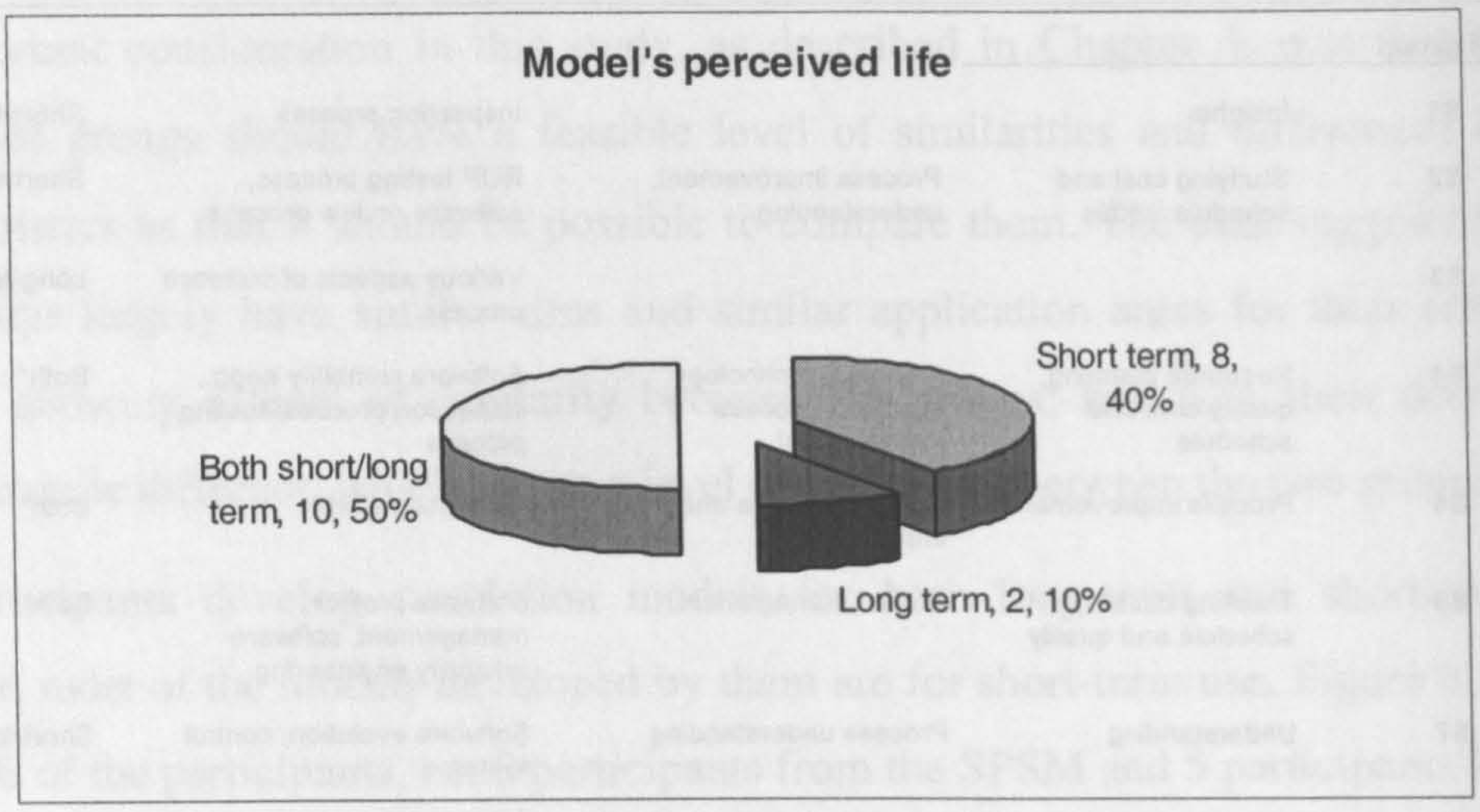
The participants develop simulation models for both long-term and short-term use; however, most of the models developed by them are for short-term use. Figure 6.3 shows that 40% of the participants, i.e. 3 participants from the SPSM and 5 participants from the OR group perceive that they develop simulation models for short-term use. A proportion of 10% of the participants, 2 from the SPSM and none from the OR group develop simulation models for long-term use. Whereas 50% of the participants, 5 from the SPSM and 5 from the OR group develop simulation models for both long-term and short-term use. However, all the participants who have developed models for long-term use indicate that there are very rare cases when a simulation model is used for a long time. It indicates that the majority of the participants mostly develop simulation models for short-term use. The model's life of use has an effect on the practices of simulation modellers, which will be described in the upcoming sections.

Table 6.3: Types of models produced by each participant

Participants	Aims of models	Application area	Problem domain	Model's perceived life
SPSM group				
S1	Insights		Inspection process	Short-term
S2	Studying cost and schedule issues	Process improvement, understanding	RUP testing process, software review process	Short-term
S3			Various aspects of software process	Long-term
S4	Resource planning, quality cost and schedule	Planning, technology adoption, process improvement	Software reliability engg., inspection process, testing process	Both*
S5	Process improvement	Process change and improvement	Simulating CMM	Both*
S6	Tracking cost, schedule and quality	Project management	Software project management, software reliability engineering	Both*
S7	Understanding	Process understanding	Software evolution, control systems	Short-term
S8	Process representation, control, resource allocation	Software project control and operational management, process improvement	Whole software process, testing process for CMM5, oil and gas pipelines, logistics	Long-term
S9	Decision support	project control, planning and process improvement	Various aspects of software processes and projects	Both*
S10	Software process performance	All areas	Various aspects of software process	Both*
OR group				
R1	Performance monitoring, scheduling	Process improvement, understanding	Airport processes, passenger flow processes, cargo, airline's call centres	Both*
R2			Manufacturing, call centres, financial services, defence	Both*
R3	Process analysis and design, scheduling	Operational management	Telecom business processes, call centres	Short-term
R4		Technology adoption, process improvement	BPM, supermarkets, financial sector, call centres, IT infrastructure	Short-term
R5	Scheduling	Operational management	Defence, telecom, supply chain, oil companies, Traffic dept.	Both*
R6		Planning and operational management	Defence, scientific, bioinformatics, software project management	Both*
R7	Process representation, resource allocation	Process understanding, planning	Health care policy modelling, disease patterns, defence	Short-term
R8			Vehicle engine manufacturing	Both*
R9	Understanding		Scientific	Short-term
R10	Cost, schedule and resource allocation	Control and operational management	Mines	Short-term

* Mostly short-term but sometimes develop models for long-term use

Figure 6.3: Life of the models developed by the participants



	Short-term use	Long-term use	Both long/short-term
SPSM	3	2	5
OR	5	0	5
Total	8	2	10

6.3.2. Modelling tools

Table 6.4 presents summarises the tools and techniques used by the participants. The participants use different tools for developing simulation models, such as Witness, Extend, Arena, Simul8, Swaim, GPSS, MS Excel, Vensim, SimuLink, iThink, SimScript, QSim, Matlab, and ModSim; and programming languages, such as Visual Basic, Java, and Pascal. Witness, Extend and Vensim are the most popular tools amongst these participants.

The participants report some advantages and disadvantages of various tools. S1 reports the problem of inter-version compatibility in Extend and restrictions on word limits in comments. S2 uses GPSS because it is a freely available tool for simulation, and Extend because of its graphical interface. S4 says that the problem with iThink is that it does not support modularity; therefore a switch was made to Extend which is much better in this regard. S5 who develops system dynamics models uses Java for simulation model development because Vensim does not provide a facility for components in models. S6 believes that the biggest problem in software process simulation is the availability of appropriate tools, as shown in Exhibit 6.1. S7 believes that for the kind of models developed by him, SimuLink is better than Vensim because of better for mathematical functions. S8 on the other hand says Vensim provides very good support for mathematical functions, but acknowledges that it does not support modularity.

Table 6.4: Demographics of modelling tools and techniques used by the participants

Participant	Techniques	Tools
SPSM group		
S1	DE	Extend
S2	DE	GPSS, Extend, Excel
S3	De, SD	Extend
S4	De, SD	Extend, Vensim
S5	SD	Vensim, Java
S6	DE, SD, HB	Extend
S7	SD	SimuLink, Matlab, Vensim, PowerSim
S8	DE, SD, HB	Extend
S9	DE, SD	Vensim, iThink
S10	DE, SD, SB	Extend
OR group		
R1	DE	Witness
R2	DE	Witness, Visual Basic
R3	DE	Witness
R4	DE	Witness, C#, Sim8
R5	DE, SD	SimScript
R6	DE, SD	Swaim, Extend
R7	DE, SD	Pascal, Simul8
R8	DE	Witness
R9	SD	QSim
R10	DE	Witness

DE = Discrete event
SD = System dynamics
HB = Hybrid models
SB = State based

In the OR group, R1 thinks that Witness is good because provides the flexibility they need. R2 says that the power of Witness comes from the fact that it provides a front-end building facility, a designer, and a command language. R2 says, however, Witness and most other commercial simulation tools suffer from the same problem; that the graphic presentation facility is not very powerful. R4 thinks that Witness and most other commercial tools have been built in a very generic manner to solve all kinds of problems; therefore, they are not very supportive for solving very specific problems, especially where optimisation is an issue. R5 says that ModSim is a 'wonderful' tool for those who want to develop simulation models using an object-oriented paradigm, as shown in Exhibit 6.1. R7 reports that most commercially available tools lack performance; R4 says the same. S8 thinks that Witness is perhaps the best commercial simulation tool available. R4 and R7 also report that most commercial tools' licenses are highly priced; therefore they cannot afford it.

Exhibit 6.1: Views of the participants about simulation tools

S2: Extend is a graphical tool and it has animations... it is very nice... when you present it to managers they are much more impressed...

S6: ...I tell you the biggest problem with software process modelling and simulation is that we don't have simple easily used tools... [the] software process modelling community needs to get together and develop a tool specifically for it

R4: You [will] find that Simul8 or Witness is not fast enough to do simulation optimisation... It's just performance side of things that we miss in commercial tools...[therefore we built our own simulation engine]

R5: It [ModSim] is beautifully object-oriented... it is a pleasure to write [the code]... the libraries are well designed... they have picked good abstractions...

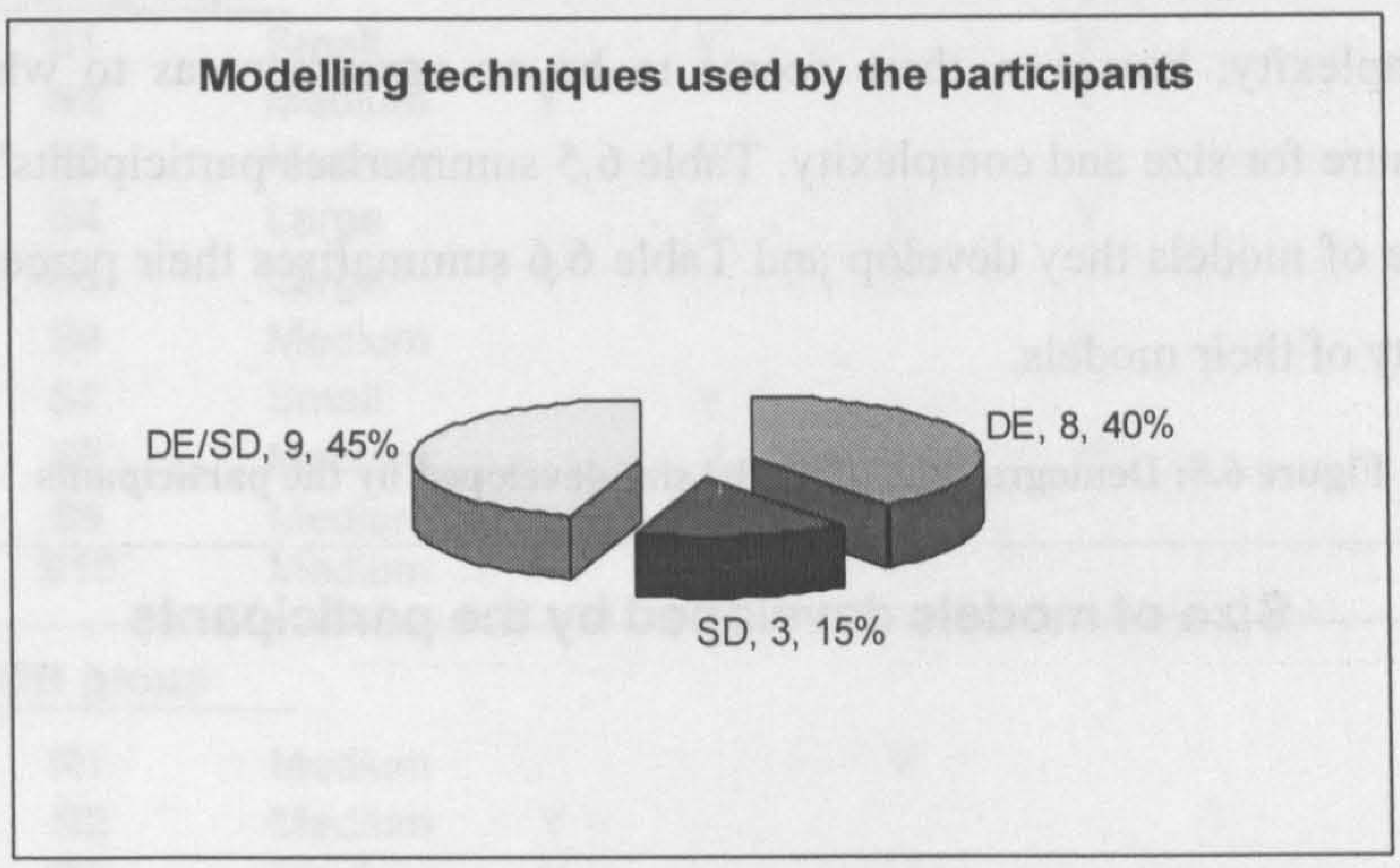
R6: you get your self into a lot of complexity produced by the poor fit between the type of model you are trying to write and tool you have got...

In the preliminary survey I did not explore how simulation tools can affect the practices of simulation modellers. It would be interesting to note that in the preliminary survey, the respondents were asked whether there are any issues to be addressed regarding simulation tools for software process simulation modelling (see Chapter 5, Section 5.2.2); none of the respondents considered the modelling tool an issue. However, my interview participants expressed concerns about choosing an appropriate tool for developing the kind of simulation model they want to develop. S6 says that the wrong choice of tool resulted in a lot of trouble; similarly R6 perceives that the selection of a wrong tool may introduce a lot of complexity in the process of developing the model, as shown in Exhibit 6.1. The results suggest that the simulation modelling practice of the participants is very much affected by the kind of tool they use; therefore, it is very important to choose the right tool for a simulation study. The selection of a tool may depend on different factors such as; budget constraints, performance requirements of the simulation model, ease of using the tool, maintenance support, documentation support, and design quality are a few mentioned by the participants.

6.3.3. Modelling techniques

Table 6.4 summarises the modelling techniques used by each participants. The participants mostly use discrete event (DE) simulation, system dynamics (SD) for simulation model development. Some participants also use state-based and hybrid (a combination of DE and SD) techniques. Figure 6.4 summarises the overall and group-wise demographics of simulation techniques used by the participants.

Figure 6.4: Demographics of modelling techniques used by the participants



	Discrete event (DE)	System dynamics (SD)	Both DE and SD
SPSM	2	2	6
OR	6	1	3
Total	8	3	9

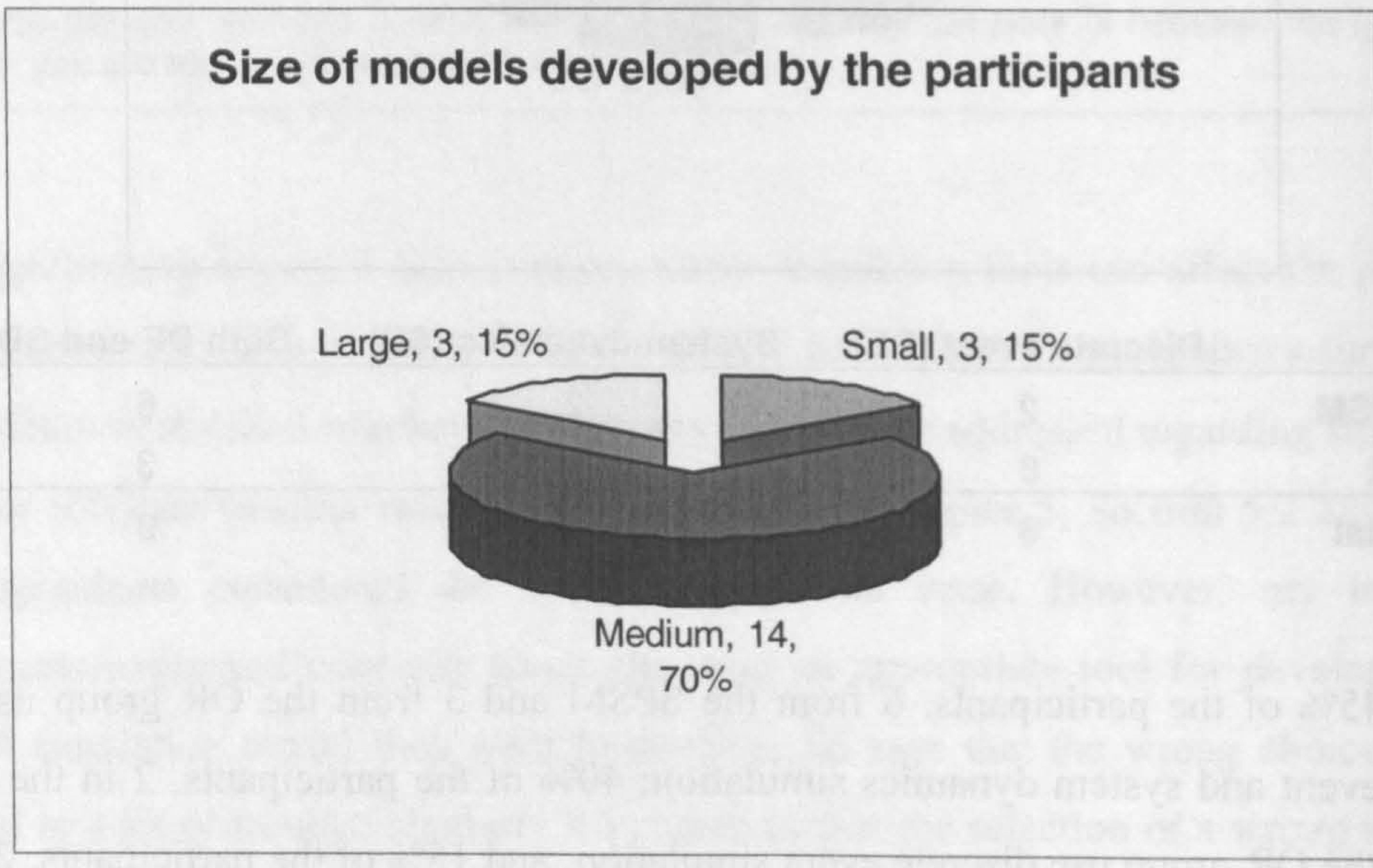
In total 45% of the participants, 6 from the SPSM and 3 from the OR group use both discrete event and system dynamics simulation; 40% of the participants, 2 in the SPSM and 6 in the OR group use discrete event simulation; and 15% of the participants, 2 in the SPSM and 1 in the OR group use system dynamics simulation. This shows that most of the SPSM participants tend to work both with system dynamics and discrete event simulation; whereas most of the OR participants tend to work with discrete event simulation only.

6.3.4. Size of simulation models

It is important to investigate the size and complexity of models the modellers develop. Because the simulation modelling to be developed is based on contexts and practices of the participants; therefore it should be used for developing the kind of models developed by the participants of this study.

The participants in this study have experience of developing simulation models of varying size and complexity. The measurement of size and complexity of the models is very subjective. The participants indicate various measures to assess a simulation model's size and complexity; however, there seems to be no agreement as to what can be a realistic measure for size and complexity. Table 6.5 summarises participants' perceptions about the size of models they develop and Table 6.6 summarises their perceptions about the complexity of their models.

Figure 6.5: Demographics of model size developed by the participants



	Small	Medium	Large
SPSM	2	6	2
OR	1	8	1
Total	3	14	3

Figure 6.5 shows that 3 participants, 15% of the total, think that they develop small models, of which 2 participants are from the SPSM and 1 from the OR group; 14 participants, 70% of the total, develop medium sized models, of which 6 are from SPSM and 8 from the OR group; 3 participants, 15% of the total, developed big models, of which 2 are from the SPSM and 1 from the OR group. This shows that most of the participants in this study develop simulation models of small and/or medium size as they perceive.

Table 6.5: Size of the models developed by the participants, and possible measures of size

Participants	Size	Time	NOV	NOEAP	NOB	LOC	AMID
SPSM group							
S1	Small		Y		Y		
S2	Medium	Y			Y		
S3	Medium		Y				
S4	Large		Y	Y	Y		
S5	Large	Y		Y			
S6	Medium				Y		
S7	Small		Y				
S8	Medium				Y		
S9	Medium		Y				
S10	Medium			Y			
OR group							
R1	Medium			Y			
R2	Medium	Y					Y
R3	Medium	Y		Y			
R4	Medium	Y		Y		Y	
R5	Medium			Y		Y	
R6	Large			Y		Y	
R7	Medium			Y			Y
R8	Medium			Y			
R9	Small		Y				
R10	Medium			Y	Y		

Time = The time it takes to develop simulation model
NOV = Number of variables
NOB = Number of blocks
NOEAP = Number of elements or entities, activities, or process steps
LOC = Lines of code
AMID = Amount of input data

Table 6.5 shows, different possible measures for the size of the models as perceived by the participants. Most participants like to perceive size of the model in terms of magnitude of the problem i.e. number of entities, elements, activities or process steps; where entities and elements mean a conceptual or physical part of the system under study, such as machines, belts, people, or process steps etc. Some participants would like to measure model size in terms of the time it takes to develop the model as shown by the transcript excerpt of R2 in Exhibit 6.2. Participants who use Witness or Extend also tend to measure size in terms of the number of 'blocks' in the model. Some participants also think that the number of variables can be a measure of size. Few participants think that lines of code will be a good measure for the size of a simulation model. R2, R4 and R7 think that the amount of input data can also be used to measure size because the more input data the bigger the model is going to be in terms of data processing.

According to the participants, the size of a model also depends on the tool or the programming language being used to develop the model. A big model developed in one tool may appear to be a small model in another tool. For example, a model developed in Java or Visual Basic may appear to be very big in terms of lines of code; however, when developed in Witness or Extend, because of the direct support in terms of model constructs and visual components it may appear to be smaller. Therefore, S1 suggests that when estimating size of the model, the tool should also be taken into consideration.

Exhibit 6.2: Participants' views about model size

S6: I guess number of blocks is one way to characterise the size of a model. And it was a couple of hundred blocks, I won't say it was a huge model. But it was relatively complicated by a medium size model. In terms of the number of the blocks in the model.

S8: Well I am consultant I measure in dollars...

R1: I would say if you are talking about elements rather than variables... if you got something like 10 to 15 elements you got a medium size model... less than 10 probably small... more than 20 means big... and what I mean by elements is machines, parts, buffers...

R2: I think it is natural for consultants [to measure in terms of time], because we would tend to when it comes to communicating with the client that how big the project is, and establishing its cost, we deal in the amount of time it takes to develop it... so yes we tend to talk in terms of development time... I think there is a fairly direct correlation between the amount of time it takes and how difficult and how complex it is to develop it...

R4: ... so you are looking at 2 to 3 thousand servers within the simulation...and a workload of 10s of thousands of calls per day... so in terms or event list it is quite a big simulation problem...

The results show that there are no agreed metrics for simulation model size and no significant debate can be found about simulation model size in the literature. One explanation might be that, because most of the simulation models developed by the participants are small or medium and for short-term use, not a lot of thinking is put into estimating model size. In addition, R2 says that establishing metrics for simulation model size might be useful from an academic perspective; however, in a commercial environment the time it takes to develop a simulation model is more appropriate measure.

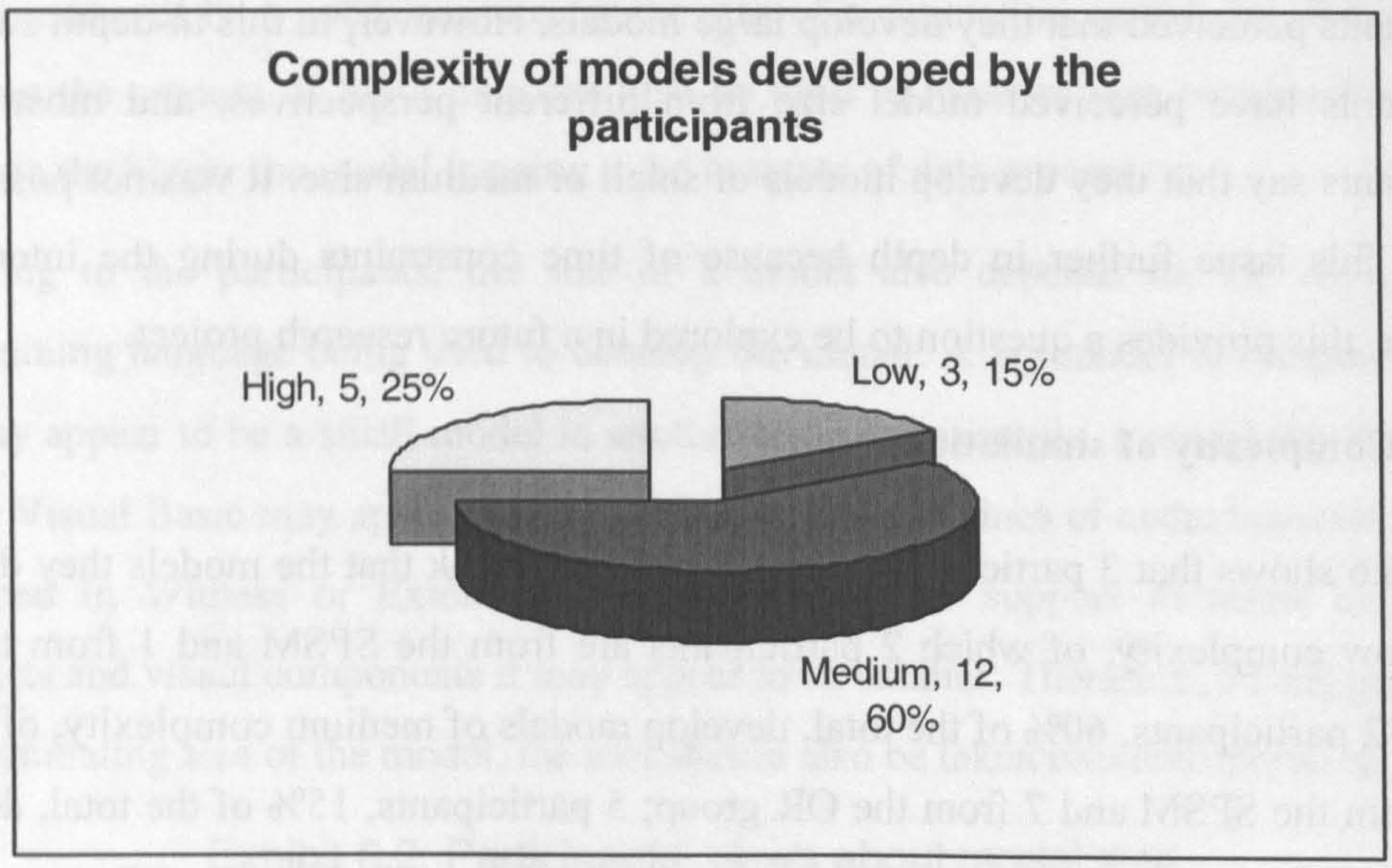
In the preliminary survey, the respondents said they work on large problems; the respondents were asked to perceive their model size in terms of variables and most of the participants perceived that they develop large models. However, in this in-depth study the participants have perceived model size from different perspectives, and most of the participants say that they develop models of small or medium size. It was not possible to explore this issue further in depth because of time constraints during the interviews; however, this provides a question to be explored in a future research project.

6.3.5. Complexity of simulation models

Figure 6.6 shows that 3 participants, 15% of the total, think that the models they develop are of low complexity, of which 2 participants are from the SPSM and 1 from the OR group; 12 participants, 60% of the total, develop models of medium complexity, of which 5 are from the SPSM and 7 from the OR group; 5 participants, 15% of the total, develop highly complex models, of which 3 are from the SPSM and 2 from the OR group. This shows that most of the participants in both groups mostly develop simulation models of low and/or medium complexity.

Most of the participants wanted to talk more about the complexity of the models rather than size, as quotes from S9 and R2 show in Exhibit 6.3. Table 6.6 shows the complexity of models and a variety of possible measures of complexity as perceived by each participant. The number of interactions (NOI) between model elements, blocks or the variables is the most popular measure perceived by the participants. They think that the greater the number of variables, blocks, elements or activities in the model, the more interactions will take place; therefore the model will be more complex. Those who had been involved in continuous simulation think that the higher the number of feedback loops (NFBL), the higher the complexity of the model would be. S4 thinks that the number of questions (NOQ) to be answered by the simulation study can be a measure of complexity because the greater the number of questions the greater the output values and analysis, hence making the simulation more complex. Some of the participants also believe that complexity in the data (CID) and complexity in the output (CIO) are good indications of the complexity of the simulation model. They think, therefore, this is directly related to the complexity of the simulation problem. S1 and R7 assume that the number of flows (NOF) in a simulation model can also be a measure for complexity.

Figure 6.6: Demographics of model complexity developed by the participants



	Low	Medium	High
SPSM	2	5	3
OR	1	7	2
Total	3	12	5

Most of the participants think that size and complexity are related most of the time; in general the larger the model size, the higher will be the complexity. Only S6 and R1 think that size and complexity are not necessarily related. R1 said that a model may be very big in terms of input data, number of blocks, and variables but different parts of a model may be replicating a similar structure, therefore, the model may not be as complex as it seems.

Table 6.6: Complexity of the models developed by the participants, and possible measures of complexity

Participants	Complexity	NOI	NOFBL	NOQ	CID	CIO	NOF
SPSM group							
S1	Low	Y					Y
S2	Medium		Y				
S3	High		Y				
S4	High	Y		Y			
S5	Medium						
S6	High	Y					
S7	Low						
S8	Medium	Y			Y	Y	
S9	Medium	Y	Y				
S10	Medium	Y	Y		Y	Y	
OR group							
R1	Medium	Y					
R2	Medium	Y			Y	Y	
R3	Medium	Y	Y				
R4	Medium	Y			Y		
R5	High	Y					
R6	High	Y	Y				
R7	Medium	Y			Y	Y	Y
R8	Medium	Y				Y	
R9	Low					Y	
R10	Medium	Y					

NOI = Number of interactions
NOFBL = Number of feedback loops
NOQ = Number of questions
CID = Complexity in data
CIO = Complexity in the output
NOF = Number of flows

Exhibit 6.3: Participants' views about complexity

S9: I think model complexity is probably more interesting [than model size]... but the point is that there is no agreed measure...

S2: I think there is a fairly direct correlation between the amount of time it takes and how difficult and how complex it is to develop it... it [size] isn't something that I find to be terribly important, what I find important is how long it takes...

S6: To me a model... the important thing about model is its degree of complexity... so complexity can be measured by the relationships amongst variables... my model probably had about 100 variables and it probably had 500 interrelationships amongst the variables... so that's where the complexity came in...

The results in this section show that most of the participants develop simulation models of low/medium complexity. Again there are no agreed metrics to measure the complexity of the models, and similarly no significant debate can be found in the literature about the complexity of models. However, the results show that complexity of models largely depends on the complexity of problems and size of the models.

6.3.6. Teamwork and collaboration

All the participants in both the SPSM and the OR group say that they typically develop simulation models alone. However, they have to work with the client, model users or the domain experts to understand the problem and get data. Most of the participants say that sometimes they have worked and collaborated with other modellers; however, it seldom happens that they work on the same model concurrently. Only R6 says that he has worked and managed simulation model development where multiple people worked on the same model. However, in that case the project was an enormous defence simulation on which around 200 people worked. In other cases, as for instance S2 and S10 say, they worked with other modellers in a managerial role. S5, S9, S10, R1, R2, R3, say that they have worked on simulation projects in teams; however, in such situations roles such as simulation modeller, data collector, and process-mapper/system-engineer were defined.

The participants give different reasons as to why simulation modellers work alone on a simulation study. One reason is that the nature of the simulation problems and the nature of modelling itself that do not require many people to work on the same project, as quoted by R2 in Exhibit 6.4. Moreover, the participants such as S2 and R2 express that having more than one person introduces a time overhead because all the people involved have to have the same level of understanding; R2 says this makes a project inefficient. R3 and R4 believe that having more than one person developing the same model introduces the problem of version/modification control. Furthermore, R9 says that if two modellers work on different parts of a model, integration of those parts becomes a problem. In the view of R2, R5, and R6, the biggest problem in teamwork is the communication between different team members. R6 states that communication becomes even more problematic if the team members come from different educational and professional backgrounds. Exhibit 6.4 shows some excerpts about teamwork problem.

The participants in this study show concerns about possible communication, coordination, and integration overheads expressed in simulation projects when developed by a team. This can be related to popular Brooks's Law [Brooks 1975] in software engineering that says, *"the programming work performed increases with direct proportion to the number of programmers (N), but the complexity of a project increases by the square of the number of programmers (N^2). Therefore, it should follow that thousands of programmers working on a single project should become mired in a nightmare of human communication and version control"*. As most of the simulation models developed by the participants are short-term, small/medium in size and of low/medium complexity, and the nature of simulation projects, as expressed by the participants, does not require many people to work on same project; therefore, simulation models are developed by individual modellers in most cases.

Exhibit 6.4: Participants' perceptions about teamwork

R2: It is partly nature of the project and I think it is part of nature of modelling [also]... that it is quite an individual thing... because it is an art rather than a science, the extraction of the pertinent details from the real world situation... it is very much our own interpretations that what the pertinent details are...
R5: you can view model development solely as an exercise of communication... everyone got his own idea of how system works inside his head... so constructing a model outside everyone's head so every can see the same thing and play with it and manipulate it in different ways... communication is the most expensive part of whole modelling activity... not only with the modellers but you got to communicate with domain experts, users and other people... you have to communicate the whole time...
R6: The primary problem I always encountered as a member of the team is a lack of clear vision of what you supposed to do...
R6: So as a team member the primary problem always was what to do, when to do, and what is the highest priority... and everybody has his own opinion that what is the most important... so if you have a clear set of objectives then that helps relationship with other team members...

6.4. Practices of the participants

This section presents the findings to answer the second research question:

RQ2: What are the practices of simulation modellers?

In this section, I discuss the simulation model documentation, maintenance and evaluation practices of the participants. Their practices related to simulation modelling process are discussed in Chapter 7.

6.4.1. Documentation

The participants in both groups have varying notions about the documentation they produce. Most of the participants think that the best documentation for a simulation model is putting comments in the code or the comment boxes provided by the simulation tool. For example R5 says that:

> *"There should be as much documentation as possible in the code [as comments] just because it can't run away [because it cannot be lost]"*

Table 6.7 shows various aspect of a simulation study that the participants think they document or should be documented. Every participant says that he/she put comments in the code or comment boxes provided by the tool. Most of them think that a model should be well commented. Most of the participants say that simulation goals and objectives should be clearly stated in the documentation and be agreed with the client. A few participants think that the scope of the model should also be defined in the documentation. Some of the participants recommend that model inputs and outputs should also be defined in order that the model should be well understood in future if needed. Some of the participants think that the relationships between data items (inputs and outputs) should also be documented along with an influence diagram or using some other diagram methods. An overview of model structure or model working is also necessary to understand the model. Most of the participants say that they produce reports or presentations of the simulation results which are presented to the client. These reports or presentation includes the report of experiments, the scenarios and assumptions under which experiments have been run, analysis of results and recommendation based on the analysis.

However, the participants think that the amount and extent of documentation needed for a simulation model depends on many factors as described below.

Type of simulation project: If a simulation model is research based it is less likely that any formal documentation would be produced. However, simulation models produced in PhD research are well documented in the dissertation. Moreover research papers serve more like documentation. For example, S7 and R9 say that their research papers are their models' documentation. As S7 says:

> *"I think [my] model is not going to be something that is safety or business critical. At least for me writing of the paper is model documentation"*

However, if it is consultancy or research in collaboration with the industry, then there can be some formal documentation but again this depends on other factors and the individual's approach.

Size and length of simulation modelling project: The size and length of a simulation project may also dictate the extent of documentation produced for a simulation model. Participants do not tend to formally document 'disposable' models. In R3's view, documentation may prove to be helpful for medium to large projects but for very large projects it is not the documentation alone but you have to rely on people who have been involved in the development of the project. As R3 says:

> *"I think there comes a point where a large manual might describe medium to large project... but when you get really large project, there is no substitute except spending time with the model and having people to explain it"*

On the other hand participants have shown concern regarding the lack of documentation. Many participants think that if the model is to be studied, used or changed in future it should be well documented.

Table 6.7: Documentation practices of the participants

Participant	Goals	Q's	Scope	Inputs	Outputs	Diagram(s)	Structure/ model working	Experimental scenarios	Assumptions	Results analysis	Simulation Recomm-endations	Comments In the model
SPSM group												
S1		X		X	X	X		X		X	X	X
S2		X							X	X	X	X
S3		X					X					X
S4	X	X	X	X	X	X	X	X	X	X	X	X
S5	X	X	X	X	X	X	X	X		X		X
S6				X	X		X	X	X	X	X	X
S7	X	X							X			X
S8												X
S9	X	X	X			X		X	X			X
S10	X	X				X		X	X			X
OR group												
R1	X	X									X	X
R2	X	X	X	X	X	X	X		X		X	X
R3	X	X						X	X	X	X	X
R4							X					X
R5							X					X
R6	X	X	X			X	X	X	X	X		X
R7	X	X		X	X			X	X			X
R8	X	X	X				X	X	X	X	X	X
R9		X		X	X	X	X					X
R10												X

For example S1 says:

> *"I have seen bigger models which were poorly documented and nobody uses them because nobody understands them".*

Similarly R9 says that:

> *"[documentation is important] because even me looking back on some of my models and trying to work out what exactly was it doing is difficult"*

<u>*Time and budget:*</u> Documentation is also driven by the time and budget for a simulation project. In a research environment, researchers do not find enough time for documentation due to other academic commitments and in a commercial environment budget is the driver of available time. Simulation consultants working under heavy commercial pressure, both in terms of time and budget, tend not to pay much attention to documentation unless it is explicitly needed by the client. In a commercial environment, a client is typically interested in the results and conclusions from a simulation study; they are not interested in the model itself. Therefore time and budget appears to be a big factor for model documentation. Exhibit 6.5 shows excerpts of participants' views about the documentation and its relation with time and budget.

Exhibit 6.5: Effect of time and budget on documentation

S8: Yeah if they pay for it I will do [document] it...

S10: I think it is true to say that modelling effort isn't particularly well funded and documentation takes time and energy and finances. So if you spend all your money on developing the model and getting results and people don't want to pay for documentation, documentation doesn't get done.

R4:Potentially a lot of production time will disappear in that documentation process.

R7: Spending 60% of our time writing documents and agreeing things formally and 30% of our time actually doing the work... then the cost benefit ratio is terrible.

<u>*Model users:*</u> In most simulation studies the simulation modellers themselves are the model users; the simulation modeller furnishes the client with only simulation results analysis and conclusions. The client may then make decisions on the basis of the report provided by the modeller. In such a context, the participants tend to do a minimum of documentation.

However, in some cases the participants have to hand over the simulation model to the client or other modellers. In such cases, the client is provided with a user manual detailing the working of the model and guidelines on how to use it. For example R2 says that:

> *"I think when you are looking at handing across the model, when potentially other people developing it in the future, it is very important to have good documentation... especially if that person [who developed the model] is not available"*

Relationship with the client: Some of the participants think that if you have a very close relationship, you may not need documentation at all. For example, S8 discusses a model on which he has worked for the last 6 years in very close contact with the client.

> *"We did the work for a telecom company, that was through the university...in that we were little bit more formal... when I did the work with oil company, I was well known and knew the people I was working with... so it was more informal... so I would say there isn't lot of formal documentation specifications... just a user manual..."*

Simulation team and model life: Simulation modelling tends to be largely an individual activity. Most of the simulation studies are conducted by a single modeller, and in some cases in a team of 2 to 5 people, in which all people will not necessarily be modellers. Moreover, because most models are disposable, it is unusual that a modeller has to maintain a simulation model developed by someone else. Therefore, in such cases, where models are not needed to be understood by others, documentation is not given attention. Participants think that in such circumstances just commenting the code will do the job.

In my preliminary survey, most of the respondents indicate that they document their models formally. This gave an impression that the survey respondents employ some rigorous documentation practices, which motivated me to explore the documentation practices of expert simulation modellers. However, the results of this in-depth study show that most of the participants tend to document their models in the form of comments within code or comment boxes provided by the tool. Secondly, if the model is to be developed for a client, then a report or presentation is provided to the client; in case of research, the model results and conclusion are documented in the form of dissertations or research papers. Moreover, simulation model documentation is heavily dependent upon time and budget constraints both in academia and industry.

The above discussion suggests that the type and extent of documentation depends on the context of individual simulation modellers. It is up to the individual to decide what kind of documentation is needed under specific context. However, I explored what the participants document in a simulation model and what should be documented as shown in Table 6.7. The findings about the documentation practices of the participants have been used to devise the documentation guidelines for simulation projects as a part of the RMSP. This will be further explained in the next chapter.

6.4.2. Maintenance

Most of the participants say that they rarely have to come back to maintain their models, and if they have to it is usually not a big problem because the model has been developed by themselves and they understand their style of model building. Therefore, to most of the participants maintenance of simulation models is not an issue. However, in the rare instances when they have to change a model developed by someone else, maintainability is an issue. Only S6 says that maintainability of the models can be a potential issue, and R2 thinks that it can be an issue only for big models. Most of the participants think that maintainability cannot be an issue for the type of models they develop. However, S8, R2, R3, R4, R5, and R6 say that they have faced problems while maintaining models developed by someone else. Only R9 points out that maintainability can be a problem even for his own models if not documented properly.

Participants think that poor documentation is one of the biggest reasons for problems in maintaining models. Other reasons, pointed out by S6 and R5, includes poor design and large amounts of input data.

The participants think that the best way to take care of the maintainability of a simulation model is to provide as many comments as possible within the model. If the model is to be used and maintained for a long time then coherent documentation should be provided. S5 and R1 think that we should make the structure of model modular because this enhances understandability, which in turn make it to maintain the model. S6 suggests that tools should be more supportive of model maintenance. S8 and R8 suggest that separating the contents (data) from the presentation (model structure) can be potentially very helpful to build maintainable models. S9, S10 say that adopting a reusable architecture would enhance maintainability. R2 and R3 say that ongoing client contact is another important aspect to be taken into account for building maintainable models. R5 says that simplicity and clarity is the key to model maintainability.

In my preliminary survey, most of the respondents indicate that they are concerned with the maintainability of the models they develop, which prompted me to explore under what situations the simulation modellers are concerned about maintainability and how do they take care of maintainability. However, the results of this in-depth study suggest that maintainability of simulation models is not an issue in most cases, mainly because models they develop are mostly for short-term use. Although the participants have mentioned various ways by which maintainability of simulation models can be enhanced, maintainability is often only an issue when in rare cases they have to maintain models developed by some other modeller.

6.4.3. Evaluation

In response to the questions relevant to simulation model evaluation, every participant straightaway started talking about validating and verifying the simulation models. To most of the participants, simulation model evaluation is driven by client satisfaction. The participants S9, S10, and R1 evaluate simulation model usability and performance; however nothing is done formally. Two participants, S4 and R8, think that a simulation model's documentation, maintainability, usability, and usefulness should be evaluated. It is interesting that both participants (S4, R8) who think that documentation, maintainability, usability, utility and performance should be evaluated are consultant/researchers. And S9, S10, and R6, who evaluate usability and performance, are also consultants/researchers. This is perhaps because these participants view evaluation from both a commercial and an academic perspective.

Most of the consultants think that conducting a formal evaluation is not of value in the commercial world where the success of a simulation project is assessed in 'pounds and pennies'. They say that clients do not have any interest in how they develop or evaluate their models; clients are just interested in results, and the value that simulation may bring to them. If we save them money with simulation results, or they understand what they are trying to understand through simulation, they are happy. To the consultants in this sample, satisfying the client is the best way to evaluate a simulation project. Moreover, they say that in the business world, most simulation models are small, quickly developed for some specific problem, and given that the business context changes over time, the model developed may not be useful after a month. The cost of putting lots of resources into evaluating these disposable simulation models would be excessive compared to the benefits. In R2's opinion it can be a good research question as to how to evaluate simulation models, but the commercial world is driven by financial gains from simulation studies. Exhibit 6.6 presents some excerpts of the conversation with practitioners about evaluation:

Exhibit 6.6: Quotes from transcripts about simulation model evaluation

R2: *"Well, I think it [not doing formal evaluation] is certainly an intellectual compromise...I think on the other hand you can know by looking at the commercial benefits that you are producing...so things round about between the two really..."*

R3: *"evaluation from my point if view would be customer satisfaction... you know it doesn't really matter whether a model is 60% or 100% accurate if the customer is happy with your analysis and results"*

S10: *Surely we monitor performance for the models because that's important and in terms of usability, we are quite sensitive about that*

S10: Yes, we ask the user, do you like it? He may say yes or no... so we can ask what you don't like and they tell us and we change (laughing)...

Most of the researchers in this sample think that a rigorous evaluation of simulation models is not needed in research, because they publish papers on simulation models which are peer reviewed and presented at conferences. They say that the assessment of PhD dissertations by the examiners is also a kind of evaluation for their simulation models. Furthermore, in research, along with other academic responsibilities, they do not get enough time to do a lot of evaluation.

The results of this section are also contrary to what I found in my preliminary survey. In my preliminary survey, most of the respondents indicate that they formally evaluate their simulation models, which inspired me to discover what formal evaluation means to expert simulation modellers. In this in-depth study, the results suggest that validation and verification of simulation models and client satisfaction is equivalent to evaluation for most of the participants. Other aspects of evaluation such as documentation, maintenance, usability, and performance are also important; however, the nature of the simulation models they develop do not require rigorous evaluation, and their circumstances do not allow them to perform evaluation of these aspects.

6.5. Conclusion

In this chapter, I have reported the results related to answering my first two research questions:

RQ1: What are the modelling contexts of simulation modellers?

RQ2: What are the modelling practices of simulation modellers?

I have presented the results from an interview study investigating the contexts and practices of the simulation modellers who participated in this study. There are 20 participants in total; 10 participants come from software process simulation modelling (SPSM) and the other 10 from operational research (OR) simulation modelling. Both groups have a mix of simulation researchers and consultants. The average experience of the sample in simulation is 8.5 years.

The contexts of the participants in this study includes the types of simulation models developed, simulation tools and techniques, size and complexity of models, and the kind of teams they work in.

The types of model developed by the participants have been classified with regard to their aims, application area, problem domain, and term of use. Most the participants develop process simulation models to study, plan, control, and manage the issues of cost, quality, and resources. The models developed by most of the participants are for short-term use, however, on rare occasions they have also developed models for longer term use.

Witness, Extend, and Vensim are the most popular tools amongst these participants. Some participants indicate that the tool selection is a crucial decision for simulation model development. Most of the participants have experience of working both with discrete event and continuous techniques. Only 3 participants have experience of using continuous simulation exclusively while 8 participants have worked exclusively with discrete event simulation.

Most of the participants develop simulation models of small and medium size. Also most of the participants develop simulation models of low or medium complexity. Most of the participants also believe that simulation model size and complexity are related, i.e. the bigger the simulation model, the higher the complexity will be.

Most of the participants work alone on their simulation projects. On rare occasions, most of them have worked in small teams (2-5 people) with other modellers, data collectors, or domain expert. Communication with other people involved appears to be the single biggest problem when a simulation modeller has to work in a team.

The practices of the participants include their documentation, maintenance, and evaluation practices.

Most of the participants think that the best documentation for a simulation model is comments within the code or the comment boxes provided by the simulation tool. The amount and extent of documentation for a simulation model depends on many factors such as type of simulation project, size and length of simulation project, time and budget available, model users, relationship with the client, and simulation team and model life.

Even though on rare occasions many of the participants have had to maintain simulation models developed by someone else and they faced problems in doing so, maintenance does not seem to be an issue. This is primarily because models are rarely maintained and very few simulation models are of long-term use. The participants think that the best way to enhance the maintainability of a simulation model is to provide as many comments in the model as possible, together with other documentation. Other recommendations include building the model in a modular structure, separating data from presentation, heavy client contact, and keeping models simple and clear.

To most of the participants, client satisfaction is the key indicator for model evaluation. Validation and verification appears to be the key evaluation activity. A few of the participants say that they sometimes evaluate usability, performance and documentation of the models. In the case of research, the participants say that their papers are peer reviewed and dissertations examined by the supervisors and examiners, which work as evaluation.

A discussion of simulation modellers' contexts and practices has provided a background within which the RSMP has been developed. In the next chapter, I analyse and discuss the simulation modelling process of each participant and explain how the RSMP has been developed in the context of results presented in this chapter.

7. Chapter seven: Developing the RSMP

7.1. Introduction

In this chapter I seek to answer my third research question:

> *RQ3: What process emerges by investigating the contexts and practices of simulation modellers?*

I describe my approach to developing the rapid simulation modelling process (RSMP) for novice software process simulation modellers. The RSMP is based on the analysis of empirical data collected in the semi-structured interviews with expert modellers in software process simulation modelling (SPSM) and operational research (OR). Chapter 6 has presented the results of the interviews describing the contexts and practices of the participants. In this chapter, I present a bottom-up approach by which I have analysed the simulation modelling process of each participant, providing a background to their context and practices, identifying commonalities and differences between the two groups. The RSMP has been built on success criteria described in Chapter 4 and evaluated subsequently against those criteria in Chapters 8 and 9.

At this point, it would be useful to restate the steps taken to develop the RSMP to increase the internal validity of the RSMP. Although many simulation modelling processes have been reported in the literature, nevertheless it is very difficult to find out the steps taken by the authors to develop the processes. This will not only provide evidence to internal validity of the RSMP but also provide a baseline for the replication of such studies.

The following seven steps have been undertaken to develop the RSMP:

1. Conceptualise the ideas to be explored and establish the research questions
2. Define objectives of the RSMP
3. Establish the process development and evaluation criteria

4. Conduct semi-structured interviews with expert simulation modellers

5. Analyse the contexts and practices of the interview participants

6. Analyse the simulation modelling processes of the interview participants

7. Define the RSMP

8. Compare the RSMP with the literature

This chapter reports on the latter four steps of the process of establishing the RSMP.

This chapter comprises of 5 sections. Section 7.2 presents an analysis of simulation modelling processes of the participants with a reference to their contexts. Section 7.3 defines the RSMP. Section 7.4 compares the RSMP with other simulation modelling processes reported in the literature. Finally, Section 7.5 concludes the chapter.

7.2. Analysing simulation modelling process of the participants

In this section I present an analysis of the simulation modelling process of participants and how the RSMP has been developed. There are 35 themes relevant to simulation modelling processes which have been identified from the interview transcripts. Each participant described his/her simulation modelling process at varying levels of detail. I present a summary of simulation modelling processes of the SE and the OR group. Then in section 7.2.1, I discuss each theme and compare the two groups; Section 7.2.2 explains how the large number of themes has been merged and consolidated into smaller number of themes to devise the RSMP.

Each participant's simulation modelling process has been summarised in a process matrix along with a summary of their contexts as shown by Table 7.1. In Table 7.1, S1 to S10 are the SPSM participants and R1 to R10 are the OR participants. Section 1 of Table 7.1 summarises the contextual information of the participants from Chapter 6.

Section II of Table 7.1 summarises 35 aspects of the simulation modelling processes used by the participants. Section II has been further divided into three sections; Phase-I, Phase-

II, and Phase-III of the simulation modelling processes. Appendix B8 provides definition for each theme presented in the Table 7.1.

A process diagram summarising each participant's simulation modelling process has also been sketched using the process matrix and analysing the data collected from the participants. These diagrams have been put together in Appendix B9. Figures S1 to S10 in Appendix B9 show simulation modelling process of the SPSM participants; figures R1 to R10 in Appendix B9 show process diagrams of the OR participants. The process matrix and process diagrams present a comprehensive overview of the process activities of the participants. This overview of process activities of the participants allowed commonalities and differences between the two groups to be identified. These are discussed in the next subsection.

Most of the participants described their process in a linear fashion, emphasising that there is always a fair amount of iteration in their process. The main process activities described by the participants are problem communication with the client, defining simulation objectives and questions, problem understanding and analysis, definition of inputs and outputs from the simulation model, model design, construction, verification and validation, and experimentation.

Figures S1 to S10 of Appendix B8 describe simulation modelling processes of the SPSM participants. Table 7.1 and the process diagrams show that some of the SPSM participants tend to use software engineering terms such as requirements, requirements analysis, basic and detailed design, and testing. S2 describes a spiral approach to simulation model development and S8 describes an evolutionary and iterative approach. S4, S5 and S10 describe a process similar to the waterfall model of software development, with steps such as requirements gathering, analysis, design, implementation, and testing (validation and verification). S7 said that he/she has a completely ad-hoc approach to simulation model development with no specific process steps. However, further discussion with S7 resulted in a four basic step processes as shown in figure S7 in Appendix B8.

Table 7.1: Context and Process matrix of the participants

		The SPSM group										The OR group									
		S1	*S2*	*S3*	*S4*	*S5*	*S6*	*S7*	*S8*	*S9*	*S10*	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
Section I – Context		* C = consultants, R= Researcher, CR = consultant cum researcher																			
1	Experience	*2*	*2*	*3*	*9*	*9*	*4*	*6*	*16*	*11*	*20*	13	2	7	6	14	8	10	4	6	9
2	Professional role	*R*	*R*	*C*	*CR*	*CR*	*C*	*R*	*C*	*C*	*CR*	C	CR	C	C	C	CR	R	CR	R	C
3	Discrete event simulation	X	X	X	X		X		X		X	X	X	X	X	X	X	X	X		X
4	System dynamics simulation			X	X	X	X	X	X	X	X					X	X	X		X	
5	Short-term use	X	X		X			X		X	X	X	X	X	X	X	X	X	X	X	X
6	Long-term use			X		X	X		X							X	X		X		
7	Small size	X						X												X	
8	Medium size		X	X			X		X	X	X	X	X	X	X	X		X	X		X
9	Large size				X	X											X				
10	Low complexity	X						X												X	
11	Medium complexity		X			X			X	X	X	X	X	X	X			X	X		X
12	High complexity			X	X		X									X	X				
13	Heavy client contact				X	X	X		X	X	X	X	X	X	X	X	X				X
Section II - Simulation Modelling Process																					
		Phase - I																			
1	Initial contact with client									X		X			X						
2	Problem communication									X		X	X		X		X				
3	Quick sessions with customer															X					
4	Simulation user/domain expert identification			X					X	X		X	X						X		
5	Setting goals	X	X		X				X	X		X	X	X	X		X				X
6	Questions	X			X		X	X	X			X	X		X		X		X		X
7	Requirements gathering		X		X						X			X							
8	Req. Validation				X																

		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10
9	Identify and define model inputs	X	X	X	X					X		X	X	X	X						X
10	Identify and define model outputs	X		X	X							X	X	X	X						X
11	System/problem understanding and Scope			X			X	X		X		X	X	X	X			X	X		
12	Requirements/process Analysis	X		X	X	X	X			X	X			X			X	X	X	X	
13	Data/ analysis			X	X		X							X							
14	Conceptual modelling											X		X							
15	Conceptual model validation													X							
16	Influence diagram	X		X						X	X			X			X	X			
17	Scenarios					X				X	X										
18	Technical feasibility check			X						X		X			X						
19	Build prototype								X	X		X			X		X		X		X
20	V&V of prototype								X	X							X				
21	Planning																X				
22	Tool selection						X	X										X			
	Phase II																				
23	Design		X		X	X					X					X					
24	Basic design				X	X					X							X	X		
25	Detailed design				X	X					X										
26	Construction/implementation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
27	Model verification	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
28	Model validation	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
29	Calibration	X						X			X										
30	Testing					X					X										
	Phase III																				
31	Design Experiments		X	X						X			X	X	X			X			
32	Conduct experiment	X	X							X			X	X	X			X	X		X
33	Experiment results analysis											X		X	X						
34	Results presentation											X		X	X			X	X		X
35	Maintenance									X											

S3, S4, S5 and S9 described their process in much more detail than the others. S3 and S4 develop highly complex models and S5 develop large models; perhaps this could explain the detailed natured of their process. Also S3 and S4 have experience of working both with discrete event and continuous simulation.

Figures R1 to R10 of Appendix B8 describe the simulation modelling processes of the OR participants. The OR participants generally use mainstream simulation terminology. R1, R3 and R4 described their process in a highly detailed manner. R5 and R9 described their process at a very low detail.

7.2.1. Comparison of contexts and practices of the SPSM and OR participants

The RSMP is built on the basis of comparative analysis of the two groups of simulation modellers. Comparison between the groups identifies where the two groups differ and provides basis for inclusion or exclusion of process activities in the RSMP. This section brings forward a summary of findings about the contexts and practice of the participants to set the scene for the RSMP development.

Analysing the two groups, several commonalities and differences can be observed between them:

Modelling contexts

1. The average simulation experience of both groups is similar i.e. 8.2 years for SPSM group and 8.9 years for the OR group.

2. Both groups have an equal number of participants who are consultant cum researchers. There is a little difference in number of researchers and consultants in both groups.

3. Both SPSM and the OR group develops simulation models which are mainly applied in the areas of process improvement, process understanding, project planning and management, technology adoption, and project/process control and operational management.

4. Participants in both groups are concerned about modelling tools and believe that modelling tools may affect the time it takes to develop the simulation model. Therefore modelling tools should be selected carefully.

5. Most of the SPSM participants use both discrete event and system dynamics for simulation modelling; while most of the OR participants use only discrete event simulation.

6. Most of the participants in both groups say that they develop medium sized simulation models.

7. Most of the participants in both groups say that they develop simulation models of medium complexity.

8. The majority of the participants in both groups say that the models they develop are generally of short-term use.

9. All the participants in both SPSM and the OR group say that typically they develop simulation models alone. Therefore, simulation model building tends to be an individual activity. However, they have to work with the client, model users or the domain experts to understand the problem and get data.

Modelling process: Phase I

10. Only three participants in each group mentioned simulation user identification as a step in their process. The user can be the client or some other person in the organisation who needs results from the simulation study. They claim that establishing who the user of the simulation is very important to increasing confidence in the study results. This is because without close interaction with the user, a simulation study may not be of any value to its users. Moreover it is also important to identify the domain or subject matter experts with whom the simulation modeller may need to liaise during the model development.

11. Most of the participants in both groups indicate that the identification of simulation goals/objectives and simulation questions is one of their earliest steps in a simulation study.

12. Some of the SPSM participants used the term "requirements gathering" while talking about simulation goals and questions. This is perhaps because of their software engineering background.

13. Some participants in both groups (S7, S8, R2, R5, R10) do not spend much time on analysis and design, rather they identify simulation goals, gain a basic understanding of the problem and develop a simple and small simulation model straightaway, adding details as they go.

14. Most of the participants in both groups emphasised developing a firm understanding of the problem and capturing the scope of the problem. They talked about identifying the factors contributing to a system/process, understanding relationships between different factors/variables, and confirming those relationships with the client/users.

15. Some of participants in both groups emphasised that diagramming methods should be used to illustrate relationships between various factors. This would not only enhance problem understanding but also helps validating the problem understanding with the client.

16. Most of the participants in both groups say that identification and definition of inputs and outputs of a simulation model is very important and should be started in the earliest stages of a simulation study.

17. Two participants from the OR group mentioned conceptual modelling as part of their simulation process. Conceptual modelling in the general simulation literature is said to consist of detailed analysis of the problem and designing the simulation. Analysis would be a detailed account of all the activities performed for problem understanding, identification of variables and the relationship between them. Robinson [2004] defines a conceptual model as, "*a non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model*".

18. Two participants in each group mentioned checking technical feasibility; i.e. whether simulation is an optimum tool for answering the problem. Moreover, simulation may not

be needed to solve certain simple problems; in such cases simulation would prove to be rather an expensive solution.

19. The OR group (R1, R4, R6, R8, and R10) emphasised on prototyping or building an initial simple abstraction of the whole problem, whereas in the SPSM groups, only S8 and S9 explicitly talked about prototyping. These participants think that building a prototype and then getting feedback from the client helps validate problem understanding and also in checking the feasibility of the simulation tool.

20. Only one participant, R6, mentioned planning as a step in the simulation modelling process. R6 developed very big and highly complex models with a team of people; perhaps this is the reason that he/she mentioned planning as an important step.

21. Simulation tools can positively or negatively impact the efficiency and performance of simulation modellers, according to S6, S7, and R7. None of the other participants mentioned tool selection as a part of their process.

Modelling process: Phase II

22. Only a few of the participants in either group mention simulation model design as part of their process. Only three participants in each group talk about design as a process step; three of these participants claim to be developing big and highly complex models. The results from my preliminary survey indicate that simulation model design is considered to be an issue, however, only a few participants in this study indicate that they do model design any formally. One possible explanation, as mentioned by S2, that the nature of simulation modelling does not require to devise a design prior to constructing the model; because most of the time in the early stages of modelling, neither client nor modeller understand the problem for which the model is to be designed; therefore it is difficult to design a model for which requirements are not clear. Another possible explanation could be that most of the simulation projects developed by these participants are small or medium which take a few days, weeks or months to develop; for such small projects as S8 says, it is not feasible to spend too much time on formally designing the simulation model.

23. All participants talked about building or constructing the simulation model using some simulation tool or programming language. Verification of the model is performed as the model is constructed. Most of the participants say that the whole simulation should not be constructed in one go, rather the validation of the model with the customer should be performed as parts of model are completed. During verification or validation, the modeller may discover some bug or problem with the model and may have to go back to develop further understanding of the problem. Almost all the participants emphasise that a modeller must provide sufficient comments in code or comment boxes while developing the model. This is crucial to understanding the model in case the modeller or some other person has to change the model at some later time.

24. Both groups have a similar view of evaluation; they consider validation and verification as equivalent to evaluation. Evaluation is driven more by customer satisfaction than any other factor. Participants in the SPSM group refer to model validation and verification in numerous ways such as testing, calibration and validation and verification. However, the OR groups has one universal term, validation and verification.

Modelling process: Phase III

25. Most of the OR participants explicitly mention experimentation as part of modelling process. They describe that designing the experiments, analysing the results and presenting the results to the client are important tasks for conducting experiments with the simulation models.

26. Most of the participants in the SPSM group do not appear to discuss experimentation as part of their process. In simulation, experimentation means using the model for the purpose it has been built i.e. gaining the results for decision making; as described earlier, most of the times simulation models are used by the modellers to draw results and present to the customer. In software engineering, however, software is developed, tested, and handed over to the customer for its use; therefore, the use of software is not typically part of software development process. Perhaps this is the reason that most of the SPSM participants, affected by their software engineering background, do not mention experimentation as part of their process.

Client contact and rapid development

27. Most of the participants in both groups emphasise heavy client contact. It is important to note that those who have emphasised heavy client contact are consultants or researchers cum consultants. This is perhaps because in a research environment there is usually no client; therefore, the researchers do not mention heavy client contact as an important part of their process.

28. Most of the consultants indicate that in the commercial world it is very important to deliver a solution to the client very *rapidly*; because processes have to adapted according to changing business need. If a simulation study takes months or years to deliver the results, it may not be of use to the client because during that time the business would have changed even further. Moreover, when the client is spending money on a simulation study, he/she wants to see the results instantly. Therefore, a simulation modeller must involve the client heavily and adapt his/her modelling process according to the client needs in order to deliver the results and recommendation quickly.

Documentation practices

29. Most of the participants think that the best documentation for a simulation model is to put comments in the code or the comment boxes provided by the simulation tool rather than producing formal documents.

30. As shown in Chapter 6 (Table 6.10), most of the participants say that simulation goals and objectives should be clearly stated in the documentation (in comments or in formal documents) and be agreed upon with the client. However, a few of the participants also think that the scope of the model should also be defined in the documentation.

31. Some of the participants recommend that model inputs and outputs should also be defined so that the model can be well understood in future if needed.

32. Some of the participants think that the relationships between data items (inputs and outputs) should also be documented along with an influence/process diagram or using

some other diagram methods. An overview of model structure or model working is also necessary to understand the model.

33. Most of the participants say that they produce reports or presentations of the simulation results which are presented to the client. These reports or presentation include the report of experiments, the scenarios and assumptions under which experiments have been run, analysis of results and recommendations from the analysis.

Others

34. Most of the OR participants do not consider it important to reuse the model for a similar problem in future. This is because they think that a model developed at one point in the past may be not depict the real world as it is now; as R3 says "*the business changes so much that the objects become out of date; I wonder if they are updatable*". However, some of the participants mention that the experience and learning gained from simulation projects is reused in subsequent projects. This finding is similar to what is found in literature that reuse in simulation is difficult therefore not much practiced [Robinson et al. 2004].

35. Two of the SPSM participants, S4 and S6, mention that they reuse parts of their existing models.

36. Neither group emphasises simulation model maintenance. Only S9 explicitly mentions maintenance as part of the process; no one else discuss maintenance as part of their process.

7.2.2. Consolidation of process matrix

I identified 35 low level themes related to process activities by the analysis of the participants' interview data as shown in Table 7.1. Many of these themes share some similarities and can be put together as one theme. In this section, I describe how the similar low level themes have been put together in order to devise the RSMP. Table 7.4 shows the corresponding themes of Tables 7.2 and 7.3.

Table 7.2: Consolidated RSMP process matrix

	The SPSM group										The OR group									
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S10**	**R1**	**R2**	**R3**	**R4**	**R5**	**R6**	**R7**	**R8**	**R9**	**R10**
Phase I - Foundation																				
1. Problem communication									X		X	X		X	X	X				
2. Problem definition																				
2.1. Simulation user/domain expert identification			X					X	X		X	X						X		
2.2. Define simulation goals and questions	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X				X
2.3. Identify and define model inputs	X	X	X	X					X		X	X	X	X						X
2.4. Identify and define model outputs	X		X	X							X	X	X	X						X
2.5. System definition	X	X	X	X	X	X	X		X	X	X	X	X	X		X	X	X	X	
2.6. Influence diagram	X		X						X	X			X			X	X			
2.7. Initial identification of experimental scenarios					X				X	X										
2.8. Technical feasibility check			X						X		X			X						
3. Prototyping								X	X		X			X		X		X		X
4. Tools selection						X	X										X			
Phase II - Construction																				
5. Design model structure		X		X	X					X					X		X	X		
6. Construction/implementation	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
7. Model verification	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
8. Model validation	X	X	X	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X
Phase III - Construction																				
9. Design Experiments		X	X						X			X	X	X			X			
10. Conduct experiment	X	X							X			X	X	X			X	X		X
11. Experiment results analysis											X		X	X						
12. Results presentation											X		X	X			X	X		X

Table 7.3. Consolidation of process matrix

Process matrix of Table 7.1			Consolidated process matrix of Table 7.2	
Phase I – Foundation				
1	Initial contact with client	>>	1	Problem communication
2	Problem communication			
3	Quick sessions with customer			
			2	Problem definition
4	Simulation user identification	>>		2.1. Simulation user identification
5	Setting goals	>>		2.2. Define simulation goals and questions
6	Questions			
7	Requirements gathering			
8	Req. Validation			
9	Identify and define model inputs	>>		2.3. Identify and define model inputs
10	Identify and define model outputs	>>		2.4. Identify and define model outputs
11	System/problem understanding or Scope	>>		2.5. System definition
12	Requirements/process Analysis			
13	Data/ analysis			
14	Conceptual modelling			
15	Conceptual model validation			
16	Influence diagram	>>		2.6. Influence diagram
17	Identification of initial experimental scenarios	>>		2.7. Identification of initial experimental scenarios
18	Technical feasibility check	>>		2.8. Technical feasibility check
19	Build prototype		3	Prototyping
20	V&V of prototype			
21	Planning			
22	Tools selection	>>	4	Tools selection
Phase II – Construction				
23	Design	>>	5	Design model structure
24	Basic design			
25	Detailed design			
26	Construction/implementation	>>	6	Construction/implementation
27	Model verification	>>	7	Model verification
28	Model validation	>>	8	Model validation
29	Calibration			
30	Testing			
Phase III - Experimentation				
31	Design Experiments	>>	9	Design Experiments
32	Conduct experiment	>>	10	Conduct experiment
33	Experiment results analysis	>>	11	Experiment results analysis
34	Results presentation	>>	12	Results presentation
35	Maintenance	>>		

Process activities which occur in the processes of six or more participants have been retained in the consolidated process matrix (Table 7.2). Moreover, three process activities, 'initial identification of experimental scenarios' (theme 17 of Table 7.1), 'technical feasibility check' (theme 18 of Table 7.1), and 'tools selection' (theme 22 of Table 7.1) has been retained, which have been included in the RSMP as optional activities. However, the process activities which occurred only once, for example 'planning', (theme 21 of Table 7.1) and 'maintenance' (theme 36 of Table 7.1), have been removed because the majority of the participants do not mention in the simulation modelling process.

Here one may question as to how I have decided on the threshold of themes occurrences so that they should be included in the consolidate process matrix. This is a very subjective decision. I decided to include only that process activity for which a justification of its importance can be found in the interview data and it has occurred at least six times. If I had decided on a higher threshold, for example 10 occurrences, a number of important process activities such as the whole experimentation phase would have been lost. There is no doubt 'planning', which has been mentioned by only participant R6, is an important process activity and has not been retained in the consolidate process matrix (Table 7.2); perhaps, this is because R6 works on very large and complex simulation projects involving teams of simulation modellers, users, and domain experts. Planning is certainly an important activity when there is a large simulation projects, however, most of the participants in this study do not mention it, perhaps because they work on comparatively smaller and short-term projects.

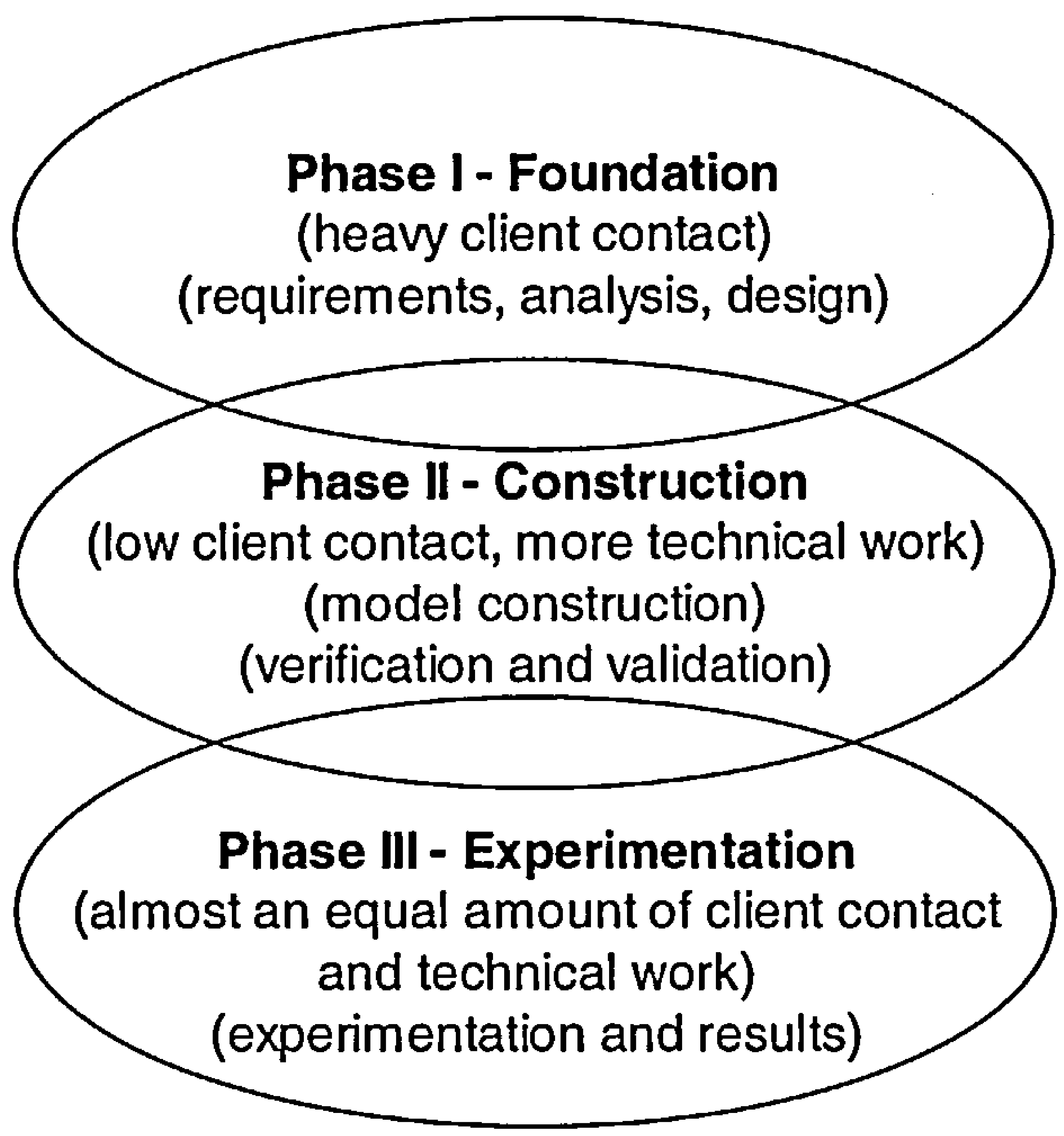
The process activities shown in the process matrix (Table 7.1) are fairly low level, and similar themes have been grouped under one theme to form a generic set of activities. Therefore, similarity between themes in the process matrix (Table 7.1) have been identified and consolidated into generic themes. Analysing the themes in Table 7.1 reveals that three phases can be observed in the simulation modelling process of both groups as shown in figure 7.1. However, these phases cannot be said to be completely mutually exclusive. The consolidation of low level themes into generic themes resulted in a consolidated process matrix as shown in Table 7.2. The consolidated process matrix (Table 7.2) and Figure 7.1 shows that Phase-I of the process matrix has been named the Foundation phase, Phase-II the Construction phase, and Phase-III the Experimentation phase. These three phases are summarised as follows:

Phase-I: consists of non-technical work, where the modeller is in heavy contact with the client for problem understanding and analysis and/or design of the simulation model. The simulation modeller may do some technical work such as prototyping but this is to gain deeper understanding of the problem situation.

Phase-II: consists of the technical work for model building in simulation tool; there is a low amount of client contact. The client is contacted mainly during the validation of the simulation model. The simulation modellers may have to cycle between Phase-I and Phase-II if needed.

Phase-III: mainly consists of experimentation; experimentation may add to further validation of the simulation model; almost an equal amount of client contact and technical work has to be performed depending on the circumstances. Modellers may have to revisit to Phase-I or Phase-II.

Figure 7.1: Three phases of simulation modelling process



Following I explain how each of the three phases have been consolidated. Table 7.3 summarises the transformation of process matrix (Table 7.1) to consolidated process matrix (Table 7.2)

Phase-I - Foundation

Phase-I of the consolidated process matrix is called foundation. In this phase simulation modellers do the activities which build the foundation of a simulation project.

- Table 7.4 shows that the first three themes of the process matrix (Table 7.1), which are related to the problem communication with the client have been put under one theme in the consolidated process matrix (Table 7.2) as 'problem communication'.

- Table 7.4 shows that themes 4 to 18 of the process matrix (Table 7.1), which show the activities relating to problem understanding and definition, have been combined into 'problem definition' in the consolidate process matrix (Table 7.2).

- Table 7.4 shows that Problem definition of the consolidated process matrix (Table 7.2) has 8 sub-tasks; where some of these have been copied from the process matrix (Table 7.1) as they are while others are a consolidation of themes 5 to 18 of the process matrix (Table 7.1).

- Table 7.4 shows that themes 5 to 8 of the process matrix (Table 7.1), has been put together as 'define simulation goals and questions' in the consolidated process matrix (Table 7.2).

- Table 7.4 shows that themes 11 to 15 of the process matrix (Table 7.1), which relate to problem understanding and analysis, have been put together as 'system definition' in the consolidated process matrix (Table 7.2).

- Theme 21, 'planning', of the process matrix (Table 7.1), which was mentioned by only one participant, has been removed.

Phase-II – Construction

Phase-II of the consolidated process matrix is called construction. In this phase, simulation modellers do the technical activities related to development of the simulation model.

- Table 7.3 shows that themes 23 to 25 of the process matrix (Table 7.1), which are related to designing the model have been put together in one theme as 'design model structure' in the consolidated process matrix (Table 7.2).

- Table 7.3 shows that themes 28 to 30 of the process matrix (Table 7.1) have been put together as model validation in the consolidated process matrix (Table 7.2).

Phase-III - Experimentation

Phase-III of the process matrix is called experimentation. In this phase, simulation modellers conduct experiments with the simulation models, analyse the results and report those results to the client.

- Table 7.3 shows that themes 31 to 34 of the process matrix (Table 7.1), which are all related to conducting experiments, have been retained unchanged in the consolidated process matrix (Table 7.2).

- Theme 35, 'maintenance' of the process matrix (Table 7.1) has been removed because only one participant mentioned maintenance as part of the simulation modelling process; whereas none of the other participants talk about it being a step in their simulation modelling process.

7.3. Definition of the RSMP

Based on the comparative analysis of the contexts and practices of the two participant groups I have devised the rapid simulation modelling process (RSMP). This section presents an overview of the RSMP. A detailed description of the RSMP has been provided in Appendix C1.

The RSMP has three core phases; foundation, construction, and experimentation.

The RSMP also has two Key Process Areas (KPA); client contact, and documentation.

The RSMP core phases and the two KPAs have been determined by the analysis of empirical data gathered from the participants in this study. This section describes the scope under which the RSMP should be used, the RSMP core phases, and two KPAs of the RSMP.

Scope of the RSMP

Before describing the RSMP, first I must set out the scope under which RSMP should be used. The scope of the RSMP has been determined by considering the general contexts under which the participants of study develop simulation models.

- The RSMP is for individual modeller

  Most of the participants in this study say that they typically develop simulation alone. Therefore the RSMP is for individual modellers. If multiple modellers are working on the same simulation project, the RSMP as it stands may not be appropriate.

- The RSMP has been designed for use by novice software process simulation modellers

  The RSMP is aimed at novice software process simulation modellers to improve their simulation modelling practice; and it will be evaluated for novice modellers. I do not claim with confidence that the RSMP would be useable or useful for experienced modellers. However, as the findings are based on expert opinions, therefore expert simulation modellers may learn from each other's experience to refine their approach to simulation modelling.

- The RSMP is for small/medium simulation projects with low/medium complexity

  Most of the participants in this study work on simulation studies of small and/or medium with low and/or medium complexity. Therefore it should be used for such simulation studies. Novice software process simulation modellers, however, may need guidance as to scoping the size and complexity of a simulation model..

  Based on the data collected in this study, it is very difficult to define the size and complexity of a simulation modell; therefore it is up to the individual to decide subjectively the size and complexity of a simulation study. Nonetheless interview data indicates that there are a number of factors which may be considered to indicate the size and complexity of a simulation model. Figure 7.2 summarises the factors which can affect size and complexity of a simulation model.

Figure 7.2 shows that the size and complexity of a simulation model increases as the number of factors shown in the figure increase. For example, greater the number of question, greater will be the number of outputs, therefore higher the complexity. Similarly, greater the number of process steps to be simulated, larger the model size..

Figure 7.2: Factors affecting simulation model size and complexity

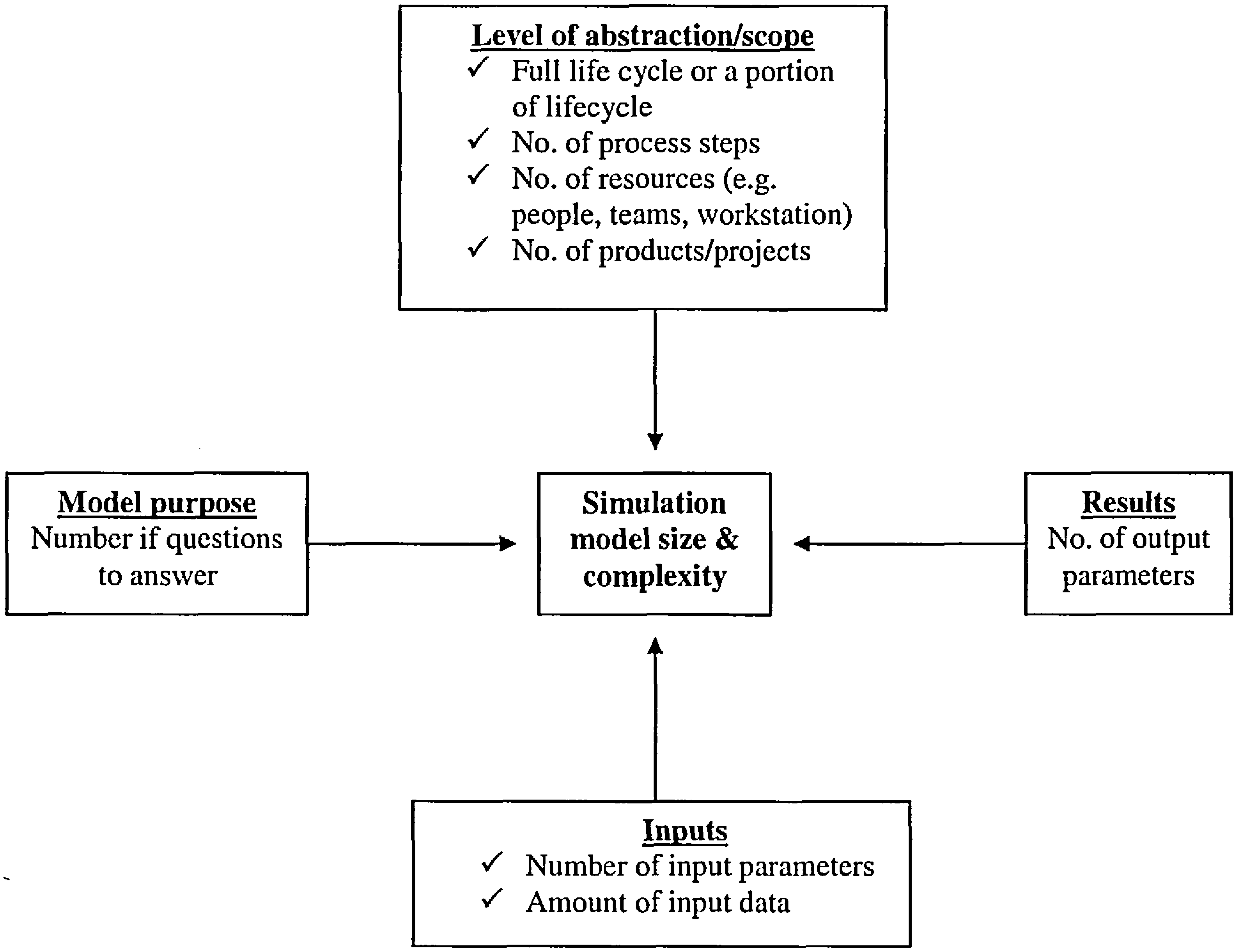


Figure 7.3 shows an example of a system dynamics simulation model of small size and low complexity. Figure 7.4 shows and example of a system dynamics simulation model of medium size and complexity.

Figure 7.3: An example of simulation model of small size and low complexity (Brooks law) [Madachy 2005]

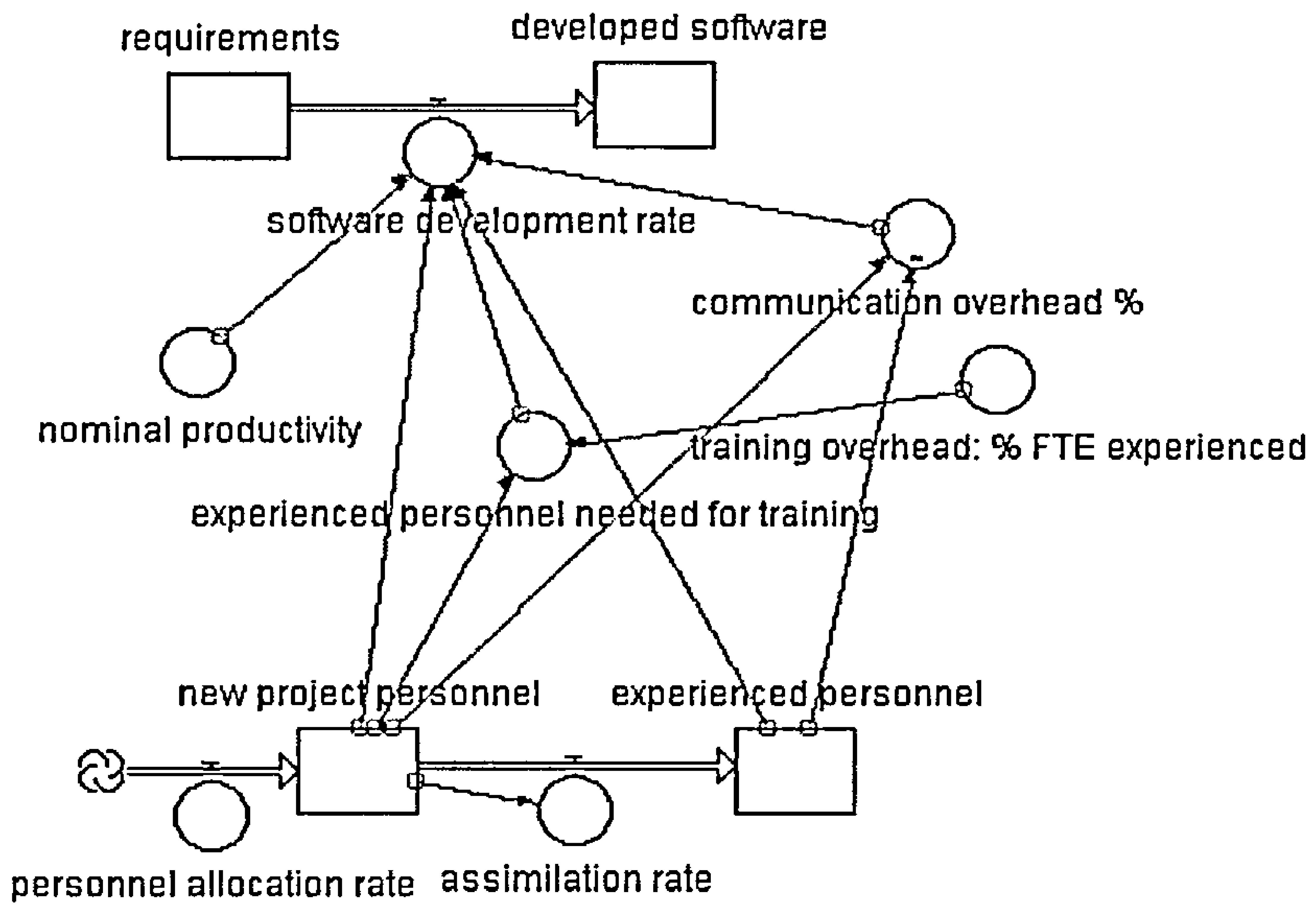
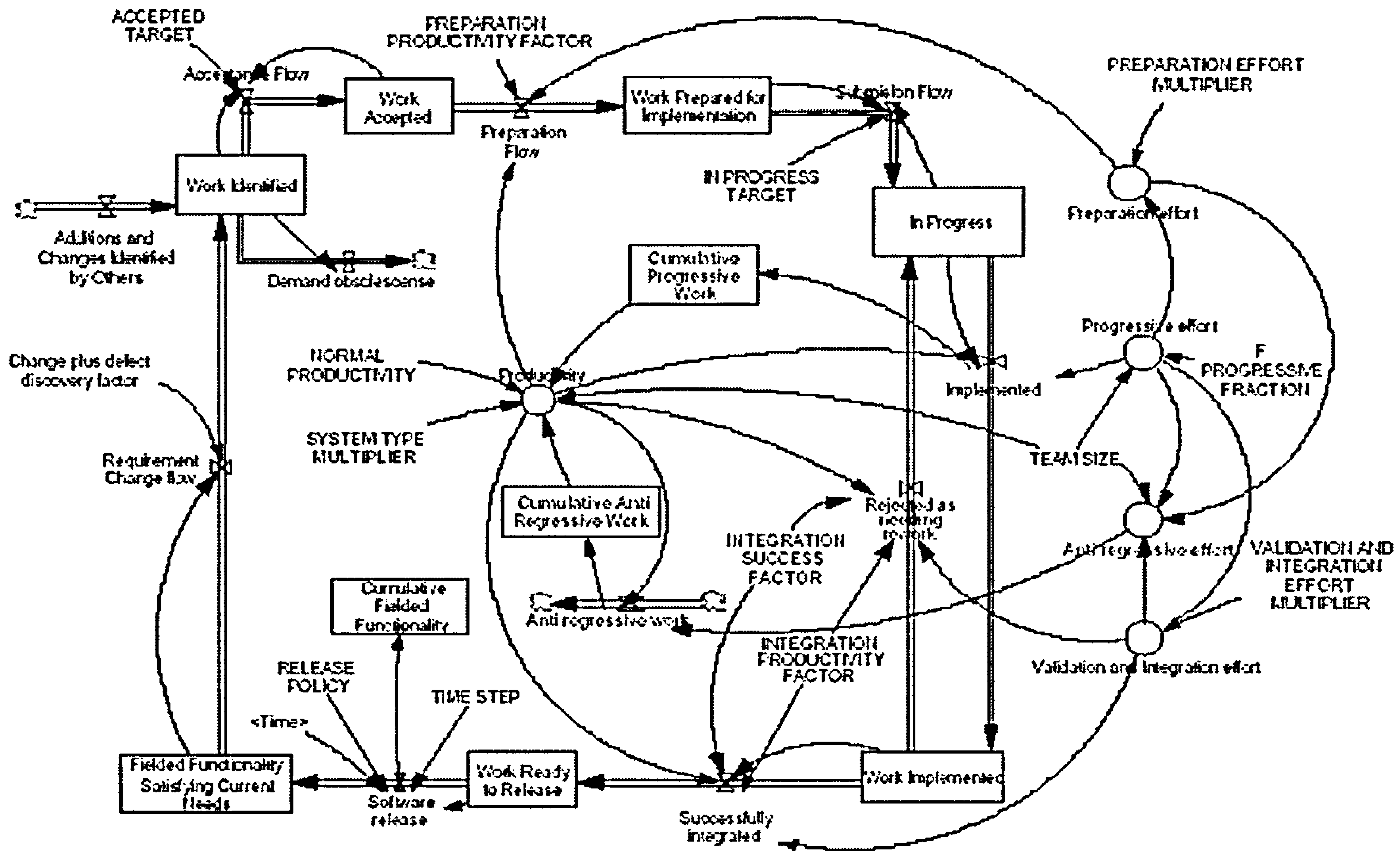


Figure 7.4: An example of simulation model of medium size and complexity (software evolution) [Lehman and Ramil 1999]



- The RSMP is intended to be independent of a particular simulation techniques (i.e. discrete event or continuous simulation)

  The participants in this study included modellers who work or have worked both with discrete event and continuous simulation. The RSMP is intended to be generic and independent of these simulation techniques; therefore can be used both for discrete event and continuous simulation.

The RSMP core phases and the two KPAs are described the next three sub-sections.

7.3.1. The RSMP core phases

The RSMP has three phases that should be followed for the development of a simulation model.

The RSMP core phases have been established from the consolidated process matrix (Table 7.2). The RSMP is an incremental and iterative process for simulation model development; movement is possible from one phase to other phases in the process of simulation model development. The RSMP has three phases as following:

- Foundation
- Construction
- Experimentation

Figure 7.5: High level structure of the rapid simulation modelling processes (RSMP)

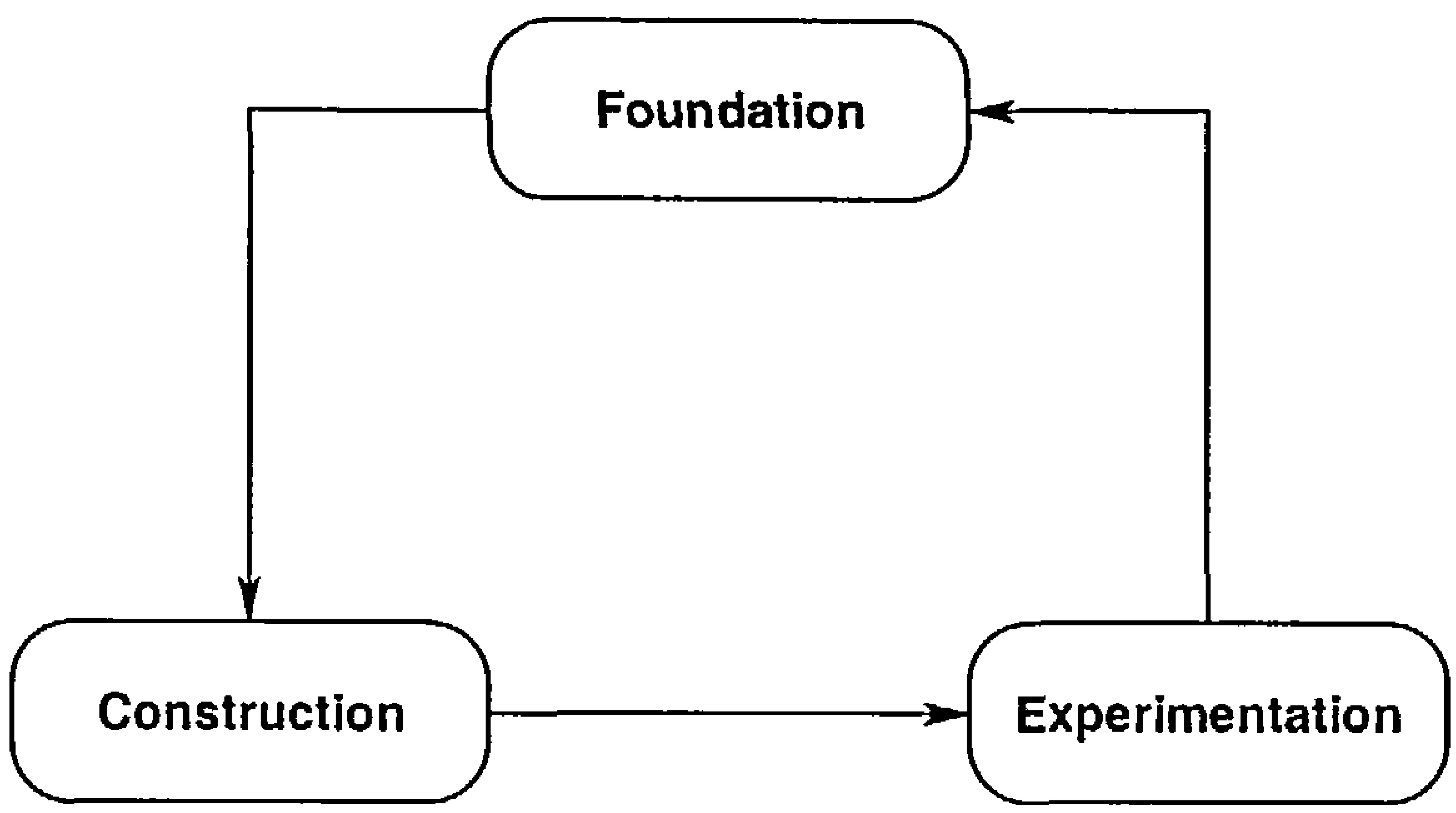
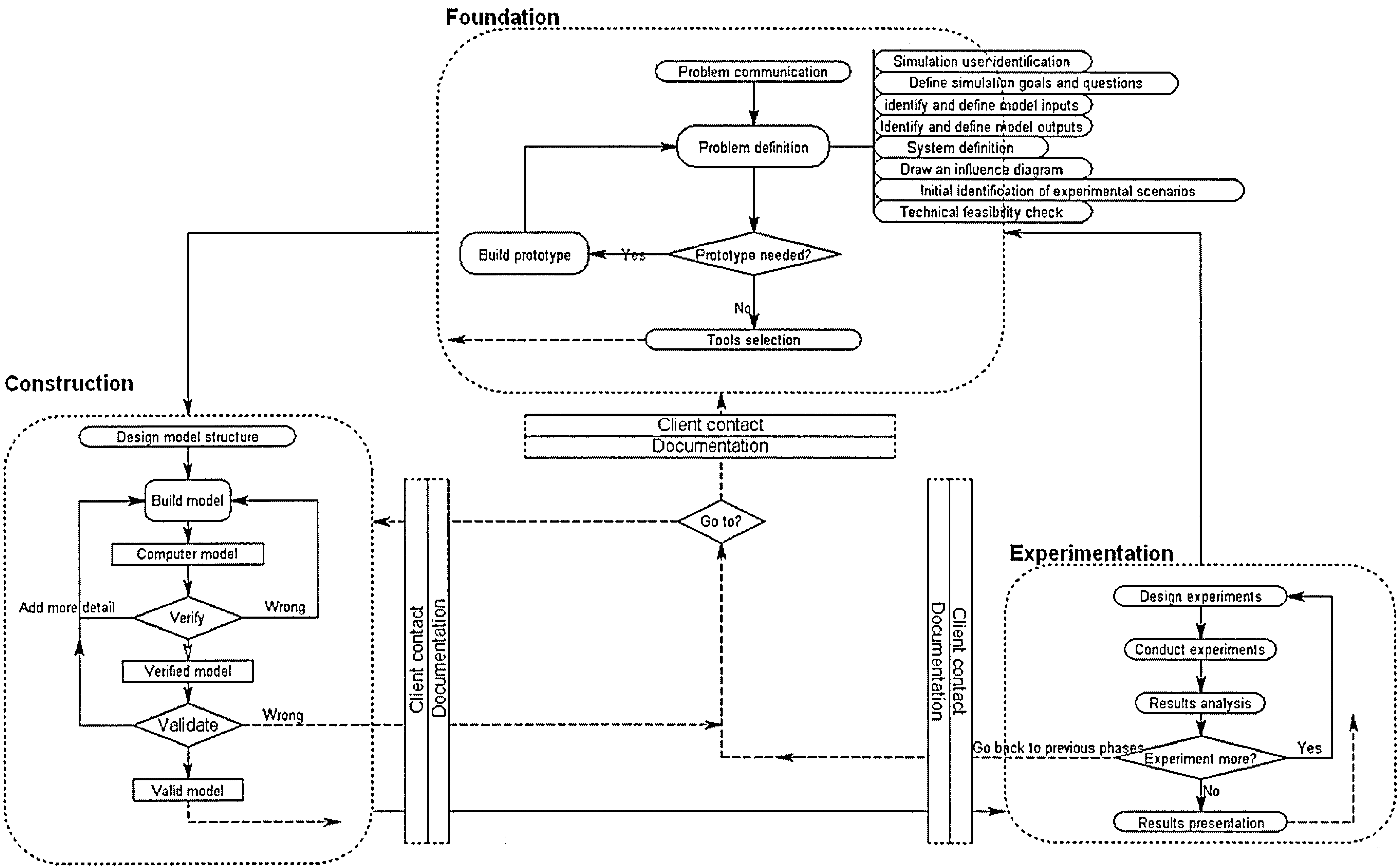


Figure 7.6: Detailed structure of the rapid simulation modelling processes (RSMP)



Each phase of the RSMP is defined in the next three subsections. Figure 7.5 gives a high level graphical representation of the RSMP. Figure 7.6 gives a detailed graphical representation of the RSMP. The notation in figures 7.5 and 7.6 have been adopted from Scholten and Udink [1999] to represent a process; where round cornered boxes represent activities, sharp cornered boxes represent products of the process activities, and diamonds represent actions. In Figure 7.6, the mandatory activities of the RSMP have been shown with a grey background, and the optional activities have been shown with a white background. Two thick parallel arrows show the two KPAs of the RSMP; the client contact and documentation throughout the process. Appendix C1 provides a detailed description of the RSMP in a tutorial format.

Foundation

The foundation phase sets up the foundation of the simulation study. It focuses on defining the modelling problem. There are several steps in the foundation phase. If a simulation is to be developed for a client then the client will communicate the problem to the modeller i.e. "problem communication" will typically be the first step.

The problem definition step comes after the problem has been communicated with the client. Problem definition includes defining the system, process or real world phenomenon that is to be modelled. There are several tasks in the problem definition step. Following a strict order of activities in problem definition is neither necessary nor practical. However, the identification of simulation users and/or domain experts should normally be the first step. The rest of the activities are not mutually exclusive, in fact they inform each other.

The whole simulation project is driven by simulation goals. A modeller needs to define the goals with the customer clearly and upfront. There can be single or multiple goals of a simulation study. On the basis of the simulation goals, the modeller will define the questions for which the client needs answers. System definition includes gaining an understating of the problem by analysing the problem, relevant and available data, and defining the problem scope.

Identifying proper and relevant input variables is very important to simulation. Precise and accurate data increase confidence in the results of a simulation study. Therefore, input data requirements will need to be identified and specified to the client. The analysis of outputs from a simulation model answers the questions for which the simulation study has to be carried out. Therefore outputs needed from a simulation model must also be defined. Model output will be defined based on model goals and simulation scope. Initially identified inputs and outputs may change over the course of analysis and model development.

Definition of model objectives, scope, inputs and outputs provides the modeller with an opportunity to identify the scenarios for which a simulation model will be experimented. It is a good practice to identify these scenarios in advance by discussing with the simulation users and refine them later when performing the experiments. However, this is an optional task. It is sometimes important to check whether it is technically feasible to develop a simulation of the problem in hand, therefore, technical feasibility check has also been included as an optional task.

The next step for the modeller is to decide whether a prototype should be built to gain deeper understanding of the problem under study. Talking through an initial prototype with the client may further inform the problem definition. The next step would be tool selection depending on the type of problem being simulated.

Construction

In the construction phase, a simulation model is generated using a simulation tool or programming language on a computer.

First of all the model structure should be designed. Different modellers may have different ways to structure their model. RSMP does not makes it mandatory to produce a design of the simulation model to be built; but, recommends it as a good practice to produce a model design before building the model. The structure of the model may be designed on paper or using a tool, depending on the nature of the problem.

Then start on building the model. This may be one sub-model or module or it may build on the initial prototype produced in the foundation phase.

The computer model is then verified. Verification is a micro-level check on model behaviour i.e. the modeller will check that correct logic has been employed. It is similar to software code debugging. If any problem is found in the model, the modeller may have to go back to the previous step and make changes in the computer model.

The next step is validating the model. Validation checks whether you have built the right model. The purpose of validation is to ensure that model behaves correctly overall. There are two dimensions to model validity; one from the modeller's perspective and the other from the client's perspective (often called credibility). In any model validation the client must be heavily involved. There are various validation techniques e.g. face validity, sensitivity analysis, and comparison with the real system. If the model is invalid, the modeller may have to revisit the foundation phase and then change the computer model as necessary.

Experimentation

Once the model has been validated the simulation study is still not complete. The experimentation phase is intended to provide the client with the answers to the questions he/she wants from a simulation study.

The experimental design is driven by the goals, questions and scope of the problem in the simulation study. Different simulation run scenarios are discussed with the client, which the model has to simulate. Experiments are designed on the basis of these scenarios. The rigour of experimentation depends on the scope and goals of the problem.

The results obtained from the experimental runs are analysed. At this point some changes may have to be made in the simulation model depending on the kind of results obtained. Under certain situations, clients may run experiments themselves and analyse results. The client may ask to change or add features to the model on the basis of the analysis. As a result the modeller may have to revisit foundation and/or construction phases

Once the results have been analysed they are put in a presentable format to facilitate the client with decision making. Results may be put in graphs or tabular formats. Any statistical analysis is discussed and conclusions provided.

7.3.2. KPA-I: Client contact

Most of the participants in this study have particularly emphasised the value of client contact. Therefore client contact has been included as a key process area in the RSMP. The aim of heavy client contact in the RSMP is to ensure continuous validation and verification of simulation modelling activities.

The success of the simulation study very much depends on how well the problem has been communicated between the modeller and the client. The foundation phase of the RSMP is highly client-intensive. The modeller works very closely with the client asking various questions to define the problem to be simulated. The modeller verifies and validates the identified inputs, outputs, problem understanding and scope, and influence/process diagram with the client.

In the construction phase of the RSMP, there is less client contact comparatively; however, the validation of a simulation model does need heavy client contact.

The experimentation phase entails both heavy client contact and technical work; where the simulation modeller communicates about the experimental scenarios and assumptions with the client, conducts experiments with the model, and present recommendations to client based on the results of the experiments.

The participants in this study view simulation modelling as an exercise of communication between the simulation modeller and the client. Therefore the RSMP requires a simulation modeller to have heavy client contact with the client during a simulation study.

7.3.3. KPA-II: Documentation

Documentation is the second key process area of the RSMP. The RSMP proposes documentation guidelines based on the data collected from the participants as described in Section 6.4.1 of Chapter 6. Appendix C1 provides a documentation template as a guideline for novice software process simulation modellers to document their models.

The most important aspect of documenting a simulation model is to provide comments when developing the model in the simulation tool. Comments are considered to be the most powerful form of documentation by the participants of this study. Therefore, the RSMP emphasises building highly commented simulation models.

The RSMP documentation guidelines mainly consist of defining the simulation model goals and questions, defining the scope of the simulation study, defining inputs and outputs, providing an influence/process diagram which shows how different factors interact with each other, and detailing how the model works.

The RSMP also provides guidelines on how to document experiments to be conducted with the simulation models. This entails defining the experimental scenarios, defining the assumptions under which each experiment is conducted, reporting on experiment results, analysing those results and presenting conclusions to the client.

The RSMP does not make it mandatory for simulation modellers to strictly adhere to the documentation guidelines; however, they provide a framework for documentation. This is because the rigour of documentation required in every simulation study is different based on various factors as described in Chapter 6. A simulation modeller may adapt these guidelines according to his/her own style and circumstances.

7.4. Comparison with the literature

The RSMP has been compared with simulation modelling processes reported in the literature to validate the RSMP and examine how well meets with its objectives.

The two objectives of developing the RSMP were (as described in Chapter 1):

I. Provide novices with a simulation modelling process which is close to real world simulation practice

II. Develop a simulation process which is independent of a particular simulation technique (i.e. discrete event and system dynamics)

Both in the software process simulation literature and the general simulation literature, authors have reported various proposed and practiced processes for simulation model development.

Table 7.4: The RSMP comparison matrix with the literature

	Rus et al. [2003]	Pfahl & Ruhe [2002]	Robinson [2004]	Law & Kelton [2000]	Shannon [1998]	Nordgren [1995]
Phase I – Foundation						
1. Problem communication		X		X		
2. Problem definition						
2.1. Simulation user and domain expert identification		X	X	X	X	
2.2. Define simulation goals and questions	X	X	X	X	X	X
2.3. Identify and define model inputs	X	X	X	X	X	X
2.4. Identify and define model outputs	X	X	X	X	X	X
2.5. System definition (scope and analysis)	X	X	X	X	X	X
2.6. Influence diagram	X	X	X	X	X	X
2.7. Initial identification of experimental scenarios	X				X	X
2.8. Technical feasibility check		X	X			
3. Prototyping		X				
4. Tools selection						
Phase II – Construction						
5. Design model structure	X					
6. Construction/implementation	X	X	X	X	X	
7. Model verification	X	X	X	X	X	
8. Model validation	X	X	X	X	X	
Phase III – Experimentation						
9. Design Experiments			X	X	X	X
10. Conduct experiment			X	X	X	X
11. Experiment results analysis			X	X	X	X
12. Results presentation			X	X	X	

These simulation modelling processes were not reviewed in detail until the RSMP had been developed so that the RSMP should not be affected by pre-knowledge gained from the literature.

In this section I compare the RSMP with some of the reported simulation modelling processes in the literature. Rus et al. [2003] and Pfahl and Ruhe [2002] propose processes for software process simulation modelling. Robinson [2004], Law and Kelton [2000], Shannon [1998], and Nordgren [1995] report simulation modelling process in OR. Robinson [2004] and Law and Kelton [2000] are text books, while Shannon [1998] and Nordgren [1995] are research papers reporting on the simulation modelling processes.

Table 7.4 compares the RSMP with other simulation modelling processes. A vis-à-vis comparison with all these processes is not possible because every author shows his/her process steps differently, but similarities and differences can be identified.

7.4.1. The RSMP and Rus et al. [2003]

Rus at al. [2001] proposed a simulation modelling process for the development of discrete event models of software development processes. Rus et al. [2003] suggest applying software engineering practices in a simulation modelling process. This process model consists of four steps;

[1]. Requirements identification and specification for the model to be built

[2]. Analysis of specification of the modelled process

[3]. Design of the model

[4]. Implementation of the model

This is very similar to a classic waterfall model. Rus et al [2003] say validation and verification is conducted concurrently with the model development.

Table 7.4 shows the similarities of the RSMP with the simulation modelling process of Rus et al [2003]. Rus et al.'s requirements identification step is similar to RSMP's goals and questions identification; their analysis step is similar to RSMP's input and output definition, system definition, and drawing the influence diagram. Rus et al's step 3 and 4 are similar to RSMP's construction phase.

Rus et al. do not mention the identification of user and domain experts as part of their process. Moreover, a technical feasibility check, prototyping, and tool selection have not also been considered.

Model implementation is the final step of Rus et al.'s process; where implementation means coding or building the model using a simulation tool or a programming language i.e. implementing requirements and design into a computer model. In the general simulation literature, the term implementation is used in a different context i.e. implementing the results obtained from the simulation study. For example Robinson [2004] defines implementation in three ways:

- Implementing results/findings of the simulation in the real world
- Implementing the model for day-to-day decision making
- Implementation as learning, where the simulation study provides enhanced learning to decision makers about their process

Implementation is the term used by many participants in my interview study; by implementation they mean building the model. Most of these participants have software engineering or computer science background. This shows a difference in the meanings of the same terminology amongst different domains of simulation modelling. Therefore the RSMP uses the term construction/implementation to maintain clarity in terminology

However, the main difference between the RSMP and Rus et al.'s process is experimentation. Implementation (model building) is the final step of Rus et al.'s process; they do not mention when to conduct experiments to gain the desired results from the simulation study. Even though Rus et al. include the 'definition of simulation model usage scenarios' as part of their process; it is apparent that they do not consider experimentation as part of the simulation modelling process, rather perhaps an activity apart from the simulation modelling process. The RSMP proposes that experimentation to be an integral part of simulation modelling process because the findings from my study suggest that during experimentation a modeller may have to go back to previous steps to refine the model scope or change the computer model.

The importance of client contact does not have a formal position in Rus et al.'s process. However, they emphasise documenting the requirements, analysis and design of the simulation models.

7.4.2. The RSMP and Pfahl and Ruhe [2002]

Pfahl and Ruhe [2002] propose a four phase process based on their experience of the development of system dynamics models of software engineering problems. These process guidelines are one component of a larger framework called a methodology for 'integrated measurement, modelling and simulation (IMMoS)'. Pfahl and Ruhe [2002] describe the following as four components of IMMoS:

- Process guidance for system dynamics model development
- A goal definition taxonomy which takes into account the roles involved in simulation, the scope of the simulation study, the purpose of the simulation, the focus (e.g. cost, quality, resource allocation etc.), and the organisational context in which the simulation is to be developed and applied.
- Integration of a system dynamics model with static SE models such as descriptive process models (DPMs) and quantitative models (QMs)
- Method integration: describing how system dynamics modelling of software process relates to the goal question metric (GQM) methodology of software engineering and enhancing the established GQM approach into a 'dynamic GQM'

Table 7.4 shows the similarities between the IMMoS process guidelines and the RSMP. The IMMoS modelling process consists of following four phases

[1].Pre-study

[2].Initial model development

[3].Model enhancement

[4].Model application

IMMoS phase 1, pre-study, largely consists of managerial activities of a simulation study such as customer agreement, project plan etc. The RSMP's foundation phase is very similar to some of the activities proposed in IMMoS process phase 1 and 2; however, identification of experimental scenarios and tools selection has not been considered in IMMoS. Moreover, it is not clear under which step of IMMoS process guidelines the definition of inputs and outputs is conducted.

The RSMP's construction phase is also quite similar to IMMoS process phase 2 and 3, except that IMMoS does not mention designing the model structure.

Again the main difference between the RSMP and IMMoS is experimentation. It seems that IMMoS considers experimentation as an implicit part of its phase 4, model application; where it does not explicitly mention that experimental scenarios are to be defined, experiments are to be designed, and experiment results are to be analysed.

Simulation model maintenance is considered to be a core activity of IMMoS phase 4. Amongst the six simulation modelling processes with which I have compared the RSMP, only IMMoS considers maintenance as an explicit part of the process.

Client contact does not have an explicit mention in IMMoS. However, most of the activities of IMMoS require a high degree of client contact. Moreover, IMMoS requires documenting all the activities very rigorously during the whole simulation modelling process.

A high degree of formality, breadth, and complexity in the terminologies used in IMMoS makes it very difficult for a novice simulation modeller to understand it. Moreover, the process guidelines heavily depend on other components of the IMMoS, which may make it hard to apply in a practical context.

7.4.3. The RSMP and Robinson [2004]

Robinson [2004] describes a process for the development of discrete event simulation model in operational research. Table 7.4 summarises the similarities of the RSMP with [Robinson 2004]. Robinson describes the simulation modelling process in four steps

[1].Conceptual modelling

[2].Model coding

[3].Experimentation

[4].Implementation

Robinson's conceptual modelling step entails most of the activities which are included in RSMP's foundation phase such as definition of goals and questions, definition of inputs and outputs, system definition (analysis and scope), influence diagram, and technical feasibility check. The difference is that the RSMP also includes an initial identification of experimental scenarios, prototyping, and tool selection as part of the process, which have not been taken into account in Robinson's process.

Robinson's process step 2 is similar to RSMP's construction phase with the difference that apparently Robinson does not take the model design into account.

The experimentation phase of the RSMP is very similar to Robinson's experimentation step.

However, Robinson's implementation step is not considered to be the part of the RSMP, where 'implementation' means implementing the simulation model or results of the simulation in real world.

Robinson's process steps are highly client-intensive; however, client contact does not have a formal position like the key process area in the RSMP.

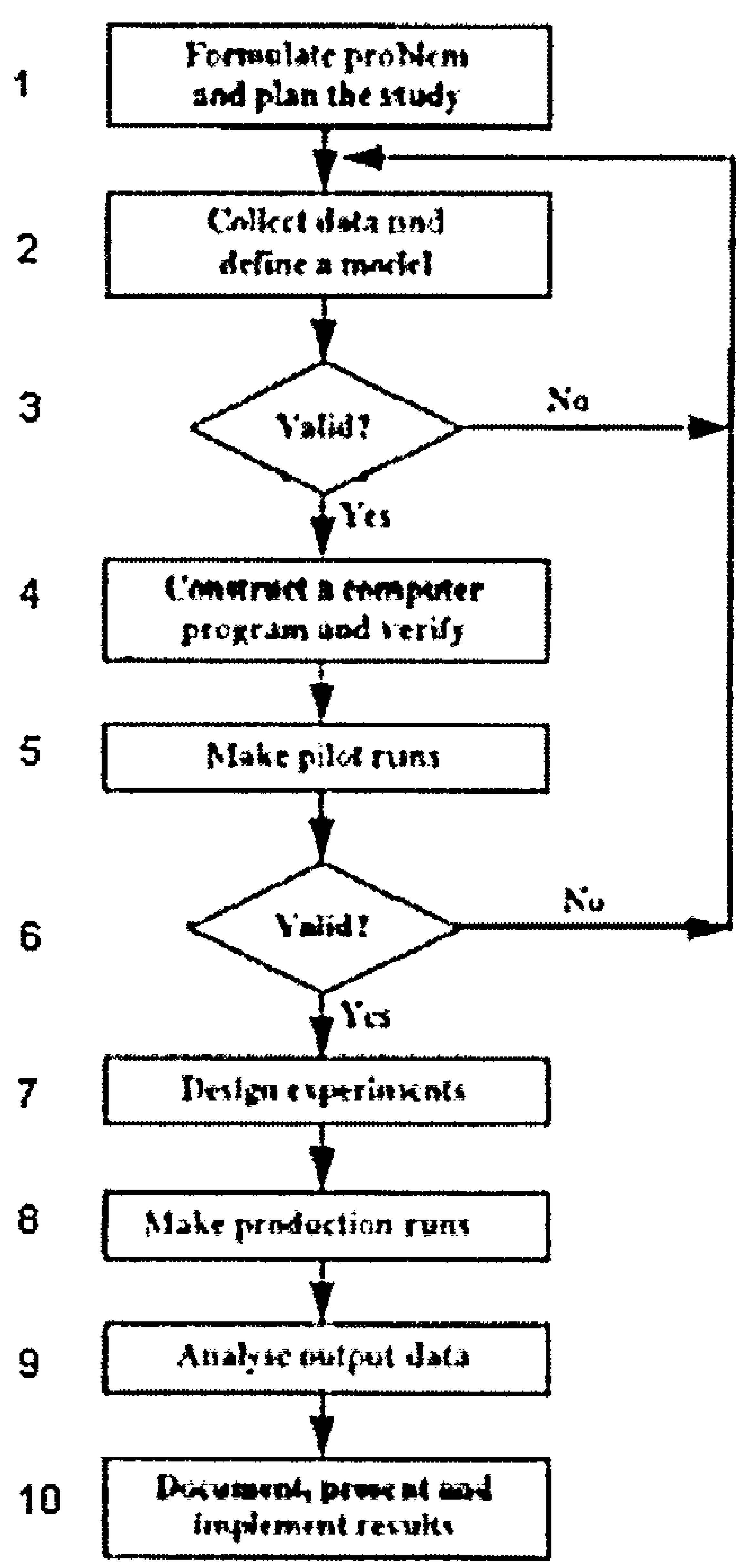
Robinson suggests three areas in which a simulation study should be documented; model documentation (input/out definition, model structure and working, comments in the code), project documentation (project specifications, experiments and their results, final report); and user documentation, which should be provided only when the simulation model is to be handed over to the client. In contrast to that, the RSMP documentation guidelines propose only model documentation and project documentation which are similar to Robinson's guidelines. The RSMP does not provide guidelines for user documentation because all the participants of this study indicated that they rarely have to hand over the model to the client. Robinson also notes that the required degree of documentation depends on the project circumstances and requirements.

7.4.4. The RSMP and Law and Kelton [2000]

Law and Kelton [2000], one of the most used text books for simulation modelling, proposes ten step process for the development of simulation models, as shown in Figure 7.7.

Steps 1 and 2 of Law and Kelton are similar to the RSMP's 'problem definition' step. Law and Kelton say that in the first step, the simulation modeller establishes simulation objectives and questions with the client and defines the scope; and in the second step collects data, analyses the problem, and builds a conceptual model. In contrast to that the RSMP does not propose such a sequence in problem definition, rather all these tasks in problem definition are inter-dependent and are performed virtually concurrently. Therefore the RSMP does not impose a strict order on the sequence of tasks to be performed in the 'problem definition' step.

Figure 7.7: 10 steps in a simulation study [Law and Kelton 2000]



Law and Kelton's process does not take into account other aspects of RSMP's foundation phase such as the initial identification of experimental scenarios, a technical feasibility check, prototyping, and tools selection. Moreover, Law and Kelton also do not include model design as a process step. The rest of the steps in Law and Kelton's process are similar to those of the RSMP.

Law and Kelton suggest documentation as a last step of simulation modelling process; in contrast to that, the RSMP emphasises documenting the simulation study as the study progresses. These guidelines have some similarities with the RSMP.

7.4.5. The RSMP and Shannon [1998]

Shannon [1998] proposes a twelve step process for simulation model development

[1].Problem definition

[2].Project planning

[3].System definition

[4].Conceptual model formulation

[5].Preliminary experimental design

[6].Input data preparation

[7].Model translation

[8].Verification and validation

[9].Final experimental design

[10]. Experimentation

[11]. Analysis and interpretation

[12]. Implementation and documentation

Shannon's [1998] 1st step is equivalent to RSMP's subtasks 2.1 and 2.2; step 3 is same as RSMP's subtask 2.5; step 4 is same as RSMP's subtask 2.6; step 5 is equivalent to RSMP's subtask 2.7; and step 6 is equivalent to RSMP's subtask 2.3. While RSMP does not have an explicit task of planning the project, Shannon [1998] proposes project planning as the 2nd step in simulation modelling process.

Shannon [1998] also does not take into account a technical feasibility check, prototyping, and tool selection as part of the process, which have been included in the RSMP. Similarly, in contrast to RSMP, Shannon [1998] has not included model design as part of the simulation modelling process.

The rest of the steps proposed by Shannon [1998] are similar to those of the RSMP. However, documentation has been proposed as a final step; this is contrary to the RSMP, where the RSMP emphasises documenting the model as it is developed. Moreover, Shannon [1998] does not provide guidelines for documenting the model.

7.4.6. The RSMP and Nordgren [1995]

Nordgren [1995] proposes nine step process for simulation modelling:

[1]. Review of facilities and processes

[2]. Establishment of goals and objectives

[3]. Design of experiments

[4]. Flow charting of system elements

[5]. Data collection and system assumptions

[6]. Phased model development

[7]. Model validation and verification

[8]. Run experiments

[9]. Simulation output analysis

An interesting difference can be identified in Nordgren's process compared to the other processes discussed so far; that is, Nordgren proposes to understand system or processes to be modelled before establishing the goals and questions of the simulation study, whereas most other simulation process models typically consider it to be a step after having identified simulation goals. However, the RSMP does not suggest an order in which to identify the goals first or study and define the system.

Nordgren's 1st step is similar to RSMP's subtask 2.5; step 2 is similar to RSMP's subtask 2.2; step 3 is similar to RSMP's subtask 2.7. However, Nordgren seems to suggest that experiments should be designed thoroughly at that point. Nordgren's 4th step is similar to RSMP's subtask 2.6, and step 5 is similar to RSMP's subtask 2.3.

The rest of the steps in Nordgren's process are quite similar to those of the RSMP.

Another similarity between the RSMP and Nordgren's process is that Nordgren provides a list of tasks to be documented at the end of each step of the process.

7.4.7. Comparison of the RSMP: Discussion

Comparing the RMSP with other published processes enhances the internal validity of the RSMP. The comparison results suggest that the two objectives of the RSMP, as stated earlier, have been sufficiently addressed. All the simulation processes described above including the RSMP are iterative and incremental in nature. Moreover, all processes, including the RSMP, recommend that validation and verification should be done throughout model development.

Following I discuss the key findings resulted by comparing the RSMP with other processes.

<u>Meeting the objectives of the RSMP</u>

Close to real world simulation practice: The RSMP has been developed by analysing the practices of expert simulation modellers (both researchers and practitioners from SPSM and OR). Prior to embarking on to this study, it was not clear whether this empirical investigation would result in a simulation modelling process different from those reported in the literature or be similar to them. However, the comparison shows that the RSMP has many similarities with the existing practices reported in the literature. This provides evidence that the RSMP, based on an empirical investigation and compared with simulation modelling process reported in the literature, is close to real world simulation modelling practice.

Independent of a particular technique: The sample in this study was a mix of discrete event simulation and system dynamics modellers. Moreover, the RSMP has been compared with simulation modelling processes for both discrete event simulation and system dynamics. The fact that the RSMP has been developed by analysing practices both discrete event and system dynamics modellers and the similarities between the RSMP and simulation modelling processes reported in the literature suggest that the RSMP is independent of a particular simulation technique.

Although the RSMP is not very different from the processes from the OR literature, the RSMP, based on an independent empirical investigation, provides additional supporting evidence for the practices existing in simulation modelling. Although the main aim of comparing the RSMP with other processes was to test its validity, the findings from this research can also be used the other way round i.e. to validate the practices reported in the literature through the findings from an empirical study.

<u>An empirical basis:</u> The RSMP has been developed through an empirical study of the practices of simulation modellers in software engineering and operational research; whereas all of the simulation modelling processes presented in Table 7.4 are based on the personal experience of the author(s).

<u>Scope:</u> The scope of the RSMP has been clearly defined; whereas the simulation modelling processes presented in Table 7.4 do not make clear the scope of their usage.

<u>For the individual:</u> The RSMP is intended for use by individual software process simulation modeller and does not address the issues which may arise in a team of modellers; other simulation modelling processes do not make it clear whether they are for individual modeller or can also be used in a team.

<u>Generic:</u> The RSMP is a generic process and can be used with discrete event or system dynamics simulation. The simulation modelling processes presented in Table 7.4 are either for discrete event or system dynamics modelling. The participants in this study develop both discrete event and system dynamics models. The findings from this study provide evidence that on an abstract level the process of simulation modelling is similar for both techniques.

For novices: The RSMP is for novice software process simulation modellers; whereas the simulation modelling processes included in Table 7.4 do not make it clear whether they are for novices. However, considering the fact that both [Robinson 2004] and [Law and Kelton 2000] are from textbooks, they can be said to be intended for novices. The RSMP shares many similarities with the other processes; therefore it may also be suitable for use by experienced simulation modellers. However, because at this stage I aim to test the RSMP with novices, I do not claim it to be aimed at experienced simulation modellers.

Organisation: The RSMP has been organised in three core phases and two key process areas; client contact, and documentation. This is to make a clear emphasis on each phase of model development and key process areas.

Breaking down the simulation modelling process into three virtually discrete phases and subtasks in each phase is to clearly define the sort of activities simulation modellers do in real world simulation practice.

The processes presented in Table 7.4 do not explicitly emphasise these key process areas; rather client contact and documentation is considered an implicit part of the process. Therefore, the RSMP highlights important aspects which should be taken care of while developing simulation models.

Use of Software Engineering principles

Both Rus et al. [2003] and Pfahl and Ruhe [2002] seem to apply software engineering methods and principles for simulation model development. Whereas the findings of my study suggest that the application of such rigorous software engineering methods are not necessarily required because most of the simulation studies are conducted by individuals, entail a very short period of time, and the models produced are rarely used in the long-term even if developed with a view to long-term usage. Therefore rigorous methods of software engineering intended for software developed by teams, over a long period of time, and intended to be used for long-term, are not necessary for simulation modelling.

Close to the OR simulation processes

In contrast to the processes proposed by Rus et al. [2003] and Pfahl and Ruhe [2002] for software process simulation, the RSMP has more similarity with the simulation modelling processes proposed in the OR literature. Experimentation is the main difference between the RSMP and the processes proposed by Rus et al. [2003] and Pfahl and Ruhe [2002]. It seems that they consider experimentation as an activity that is separate from the simulation modelling process. Perhaps, this is because of their tendency to use software engineering norms and principles for simulation modelling; where software is tested by the developers and then handed over to the users, hence use of software is considered to be separate from software development process. This may be the reason they consider simulation model similar to software in terms of using (conducting experiments). However, the findings from my study suggest that in most cases experiments are conducted by the modeller, and the results from those experiments are used by the client; moreover, a simulation model may have to undergo changes during experimentation.

Sequential-ism

All the processes reported in the previous section suggest that simulation modelling is an iterative activity and the modeller may have to go back and forth during simulation model development. However, in all the processes except for Robinson [2004], there is a phenomenon of sequential-ism because of they way they have been described and presented in figures. The RSMP avoids sequential-ism by presenting it in an iterative manner and repeatedly emphasising that a modeller may have to go back and forth for different tasks in simulation modelling.

Also different authors have sequenced different activities according to their own experience or preference. The findings from my study suggest that the tasks listed in the 'problem definition' step of the RSMP are inter-dependent where one activity informs another activity. Kellner et al. [1999] suggest that these tasks are inter-dependent and should not be linear. Similarly, Pidd and Woolley [1980] also observe that modellers randomly switch their attention to different tasks. Willemain [1995] also suggest that tasks in problem formulation should not be sequential. Therefore the RSMP does not suggest a strict sequence in those activities.

Planning

Planning has not been included in the RSMP as an explicit process step. This is because most of the participants in this study did not mention planning as an integral step of their process. In contrast to that, all the processes discussed above propose that planning should be an explicit step of the simulation modelling process.

Implementation

The meaning of the term 'model implementation', changes depending on the context. When Rus et al. [2003] and Pfahl and Ruhe [2002] talk about model implementation, they mean coding or building the model in a simulation tool or language. When Robinson [2004], Law and Kelton [2000], and Shannon [1998] talk about implementation, there can be three meanings as described by Robinson [2004];

- Implement the recommendation from the simulation study
- Model use for day to day decision making by the user
- Use of enhanced learning about the process gained by to decision maker or client

The RSMP separates this form of implementation from simulation modelling process because in most cases the simulation modeller acts as a consultant and is not in a position to implement the model/result. It is up to the client/user/decision maker to implement the recommendations or learning from the simulation study.

7.5. Conclusion

This chapter aimed to answer my third research question:

RQ3: What process emerges by investigating the contexts and practices of simulation modellers?

In this chapter, I have presented a detailed analysis of simulation modelling processes of the participants of my study. The analysis of simulation modelling processes of the participants underpinned the development of a rapid simulation modelling process (RSMP). The chapter built on by describing the steps taken to develop the RSMP.

The simulation modelling process of each participant in this study has been analysed to identify the activities performed for simulation model development. The simulation modelling process of each participant has been sketched in graphical form (Appendix B9), and summarised in a process matrix showing various activities of the participants. The process matrix, graphical representation of each participant's process, and the data reported in Chapter 6 provides a comprehensive view of the contexts and practices of the expert simulation modellers.

The analysis of simulation modelling processes of the participants resulted in the RSMP, consisting of three core phases and two key process areas (KPAs); client contact, and documentation. The three core phases of the RSMP are foundation, construction, and implementation. The RSMP foundation phase is highly client-intensive, laying down a firm foundation for the simulation study. The simulation modeller studies the system or process, develops an understanding of the problem, establishes simulation objectives, determines the scope, identifies inputs and outputs, and develops a prototype of the simulation model. The construction phase mainly consists of technical work involving the design of the model structure, building the model using a simulation tool or language, and verifying and validating the simulation model. The experimentation phase is, again, client-intensive, in which the simulation modeller conducts experiments with the simulation model, analyses results and presents the results to the client.

The RSMP has many similarities and differences in process activities with other simulation modelling processes reported in the literature. However, the RSMP marks a major difference with the simulation modelling processes reported in the SPSM literature, which is experimentation. Although the RSMP is very similar to the simulation modelling processes reported in the OR literature, it provides empirical evidence for the validity of the process activities recommended in by the RSMP. On the other hand, the findings from this empirical study can be used as evidence to the validity of the practices reported in the literature.

The RSMP, emerged as a result of seeking to answer my third research question, has been evaluated in two stages which include controlled experiments with novices and assessment by expert software process simulation modellers. Chapters 8 and 9 of this thesis report the results of evaluating of the RSMP.

8. Chapter eight: Evaluating the RSMP with novices

8.1. Introduction

This chapter presents the results and analysis and conclusions of the experiments conducted to evaluate the Rapid Simulation Modelling Process (RSMP). This evaluation was designed prior to the development of the RSMP using evaluation criteria previously established and described in Chapter 4 (Section 4.5). Chapter 4 (Section 4.5.1) has also provided a detailed description of the experiments for which the results are now reported.

These experiments have been conducted to answer the following research question:

> *RQ4: Will a simulation modelling process help novice software process simulation modellers to improve their simulation modelling?*

The RSMP is evaluated through these experiments on the following three of the five criteria (described in Chapter 4):

- Understandability of the RSMP by novices in SPSM
- Usability of the RSMP for novices in SPSM
- Usefulness of the RSMP for novices in SPSM

The other two criteria, scope and tailorability, along with understandability, usability, and usefulness of the RSMP have been evaluated through an expert panel (see Chapter 9).

I evaluate the understandability, usability, and usefulness of the RSMP through a two-phased laboratory study using novice software process simulation modellers. The understandability of the RSMP is evaluated using a questionnaire prior to and after the experiments (see for questionnaires, Appendix C4 and C6). The usability of the RSMP is evaluated by analysing subjects' behaviour and pattern of activities during the experiments, and the usefulness of the RSMP is evaluated by assessing the quality of the models produced by the subjects on assessment criteria (see for model assessment criteria, Appendix C9).

This chapter has been organised in seven sections. Section 8.2 introduces the experiments and describes the scope under which the RSMP has been evaluated. Section 8.3 presents results of the experiments in terms of the assessment of the models produced by the subjects. Section 8.4 analyses the behaviour of the subjects and their pattern of activities during the experiments. Section 8.5 discusses how the results of the experiment are used to evaluate the RSMP and relate it to the research question. Section 8.6 presents the perspective of the subjects about the experiments. Section 8.7 concludes the chapter.

8.2. The experiments

The first phase of controlled experiments was conducted with MSc. Software Engineering students at the University of Hertfordshire, and the second phase was conducted with MSc. Operational Research students at Warwick Business School. The first phase of the experiments is referred to as 'SE experiments' as they were conducted with software engineering students, while the second phase is referred to as 'OR experiments' as they have been conducted with operational research students. The subjects in each phase of the experiments were divided into two groups; control groups are called Non-RSMP^{SE} and Non-RSMP^{OR}, and treatment groups are called RSMP^{SE} and RSMP^{OR}. The RSMP groups in both phases of experiments were trained with the RSMP prior to conducting the experiments. Figure 8.1 shows division of Non-RSMP and RSMP groups in both phases of experiments and shows identifiers for each subject in each group. Figure 8.1 shows 4 Non-RSMP^{SE} subjects and 4 RSMP^{SE} subjects; while 2 Non-RSMP^{SE} subjects and 2 RSMP^{SE} subjects.

Figure 8.1: Non-RSMP and RSMP Groups and subjects labels

	Non-RSMP subjects					**RSMP subjects**				
SE Experiments	Non-RSMP^{SE}	*A1*	*A2*	*A3*	*A4*	RSMP^{SE}	**B1**	**B2**	**B3**	**B4**
OR experiments	Non-RSMP^{OR}	*X1*	*X2*			RSMP^{OR}	**Y1**	**Y2**		

In the SE experiments, all the subjects were given a technical software engineering problem to work on; and in the OR experiments all the subjects were given a managerial kind of problem related to software engineering. See appendix C2 and C3 for the problem statements. To emulate a real world client-modeller environment, one member of the research team acted as client with whom the experiment subjects liaised to develop simulation models.

The RSMP groups in both sets of experiments used the RSMP to develop simulation models for the given problem; while the Non-RSMP groups in both sets of experiments used their own process, which they learned from their simulation modelling lectures in class. I present the results of both the SE and the OR experiments and relate them to the evaluation criteria. The models produced by the subjects in both phases of the experiments are evaluated on the assessment criteria drawn from the literature as shown in Appendix C9.

The scope under which the RSMP has been evaluated

The RSMP is an abstract and high level process which is independent of any particular simulation technique e.g. discrete event or system dynamics. In the experiments I attempt to evaluate the RSMP in the scope prescribed in chapter 7.

- The RSMP is for individual modeller

  The RSMP is to be used by individuals, therefore in both phases of experiments the RSMP has been tested with individual simulation modellers. The subjects in both phases of the experiment were not allowed to consult with their peers who were working on the same problem. However, the subjects were provided with an environment where they could easily liaise with the client during simulation model development.

- The RSMP has been designed for use by novice software process simulation modellers

  The RSMP has been tested with students who had basic training in simulation modelling through class lectures. Therefore, the subjects in both phases of experiments are novice software process simulation modellers.

- The RSMP is intended for small/medium simulation projects with low/medium complexity

In each of the two phases of experiments, the subjects were given a problems to work on as shown in appendices C2 and C3. It is very difficult to establish whether the problems were of low or medium complexity because it very much depends on the individual's background, training, and ability. However, the aim was to give the subjects a problem of low complexity so that they should be able to finish the problem in the given limited time of two hours.

- The RSMP is independent of a particular simulation technique (i.e. discrete event or continuous simulation)

In both phases of experiments, the subjects were given a problem for which to develop system dynamics model. Although the RSMP is meant to be a high level abstract process suitable both for discrete event and system dynamics modelling, time and resource constraint limited the evaluation to only system dynamics at this point. The RSMP will be tested with discrete event problems in the future.

8.3. Results: Assessment of the models produced by the subjects

In this section, I present the results of assessing the model produced in the experiments. Assessing the model produced by the subjects helped in evaluating the RSMP in terms of its usefulness. This analysis aims to assess the models produced by the subjects on the assessment criteria presented in Appendix C9. The model assessment criteria aim to assess the models produced by the subjects for:

- Syntactic quality
- Semantic quality and design
- Quality of documentation
- Maintainability
- Performance.

The performance of models produced by the subjects in both phases of the experiments could not be assessed because the models produced by the subjects were not completely error-free, which limits the application of assessment criteria.

8.3.1. Syntactic quality of the models

The Syntactic quality of the models is assessed from two aspects. First, the correctness of the model diagrams, which was automatically managed by the modelling tool. Second, the correctness of the mathematical equations employed in the model.

In the SE experiments, out of the Non-RSMP^{SE} group only one subject, A1, provided equations in the simulation model; while in the RSMP^{SE}, all subjects, except B3, provided equations in the simulation model. Unfortunately, not all of the equations were mathematically correct in the models; therefore, their models were implemented with errors.

All the OR subjects tried to provide equations in their simulation model. However, they also made errors in their equations. The fact that all the OR subjects tried to provide equations can be attributed to the fact that they had relatively more training in simulation modelling than the SE subjects.

The subjects were asked in the experiment evaluation questionnaire about how happy they felt with the models they produced. Table 8.1 summarises responses from the SE subjects and Table 8.2 summarises responses from the OR subjects. Table 8.1 show that none of the SE subjects seems happy with the models they produced. However, amongst the OR subjects, Y2 of the RSMP^{OR} group is happy with his model. Y2 indicate in the questionnaire that if more time had been provided he/she would have been able to produce a completely working model.

The Tables 8.1 and 8.2 show that none of the SE subjects was confident with system dynamics modelling and using the Vensim tool; in contrast to them, the OR subjects indicate higher confidence with system dynamics and using the Vensim tool. All the OR subjects indicate that the limited time stopped them from finishing their model. X1 and Y2 also indicate a lack of expertise with the modelling tool; however, they also emphasise that they needed more time.

In both phases of the experiment, the simulation models produced by the subjects contained errors, therefore, the assessment of syntactic quality of the models is limited.

Table 8.1: SE Subjects' perception of the models they produced

	Non-RSMP^SE group					RSMP^SE group				
	A1	*A2*	*A3*	*A4*	*M*	**B1**	**B2**	**B3**	**B4**	**M**
1. I am happy with the SD model I have produced	*2*	*3*	*3*	*3*	*3*	3	2	2	1	2
2. I was confident with system dynamics modelling	*4*	*2*	*3*	*2*	*2.5*	3	3	2	2	2.5
3. I was confident with Vensim tool	*3*	*2*	*3*	*2*	*2.5*	3	2	1	2	2

**Responses on 5 point likert scales; Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

Table 8.2: OR Subjects' perception of the models they produced

	Non-RSMP^OR group			RSMP^OR group		
	X1	*X2*	*M*	**Y1**	**Y2**	**M**
1. I am happy with the SD model I have produced	*3*	*3*	*3*	3	4	3.5
2. I was confident with system dynamics modelling	*3*	*4*	*3.5*	4	3	3.5
3. I was confident with Vensim modelling tool	*3*	*4*	*3.5*	4	2	3

**Responses on 5 point likert scales; Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

8.3.2. Models' Semantic quality and design

The research team member who acted as client was provided with a questionnaire to assess the quality of each simulation model and the accompanying documentation. See appendix C8 for the client evaluation questionnaire. The client's responses to the questionnaire are summarised in Tables 8.3 and 8.4.

The models' semantic quality was assessed by the client in terms of face validity[5] and scope; and model design was assessed in terms of modularity, interoperability, and clarity (see Appendix C9 for the model assessment criteria).

Table 8.3 shows that according to the client assessment, only one subject, A1, from the Non-RSMP^SE group and only two of the RSMP^SE subjects, B1 and B2, produced valid models in terms of their face value. A comparison of medians, as shown in Table 8.3, suggests that the models produced by the RSMP^SE group were slightly better than those of the Non-RSMP^SE for their face validity.

[5] "Does the graphical model accurately reflect the real process? Examining face validity is typically the first step in validating a process model. It is qualitative in nature and entails having process experts review and comment upon the structure and details of the graphical model to see if there are any discrepancies between the model and reality" [Raffo and Kellner 2000]

Table 8.3: Client assessment of model's semantic quality and design for SE experiments

	Non-RSMP^{SE} group					RSMP^{SE} group				
	A1	*A2*	*A3*	*A4*	M	B1	B2	B3	B4	M
1. The model is valid on face value	*5*	*3*	*1*	*3*	3	4	4	2	3	3.5
2. Model feasibly covers the scope	*5*	*2*	*2*	*3*	2.5	5	4	3	2	3.5
3. The model is feasibly modular	*4*	*1*	*2*	*2*	2	4	4	1	2	3
4. It would be easy to couple this model with another model	*4*	*2*	*3*	*3*	3	3	3	1	3	3
5. Model layout is clear enough	*5*	*2*	*2*	*3*	2.5	4	4	2	4	4

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Table 8.4: Client assessment of model's semantic quality and design for OR experiments

	Non-RSMP^{OR} group			RSMP^{OR} group		
	X1	*X2*	M	Y1	Y2	M
1. The model is valid on face value	*1*	*2*	1.5	4	3	3.5
2. Model feasibly covers the scope	*3*	*3*	3	4	4	4
3. The model is feasibly modular	*2*	*4*	3	3	3	3
4. It would be easy to couple this model with another model	*2*	*4*	3	4	4	4
5. Model layout is clear enough	*3*	*5*	4	5	5	5

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Table 8.3 also shows that only one subject, A1, from the Non-RSMP^{SE} group and two subjects, B1 and B2, from the RSMP^{SE} group produced models which adequately cover the scope of the given problem.

Table 8.3 shows that the client is satisfied with the modularity of the models produced by A1, A4, B1, and B2. Only one subject, A1, from either group could produce a model which the client considers interoperable. A1, B1 and B2 produced models which the client considers clear enough in their layout.

The results in Table 8.3 show that according to the client subject A1 of the Non-RSMP^{SE} group produced the best model amongst the SE subjects. B1 and B2 of the RSMP^{SE} group produced a model that satisfied the client. None of the other models satisfy the client. The client's assessment shows that RSMP^{SE} subjects did not perform significantly better than the Non-RSMP^{SE} subjects. However, it is notable that two RSMP^{SE} subjects produced models which satisfy the client and only one Non-RSMP^{SE} subject produced a model which satisfies the client. This suggests that the $RSMP^{SE}$ group performed slightly better than the Non-$RSMP^{SE}$ group in terms of the semantic quality of the models.

In the case of the OR experiments, Table 8.4 shows that according to the client assessment, both the $RSMP^{OR}$ subjects produced valid models in terms of face value, while the models produced by both the Non-$RSMP^{OR}$ subjects do not satisfy the client in terms of face validity. Table 8.4 also shows that the $RSMP^{OR}$ subjects score higher than their Non-$RSMP^{OR}$ counterparts for scope coverage.

Table 8.4 shows that the client is happy only with X2's model in terms of modularity. Overall both groups score the same for modularity. The client is satisfied with the models produced by the $RSMP^{OR}$ subjects for their interoperability, while the model produced by X2 also satisfies the client for interoperability. X2, Y1 and Y2 score similar for the clarity of their model layout, while the client is not satisfied with the layout clarity of the model produced by X1. The client assessment shows that overall the $RSMP^{OR}$ group performed better than the Non-$RSMP^{OR}$ group for the semantic quality and design of the model.

In the SE experiment, although the $RSMP^{SE}$ subjects performed better than the Non-$RSMP^{SE}$ subjects overall for semantic quality and the design of model, there was not a significant difference between the two. However, in the OR experiments a greater difference of performance is observable between the $RSMP^{OR}$ and the Non-$RSMP^{OR}$ subjects i.e. $RSMP^{OR}$ group performed better than the Non-$RSMP^{OR}$ group. The reason could be that the $RSMP^{OR}$ subjects were trained comparatively better than their $RSMP^{SE}$ counterparts, therefore they were able to produce better models than those of Non-$RSMP^{OR}$ with the help of RSMP.

The verification and validation of the simulation models was also part of the semantic quality assessment, which was to be performed together by the subject and the client. However, as none of the subjects could produce a complete working model, quantitative verification and validation of the simulation models could not be performed.

8.3.3. Quality of the documentation

Table 8.5 and Table 8.6 summarises the client's response for the assessment of the model documentation produced by the SE and OR subjects respectively.

Table 8.5 shows that the client is not satisfied with the documentation provided by any of the Non-RSMP^{SE} subjects. The client is most satisfied with the documentation produced by two RSMP^{SE} subjects, B3 and B4. Although all the subjects in the experiments were advised to provide documentation with their models, the Non-RSMP^{SE} subjects provided little or no documentation. This suggests that the Non-RSMP^{SE} subjects were much more focussed on getting the model implemented using the tool than paying any attention to the documentation. However, this may also suggest that they did not know how to produce the documentation.

Table 8.5: Client assessment of the documentation produced by SE subjects

	Non-RSMP^{SE} group					RSMP^{SE} group				
	A1	*A2*	*A3*	*A4*	*M*	**B1**	**B2**	**B3**	**B4**	**M**
1. Simulation objectives have been defined well	*1*	*1*	*1*	*1*	*1*	3	1	5	5	4
2. Simulation questions have been defined well	*1*	*1*	*1*	*1*	*1*	3	1	5	5	4
3. Model scope has been defined well	*1*	*1*	*1*	*1*	*1*	3	1	4	5	3.5
4. Model inputs have been defined well	*1*	*1*	*1*	*1*	*1*	2	1	4	4	3
5. Model outputs have been defined well	*1*	*1*	*1*	*1*	*1*	2	1	4	4	3
6. Overall documentation is good	*1*	*1*	*1*	*1*	*1*	2	1	5	5	3.5

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

Figure 8.2: SE Subjects' perception of the documentation they produced

	Non-RSMP^{SE} group					RSMP^{SE} group				
	A1	*A2*	*A3*	*A4*	*M*	**B1**	**B2**	**B3**	**B4**	**M**
I am happy with the documentation I have produced	*2*	*2*	*1*	*3*	*2*	1	1	3	5	2

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

Interestingly in the RSMP^{SE} group, B3 and B4 provided good documentation but the client is not satisfied with the simulation model they produced. One explanation of this can be that B3 and B4 were too process focussed; hence they did not put enough effort into producing a good model. Whereas, B1 and B4 produced poor documentation but their models satisfied the client. This suggests that the subjects could not balance their focus between product and process in the given time. It might also be attributed to their individual skill levels of modelling and documentation.

Figure 8.2 summarises subjects' perceptions about the documentation they produced, as they were asked in the experiment evaluation questionnaire. It shows that none of the Non-RSMP^{SE} subjects is happy with the documentation he/she produced. While in the RSMP^{SE} group, although B1 and B2 provided some documentation, their satisfaction level is lower than those of Non-RSMP^{SE} subjects. This is perhaps because the RSMP^{SE} subjects were provided with documentation guidelines and therefore expected to produce good documentation, but they could not. Whereas the Non-RSMP^{SE} subjects were not provided with such guidelines, so they might have thought that documentation is not very important to produce, and whatever they have produced is good enough.

Table 8.6 shows that the client is not satisfied with the documentation provided by any of the Non-RSMP^{OR} subjects. Again the Non-RSMP^{OR} subjects provided little or no documentation.

Figure 8.3 shows that none of the Non-RSMP^{OR} subjects were happy with the documentation he/she produced. Whereas, again the RSMP^{OR} subjects were satisfied with the documentation they produced.

Table 8.6: Client assessment of the documentation produced by the OR subjects

	Non-RSMP^{OR} group			**RSMP^{OR} group**		
	X1	*X2*	*M*	**Y1**	**Y2**	**M**
1. Simulation objectives have been defined well	*1*	*1*	*1*	5	4	4.5
2. Simulation questions have been defined well	*1*	*1*	*1*	1	4	2.5
Model scope has been defined well	*1*	*1*	*1*	1	4	25
Model inputs have been defined well	*1*	*1*	*1*	4	1	2.5
Model outputs have been defined well	*1*	*1*	*1*	1	1	1
Overall documentation is good	*1*	*1*	*1*	3	2	2.5

Responses on 5 point likert scales; **Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

Figure 8.3: OR Subjects' perception of the documentation they produced

	Non-RSMP^{OR} group			RSMP^{OR} group		
	X1	*X2*	*M*	Y1	Y2	M
I am happy with the documentation I have produced	*1*	*1*	*1*	3	4	3.5
Responses on 5 point likert scales; **Strongly Disagree 1 2 3 4 5 Strongly Agree* M = *Median of the scores*						

These results show that the performance of the Non-RSMP subjects regarding documentation both in the SE and OR experiments is similar i.e. they produced very little or no documentation. On the other hand, the client assessment shows that the RSMP^{SE} subjects produced better documentation overall than the RSMP^{OR} subjects; this may be because at least two of the RSMP^{SE} subjects put more effort in documentation than model building while the Non-RSMP^{SE} group did not put any effort into documenting the models.

8.3.4. Maintainability

To assess the maintainability of the simulation models produced by the RSMP and the Non-RSMP groups in both phases of experiments, the simulation models and their documentation were swapped across the Non-RSMP and RSMP groups in both sets of experiments and subjects were provided with a questionnaire. See appendix C7 for the peer assessment questionnaire. Table 8.7 and Table 8.8 summarises the responses of the subjects in SE experiments and OR experiments respectively.

Table 8.7 suggests that the RSMP^{SE} group scores better than the Non-RSMP^{SE} group. This implies that simulation models produced by the RSMP^{SE} group are more maintainable than those of the Non-RSMP^{SE} group. We can relate this to the fact that the RSMP^{SE} group spent more time (see Table 8.13, 20.5 minutes on average) on model documentation. The Non-RSMP^{SE} group also give the RSMP^{SE} group very good scores for model documentation compared with what they obtain from the RSMP^{SE} group, as shown in Table 8.7. Also the RSMP^{SE} group obtain much better scores for model structure than that of the Non-RSMP^{SE} group. This may be related to the fact that the RSMP^{SE} group spent more time interacting with the client and doing rough work (see Tables 8.9 and 8.15). This encouraged them to think methodically about the model structure, therefore, they were able to produce a better model structure than the Non-RSMP^{SE} group. However, Table 8.7 shows that the Non-

RSMP^SE group score slightly better for meaningfulness of variable names and comments than the RSMP^SE group. This may be related to the fact that the Non-RSMP^SE group spent more time using the modelling tool (see Table 8.11) than the RSMP group; probably therefore, they had more time to name and review their variables and comments. For example A1 and A4 several times renamed their variable name and reviewed the comments in their models.

Table 8.7: SE experiments, peer assessment for maintainability of the models

	Non-RSMP^{SE} group					RSMP^{SE} group				
	B4 =>A1	*B3 =>A2*	*B1 =>A3*	*B2 =>A4*	***M***	**A3 =>B1**	**A4 =>B2**	**A2 =>B3**	**A1 =>B4**	***M***
1. Model documentation is well structured	*1*	*1*	*1*	*3*	*1*	2	1	4	4	*3*
2. Model documentation is helpful to understand the model	*1*	*1*	*1*	*3*	*1*	3	1	4	4	*3.5*
3. Model structure is easy to understand	*2*	*3*	*1*	*2*	*2*	4	3	2	4	*3.5*
4. Model has meaningful variable names	*4*	*2*	*2*	*4*	*3*	4	2	2	3	*2.5*
5. Comments in the model help me to understand the model	*3*	*1*	*1*	*3*	*2*	1	1	1	3	*1*

* *Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree***
* ***B4=>A1*** *means B4 assessed model developed by A1*
* ***M*** *= Median of the corresponding values*

Table 8.8: OR experiments, peer assessment for maintainability of the models

	Non-RSMP^{OR} group			RSMP^{OR} group		
	Y1=>X1	*Y2=>X2*	***M***	**X1=>Y1**	**X2=>Y2**	***M***
1. Model documentation is well structured	*2*	*3*	*2.5*	3	4	*3.5*
2. Model documentation is helpful to understand the model	*2*	*4*	*2.5*	3	3	*3*
3. Model structure is easy to understand	*2*	*3*	*2.5*	3	4	*3.5*
4. Model has meaningful variable names	*3*	*4*	*3.5*	4	4	*4*
5. Comments in the model help me to understand the model	*2*	*4*	*3*	4	4	*4*

* *Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree***
* ***Y1=>X1*** *means Y1 assessed model developed by X1*
* ***M*** *= Median of the corresponding values*

Analysing OR subjects' scores in Table 8.8 suggests that the $RSMP^{OR}$ group also score better than the Non-$RSMP^{OR}$ group. Again the models produced by the $RSMP^{OR}$ group are more maintainable than those of the Non-$RSMP^{OR}$ group. Again the $RSMP^{OR}$ group spent more time (see Table 8.14, 16.5 minutes on avg.) on model documentation. The $RSMP^{OR}$ group also obtain a better score for model structure than the Non-$RSMP^{OR}$ group. This may be related to the fact that the $RSMP^{OR}$ group spent more time interacting with the client and doing rough work (see Tables 8.10 and 8.16). This is similar to the results of $RSMP^{SE}$.

Table 8.8 also shows that the $RSMP^{OR}$ group scored better also for the meaningfulness of variable names and comments than the Non-$RSMP^{OR}$ group. This is the only variation in outcome of the maintainability assessment between SE and OR experiments. Again I speculate that this is because they had more training in simulation modelling.

The results of the peer assessment of maintainability are different from the client evaluation. The client was satisfied with the models produced by A1, B1 and B2. But in peer evaluation, the RSMP group scored much better than the Non-RSMP group. This can be explained by considering that the basis of client and peer evaluations were quite different. The client evaluated the models from a quality perspective. In contrast to that, the peers evaluated the models from a maintainability perspective. The Non-RSMP subjects found the models produced by the RSMP subjects more maintainable.

However, the abilities of peers to assess the models may be questionable, as the subjects in both groups did not have significant simulation modelling experience. Therefore, one may argue that subjects assessed maintainability intuitively rather than basing this on any deep understanding.

8.4. Results: Analysis of subjects' pattern of activities

Data on subjects' activities during the development of their models was recorded in the form of computer activity using screen capture software and the duration and number of client contacts for each subject. This allowed the effort spent by each subject on various tasks and their pattern of activities to be analysed. A comparison of the two groups' effort distribution and activities pattern helped identify variations and to support interpretations of subjects' behaviour during the experiments. This analysis is useful for evaluating the usability of the RSMP and any difference in the way the two groups have developed their models. The following subsections discuss and interpret the behaviour of the subjects during the experiments.

8.4.1. Client contact

Table 8.9 and Table 8.10 show the frequency and amount of client contact by all the SE and OR subjects respectively in the experiments.

Table 8.9 shows that the duration and number of client contact by the $RSMP^{SE}$ subjects are higher compared to the Non-$RSMP^{SE}$ subjects. The Non-$RSMP^{SE}$ subjects spent most of their time working with the modelling tool, whereas the $RSMP^{SE}$ subjects spent a lot more time with the client. Table 8.9 shows that the mean time spent by the Non-$RSMP^{SE}$ group on client contact is 11.25 minutes whereas that of the $RSMP^{SE}$ group is 22 minutes. A T-test to compare the means of two groups' client contact time shows a statistical significance (see SPSS output in Appendix C10). This suggests a difference of approach between the two groups. Although both groups were advised to talk to the client as much as they could, nevertheless, the Non-$RSMP^{SE}$ group preferred developing the models on their own for most of the time. However, the $RSMP^{SE}$ subjects, who were trained with RSMP, spent much more time with the client. This difference of approach can be explained by the fact that the RSMP emphasises heavy client contact.

Table 8.9: Client contact by SE subjects

	Non-$RSMP^{SE}$ group				**$RSMP^{SE}$ group**			
	A1	*A2*	*A3*	*A4*	**B1**	**B2**	**B3**	**B4**
Number of times seen the client	*2*	*2*	*2*	*1*	6	3	5	2
Client contact time^	*17*	*13*	*12*	*3*	31	15	27	15
Mean time spent on client contact	*11.25* 9.3% of total time				22 18.3% of total time			
Statistical significance value	0.039 < 0.05 is statistically significant							

^ = time in minutes
Total time = 120 minutes

Table 8.10: Client contact by OR subjects

	Non-RSMP^{OR} group		RSMP^{OR} group	
	X1	*X2*	Y1	Y2
Number of times seen the client	*3*	*1*	2	2
Client contact time^	*20*	*15*	40	22
Mean time spent on client contact	17.5 minutes. 14.5% of total time		31 minutes 25.8% of total time	

^ = time in minutes
Total time = 120 minutes

Analysing the range of results for the RSMP^{SE} experiments, it would be hard to conclude that increased client contact improved the quality of the simulation models. The client assessment indicates that a Non-RSMP^{SE} model was the best model; while the subject who developed this model had client contact of only 17 minutes, which is much lower than the best model produced by the RSMP^{SE} group where 31 minutes were spent with the client. However, two RSMP^{SE} subjects produced models which satisfy the client compared to only one subject in the Non-RSMP^{SE} group. Perhaps, the comparatively simplicity of the problem meant that it did not matter how much time a subject spent with the client. Quality may be attributed to the individual capabilities of the subjects. Especially as subject A1 was the top scorer in a system dynamics class test, whereas B1 and B2 scored lower than A1 on the same class test. This suggests that the RSMP^{SE} training equipped them with extra potential to produce a model that could satisfy the client. However, with this sample size, it would not be appropriate to generalise the result.

In the OR experiments, Table 8.10 shows that the number of client contacts is similar in both groups; however the duration of client contact of the RSMP^{OR} subjects is higher compared to the Non-RSMP^{OR} subjects. The RSMP^{OR} subjects spent 31 minutes on average with the client, whereas the Non-RSMP^{OR} subjects spent 17.5 minutes on average with the client. This adds more evidence to suggest a difference of approach between the two groups.

In the SE experiments, the difference of client contact between the RSMP^{SE} and Non-RSMP^{SE} group was high (22 minutes and 11.25 minutes respectively). However, the difference in their models' quality (by client assessment) was not very significant. Therefore it was difficult to relate client contact with the quality of models. In the OR experiments, however, the difference in client contact between RSMP^{OR} and Non-RSMP^{OR} groups may be related to the difference of model quality produced by the two groups, because the RSMP^{OR} subjects spent more time with the client and produced comparatively better models than the RSMP^{OR} group. It can also be attributed in part to the individual capabilities of the subjects; however, it is worth noting that both the RSMP^{OR} subjects were weaker students than both of the Non-RSMP^{OR} subjects based on their past performance in the course.

8.4.2. Tool use

The analysis of screen capture data for tool use is shown in Table 8.11 for the SE experiments, and in Table 8.12 for the OR experiments.

Table 8.11: Use of tool by the SE subjects

	Non-RSMP^{SE} group				RSMP^{SE} group			
	A1	*A2*	*A3*	*A4*	B1	B2	B3	B4
Minute at which first us of the modelling tool made	*1st*	*1st*	*3rd*	*12th*	53rd	33rd	N/A*	48th
Tool usage time^	*87*	*59*	*72*	*79*	34	50	N/A*	25
Average time^ spent on tool usage	*74* 61.6% of total time				37 30.8% of total time			
Statistical significance value	0.005 < 0.05 is statistically significant							

N/A* = B3 did not produce model on tool
^ = time in minutes
Total time = 120 minutes

Table 8.12: Tool usage by OR subjects

	Non-RSMP^{OR} group		RSMP^{OR} group	
	X1	*X2*	Y1	Y2
Minute at which first use of the modelling tool made	*6th*	*1st*	5th	1st
Tool usage time^	*66*	*73*	64	51
Average time^ spent on tool usage	69.5 57.9% of total time		57.5 47.9% of total time	

^ = time in minutes
Total time = 120 minutes

Table 8.11 suggests that the Non-RSMP^{SE} subjects preferred to start working with the tool as soon as they have seen the client e.g. after seeing the client for first time: A1 and A2 in the 1st minute, A3 in the 3rd minute, and A4 in the 12th minute. Comparing this with the RSMP^{SE} subjects, B1 started working with the tool in the 53rd minute, B2 in the 33rd minute and B4 in the 48th minute after seeing the client. B3 did not make use of the tool at all because of not having confidence in using the tool. It is interesting to note that the highest time spent by an RSMP^{SE} subject (B2) on the tool is 50 minutes, which is less than the lowest time spent by a Non-RSMP^{SE} subject (A2) which is 59 minutes.

Table 8.11 shows that the average time spent by the Non-RSMP^{SE} group on the tool is 74 minutes, whereas that of the RSMP^{SE} group is 37 minutes. A T-test to compare the means of the two groups' tool use time shows a statistically significant difference (see SPSS output in Appendix C10). Again this suggests a difference of approach between the two groups. This suggests that the RSMP^{SE} subjects were more focussed on developing the foundation of the simulation model prior to moving to the tool, as guided by the RSMP. Whereas the Non-RSMP^{SE} subjects seemed more interested in getting the model done, rather than first developing an understanding of the problem systematically.

The Non-RSMP^{SE} subjects spent most of their time on the tool but only one Non-RSMP^{SE} subject could produce a model that could satisfy the client. In contrast, the RSMP^{SE} subjects spent much less time on the tool but two of the RSMP^{SE} subjects satisfied the client assessment. This suggests that spending more time using the tool did not add to the quality of the simulation models produced by the Non-RSMP^{SE} subjects.

In the OR experiments, Table 8.12 shows the pattern of results are similar i.e. all the subjects started working with the model with first six minutes after seeing the client. The average time spent by the Non-RSMP^{OR} group on the tool is 69.5 minutes, whereas that of the RSMP^{OR} group is 57.5 minutes.

Although the pattern of tool use by the Non-RSMP group in both SE and OR experiments is similar, variation between the RSMP groups is apparent. The $RSMP^{OR}$ subjects started working with the tool as soon as they had seen the client, whereas the $RSMP^{SE}$ subjects did not start working with the tool until much later; and the duration of tool use by the $RSMP^{OR}$ subjects is higher than that of the $RSMP^{SE}$ subjects. In the SE experiments, the results suggest that the $RSMP^{SE}$ subjects seemed to get bogged down with the modelling process and consequently they could not balance their focus between process (the RSMP) and product (model and documentation). However, the $RSMP^{OR}$ subjects were able to keep a better balance between the process and product. This is probably why the $RSMP^{OR}$ subjects were able to produce both better models and documentation than the Non-$RSMP^{OR}$ subjects

8.4.3. Documentation

All subjects were required to provide documentation with the model they produced. The subjects were asked to document their models in Microsoft Word. Table 8.13 and Table 8.14 summarise the amount of time spent by each subject on documentation.

Table 8.13 shows that the $RSMP^{SE}$ subjects spent a substantial amount of their time on documentation but Non-$RSMP^{SE}$ subjects spent a negligible amount of time on the documentation i.e. A1, A2, and A3 spent 0 minutes and A4 spent 5 minutes. Table 8.13 also shows that the average time spent by the Non-$RSMP^{SE}$ group on documentation is 1.25 minutes, whereas that of the $RSMP^{SE}$ group is 20.5 minutes. A T-test to compare the means of the two groups' documentation time shows a statistically significant difference (see SPSS output in Appendix C10). This difference in the amount of effort spent on documentation shows that Non-$RSMP^{SE}$ subjects either did not consider documentation important or they were so bogged down in the technical work that documentation was ignored in the given time.

The results from SE experiments suggest that the more time spent on documentation, the better the documentation produced. None of the Non-$RSMP^{SE}$ subjects could produce documentation which satisfied the client (Table 8.5). The client is satisfied with the documentation produced by B3 and B4, who spent more time than any one (30 and 50 minutes respectively) on the documentation (Table 8.13). But unfortunately neither satisfies the client with their models. This suggests that B3 and

B4 could not balance modelling and documentation. On the other hand, B1 produced a model that satisfied the client; however, could not satisfy the client regarding documentation. This may suggest that following the RSMP and producing a good enough simulation and documentation requires more time than allowed in the experiments.

Table 8.13: Documentation time by SE subjects

	Non-RSMP^{SE} group				RSMP^{SE} group			
	A1	*A2*	*A3*	*A4*	B1	B2	B3	B4
Minute at which started the documentation	*N/A*	*N/A*	*N/A*	*25th*	24th	33rd	2nd	5th
Documentation time^	*0*	*0*	*0*	*5*	26	6	30	50
Average time spent on documentation	*1.25 1.1% of total time*				20.5 17.1% of total time			
Statistical significance value	0.013 < 0.05 is statistically significant							

^ = time in minutes
Total time = 120 minutes

Table 8.14: Documentation time by OR subjects

	Non-RSMP^{OR} group		RSMP^{OR} group	
	X1	*X2*	Y1	Y2
Minute at which started the documentation	*NA*	*NA*	1st	52nd
Documentation time^	*0*	*0*	12	21
Average time spent on documentation	0		16.5 minutes 13.7% of total time	

^ = time in minutes
Total time = 120 minutes

In the case of the OR experiments, Table 8.14 shows that RSMP^{OR} subjects spent a substantial amount of their time on documentation but Non-RSMP^{OR} subjects did not spend any time on the documentation. Table 8.14 shows that Y1 started documenting in the 1st minute and Y2 in the 52nd minute after seeing the client for first time. Table 8.14 shows that the average time spent by the Non-RSMP^{OR} group on documentation is 0 minutes, whereas that of the RSMP group is 16.5 minutes.

Comparing the documentation practice of the RSMP groups across both experiments shows that the $RSMP^{SE}$ subjects spent more time (20.5 minutes) on average than that of the $RSMP^{OR}$ subjects (16.5 minutes). The client assessment shows that the $RSMP^{SE}$ subjects score better for documentation than the $RSMP^{OR}$ subjects; these results suggest that more the time spent on documentation, the better the documentation produced. However, spending too much time on documentation may impinge on the quality of the models produced.

8.4.4. Other activities

Other activities undertaken by the subjects during the experiments include time spent on referring to tool help documents, rough work and thinking. Table 8.15 and Table 8.16 summarise the amount of time spent of other activities.

Table 8.15: Other activities by SE subjects

	Non-$RSMP^{SE}$ group				$RSMP^{SE}$ group			
	A1	*A2*	*A3*	*A4*	B1	B2	B3	B4
Help referring time^	*0*	*14*	*21*	*0*	0	0	0	0
Rough work and thinking time^	*16*	*34*	*15*	*33*	29	49	63	17
Average time spent on rough work and thinking	*24.5* *20.4% of total time*				31.67 26.3% of total time			
Statistical significance value	0.12 > 0.05 is Not statistically significant							

** B3 is not included in calculating avg. time of miscellaneous*
^ = time in minutes
Total time = 120 minutes

Table 8.16: Other activities by OR subjects

	Non-$RSMP^{OR}$ group		$RSMP^{OR}$ group	
	X1	*X2*	Y1	Y2
Help referring time^	*0*	*0*	0	0
Rough work and thinking time^	*34*	*32*	4	26
Average time spent rough work and thinking	33 27.5% of total time		15 12.5% of total time	

^ = time in minutes
Total time = 120 minutes

Table 8.15 shows that in the SE experiments, two Non-RSMP^{SE} subjects, A2 and A3, spent some time (14 and 21 minutes respectively) referring to the online help for the modelling tool. This shows subjects' lack of expertise with the modelling tool. All the subjects had been given the same training and experience with the modelling tool via a taught MSc. module; however, it may be that some subjects were better in using the tool than others.

Rough work and thinking is defined as the time when a subject is neither active on the computer (working with the modelling tool or documenting the model) nor seeing the client. It is impossible to separate the amount of time spent by the subjects on rough work and thinking therefore, these are combined. Table 8.15 suggests no significant difference in the time spent on rough work and thinking between the Non-RSMP^{SE} and the RSMP^{SE} group. B3 spent 63 minutes on rough work and thinking because B3 did not work with the modelling tool at all; therefore, B3 is not included in calculating the average time spent by the group on rough work and thinking. Table 8.15 shows that the average time spent by the Non-RSMP^{SE} group on rough work and thinking is lower (24.5 minutes) than that of the RSMP^{SE} group (31.67 minutes).

In the case of the OR experiments, Table 8.16 suggests a bigger difference between the two groups in the activities of the Non-RSMP^{OR} and the Non-RSMP^{OR} group. Table 8.16 shows that average time spent by the Non-RSMP^{OR} group on rough work and thinking is 33 minutes, which is much higher than the time spent, 15 minutes on average, by the RSMP^{OR} group.

There is a difference between the SE and OR RSMP subjects on the time spent on rough work and thinking. The RSMP^{OR} group spent only 15 minutes on average on rough work and thinking in contrast to 31.67 minutes spent by the RSMP^{SE} group. This difference between the two RSMP groups is difficult to explain, though it may be related to the more thorough training in simulation the RSMP^{OR} group received. This may have allowed them to work on the problem instead thinking about system dynamics technicalities and how to use the Vensim tool.

8.4.5. Analysis of documents

The rough work produced by the subjects included any preparation done by the subjects before coming to the experiments and any rough work done during the experiments. These rough documents were retained after the experiment. The rough documents and the documentation produced by the subjects were then analysed to identify the kind of activities they have done on paper. Tables 8.16 and 8.17 summarise themes identified in the rough work produced by the subjects in SE and OR experiments respectively.

Both in SE and OR experiments, as shown by Tables 8.17 and 8.18, consistency in the activities is observable amongst the RSMP subjects. This provides additional evidence that the RSMP subjects tried to adhere to RSMP guidelines. However, the rough work by A1 suggests that A1 naturally performed the activities suggested by the RSMP even though A1 was a Non-RSMP^{SE} subject.

Table 8.17: SE experiments, activities traced from rough work

	Non-RSMP^{SE} group				RSMP^{SE} group			
	A1	*A2*	*A3*	*A4*	**B1**	**B2**	**B3**	**B4**
1. Simulation objectives					X	X	X	X
2. Simulation questions	*X*				X	X	X	X
3. Input identification	*X*		*X*		X	X	X	X
4. Output identification	*X*				X	X	X	X
5. Scope definition					X		X	X
6. Model doodling	*X*		*X*		X	X	X	X
7. Equation formulation	*X*		*X*				X	
8. Influence diagram		*X*	*X*		X	X	X	X

Table 8.18: OR experiments, Activities traced from rough work

	Non-RSMP^{OR} group		RSMP^{OR} group	
	X1	*X2*	**Y1**	**Y2**
1. Simulation objectives			X	X
2. Simulation questions			X	X
3. Input identification	*X*	*X*	X	X
4. Output identification	*X*	*X*	X	X
5. Scope definition			X	X
6. Model doodling		*X*	X	X
7. Equation formulation	*X*	*X*	X	X
8. Influence diagram	*X*	*X*	X	X

Tables 8.17 and 8.18 show that there is no documentary evidence that the Non-RSMP subjects in either experiment identify simulation objectives and questions; also they do not set out scope of the problem. They might have done these activities implicitly in their minds, however, it cannot be found in documentary evidence.

The documents show that most of the Non-RSMP^{SE} subjects do not identify or define inputs and outputs in their rough work, whereas the Non-RSMP^{OR} subjects have done so. However, the RSMP subjects in both experiments identify inputs and outputs in their documents.

Moreover, in both phases of experiments, the rough work shows that most of the subjects have sketched influence diagrams and doodled model structure on paper.

Most of the subjects in the SE experiments did not formulate equations in their rough work, while all the subjects in the OR experiments attempted to formulate equations on paper and employ them in the model. This is perhaps because the OR subjects had more training in simulation modelling than the SE experiments subjects.

8.5. Evaluating the RSMP

The aim of these experiments was to evaluate the RSMP in terms of three evaluation criteria established prior to formulating the RSMP. These criteria are: understandability, usability, and usefulness of the RSMP. In this section, I will discuss the experiment results in relation to these three criteria and reflect on how well the RSMP meets with these criteria.

8.5.1. Evaluation criteria: Understandability of the RSMP

Each RSMP subject was individually tutored in the RSMP and given a questionnaire to evaluate the RSMP prior to the experiments. See Appendix C4 for the RSMP pre-evaluation questionnaire. Table 8.19 summarises the responses of the SE subjects regarding their understanding of the RSMP. Table 8.20 summarises the responses of the OR subjects regarding their understanding of the RSMP.

Table 8.19 shows that all the RSMP^{SE} subjects found it very easy to understand the RSMP, and they also found that learning the RSMP was very easy. Moreover, they think that the instructions provided by the RSMP are clear. Only one RSMP^{SE} subject, B4, appears to be confident enough to use the RSMP; while all the other subjects are not confident in using the RSMP.

Table 8.19: Understanding of the RSMP by RSMP^{SE} subjects

	B1	B2	B3	B4	*M*
1. It was easy to understand RSMP	4	4	4	5	4
2. Learning the RSMP was easy for me	3	3	4	4	3.5
3. The instructions provided in the RSMP are clear	4	4	4	5	4
4. I am confident to use the RSMP	2	3	2	4	2.5

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Table 8.20: Understanding of the RSMP by the RSMP^{OR} subjects

	Y1	Y2	*M*
1. It was easy to understand the RSMP	4	5	4.5
2. Learning the RSMP was easy for me	4	4	4
3. The instructions provided in the RSMP are clear	5	4	4.5
4. I am confident to use the RSMP	3	3	3

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Table 8.20 shows that RSMP^{OR} subjects show a similar understanding of the RSMP. Both subjects indicate that they have found the RSMP easy to understand, easy to learn and the instructions RSMP in the RSMP are clear to them. Again the RSMP^{OR} subjects are not sure whether they would be able to use the RSMP confidently.

The overall results show that the RSMP subjects in both sets of experiment found the RMSP understandable even if they lacked in confidence to use it.

8.5.2. Evaluation criteria: Usability of the RSMP

The design of the RSMP consists of three core phases and two key practice areas in simulation modelling. This section discusses how well the RSMP subjects were able to follow the recommended guidelines for the three core phases and the two key process areas of client contact and documentation.

The RSMP core phases

The RSMP has three core phases; foundation, construction and experimentation. The $RSMP^{SE}$ subjects spent about 45 percent of their time on average on the foundation phase of the RSMP during the experiments. The $RSMP^{OR}$ subjects spent about 38 percent of their time on average on the foundation phase of the RSMP during the experiments. The documentation and rough work provided by both the $RSMP^{SE}$ and the $RSMP^{OR}$ group suggest that they actually attempted to adhere to the RSMP foundation phase guidelines. Also the consistency of rough work produced by both of the RSMP groups (Tables 8.17 and 8.18) suggests their adherence to the RSMP foundation phase guidelines. All RSMP subjects established the questions to be answered by the simulation study, identified inputs and outputs, and derived an influence diagram showing the relationships between different factors in the problem. Most of the RSMP subjects also defined the system and its scope in their documentation.

An average of 30 percent of the $RSMP^{SE}$ subjects' time, and 48 percent of the $RSMP^{OR}$ subjects' time was spent on the RMSP construction step. All the RSMP subjects planned the model structure on paper prior to building the physical model, as suggested by the RSMP. Although the subjects showed their models to the client during the experiments to validate them, they could not produce fully validated models as their models contained errors.

However, neither group undertook experimentation. This is because they could not produce an error-free working model due to lack of expertise with system dynamics and the modelling tool. This should not be seen a weakness in the RSMP, rather a weakness of the study design. Analysis of the data collected suggests that RSMP subjects were easily able to follow the first two steps.

Client contact

The RSMP emphasises heavy client contact. All the $RSMP^{SE}$ and $RSMP^{OR}$ subjects spent a considerable amount of time with the client. The $RSMP^{SE}$ subjects spent an average of 22 minutes with the client (Table 8.9), which is about 18.3 percent of the total duration of the experiments. The average time spent by the $RSMP^{OR}$ subjects with the client is 31 minutes (Table 8.10), which is about 25 percent of the total duration of the experiments. This shows that the subjects were able to follow the RSMP guidelines of having heavy client contact.

Documentation

Providing model documentation is another RMSP key practice. RSMP subjects were encouraged to produce model documentation as they model. The evaluation shows that in general, both RSMP groups spent considerably more time on documentation than either Non-RSMP group. The $RSMP^{SE}$ group spent 17 percent of their time and the $RSMP^{OR}$ group spent 14 percent of their time on average on documentation (Table 8.13 and 8.14). The client was satisfied with the documentation produced by only two of the $RSMP^{SE}$ subjects and both the $RSMP^{OR}$ subjects.

Rapid development

The results of subjects' pattern of activities also show that in both sets of experiments, the RSMP subjects were able to demonstrate comparatively a rapid approach to simulation model development. This is demonstrated by the fact that in both sets of experiments, the RSMP subjects spent more time with the client (almost double of their Non-RSMP counterparts, Tables 8.9 and 8.10), much less time on the modelling tool (Tables 8.11 and 8.12), and a considerable time on documentation (Non-RSMP subjects provided no documentation, Tables 8.13 and 8.14). Despite that, the RSMP subjects generally produced better models than the Non-RSMP subjects, as demonstrated by the client evaluation. This suggests that by following the RSMP, the RSMP subjects were able to produce more and better work rapidly than the Non-RSMP subjects.

Usability perceptions of the subjects

To gain further confidence in the usability of the RSMP, all RSMP subjects were asked after the experiment whether they found the RSMP easy to follow. Figures 8.4 and 8.5 show that all the RSMP subjects found it easy to follow.

Overall these findings suggest that the RSMP is a useable approach. Subjects found it easy to understand and easy to adhere to the RSMP guidelines. An analysis of the data collected provides evidence that subjects were able to follow the RSMP. Therefore it provides encouraging evidence that the RSMP (or at least first two phases of the RSMP) is a usable process for novice software process simulation modellers.

Figure 8.4: RSMP^{SE} subjects' perceptions about usability of the RSMP

	B1	B2	B3	B4	M
1. It was easy to follow the RSMP guidelines	4	3	4	5	4

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Figure 8.5: RSMP^{OR} subjects' perceptions about usability of the RSMP

	Y1	Y2	M
1. It was easy to follow the RSMP guidelines	4	4	4

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

8.5.3. Evaluation criteria: Usefulness of the RSMP

The usefulness of the RSMP has been evaluated using the assessment criteria shown in Appendix C9. The simulation models produced by the subjects have been assessed in terms of:

- Semantic quality
- Model design
- Quality of documentation
- Maintainability

Because none of the subjects could produce error-free models, it was not possible to apply all the evaluation criteria to their models.

The assessment of semantic quality included credibility, scope coverage, verification and validation. Validation of the simulation models was impossible without error free working models. However, their credibility was assessed by the client judging their face validity. Moreover, the client also assessed whether the models produced by the subjects covered the scope of the problem. The client assessment suggests that overall the RSMP groups produced more credible models than the Non-RSMP groups.

Moreover, the models produced by the RSMP groups covered the scope of the problem better than those of the Non-RSMP groups.

Model design was assessed in terms of its modularity, interoperability and clarity. The client assessment suggests that overall the models produced by the RSMP groups were more modular and clearer in their layout compared with those of the Non-RSMP groups. However, an assessment of the interoperability of the models by the client shows no significant difference between the two groups.

The quality of documentation produced by the subjects was assessed for the definition of simulation objectives, simulation questions, scope, and inputs and outputs definition. The client assessment for the documentation suggests that the RSMP groups produced much better documentation than the Non-RSMP groups.

The maintainability of the models was assessed by swapping the models and their documentation across the Non-RSMP and the RSMP groups in both phases of experiments. This peer assessment suggests that the models produced by the RSMP groups were generally more maintainable than those of the Non-RSMP groups.

One limitation of this study is that the limited time of the experiments did not allow the subjects to do validation of executable models. The RSMP, however, does not propose new techniques for simulation model validation. Therefore, the commonly used validation techniques [Balci 1994, 1997, Robinson 1997, 2004] are applicable to the models produced by the subjects. The findings from this study suggest that the RSMP brings benefits into the areas such as; problem formulation, model design, documentation, and maintainability. The simulation literature [Rus et al. 2003, Robinson 2004, Nordgren 1995] suggests that the validity of a simulation model depends on how well the problem has been formulated. Moreover, there is a general belief in the simulation modelling literature that a good simulation modelling process leads to valid and credible models [Eriksson 2003, Pfahl and Ruhe 2002, David 2001, Robinson 1998]. The RSMP subjects were able to show a better modelling process compared to the Non-RSMP subjects. Therefore, the RSMP's usefulness in terms of problem formulation and better disciplined process has the potential to help novice software process simulation modellers to produce valid models.

Subjects' perceptions about usefulness of the RSMP

The RSMP's usefulness can be further evaluated in terms of subjects' perceptions. The pre-evaluation questionnaire shows that $RSMP^{SE}$ subjects were not sure if following the RSMP would improve the quality of their models (Table 8.21). However, in post-evaluation, two of the $RSMP^{SE}$ subjects found it useful in improving the quality of their models (Table 8.22). Table 8.21 shows that most of the $RSMP^{SE}$ subjects perceived that using the RSMP is likely to bring discipline to their simulation modelling practice. They continued this in the post-evaluation (Table 8.22). Similarly they anticipated and then found documentation guidelines were helpful to them (Table 8.21 and Table 8.22). However, B1 was not sure if RSMP would be useful but did actually find it useful, and B2 perceived that RSMP would be useful but remained neutral in the post-evaluation.

The $RSMP^{OR}$ subjects also found the RSMP useful in improving the quality of their models in both pre and post-evaluation (Tables 8.23 and 8.24). Table 8.23 shows that the $RSMP^{OR}$ subjects perceived that using the RSMP is likely to bring discipline in their simulation modelling practice and then they repeat that this was the case in the post-evaluation (Table 8.24). Similarly they respond similar in both evaluations for the helpfulness of the RSMP documentation guidelines; they anticipated and found RSMP documentation guidelines useful (Table 8.23 and Table 8.24). In the pre-evaluation, the $RSMP^{OR}$ subjects were not sure whether the RSMP would be useful for them (Table 8.23), however, in the post-evaluation they indicate that RSMP has been useful for them (Table 8.24).

Table 8.21: $RSMP^{SE}$ subjects' perceptions about usefulness of the RSMP before experiments

	B1	B2	B3	B4	*M*
1. Using the RSMP for simulation modelling will improve the quality of the models I develop	3	3	3	3	*3*
2. Using the RSMP for simulation modelling is likely to bring discipline in the my simulation modelling practice	4	4	3	4	*4*
3. The documentation guidelines of the RSMP are helpful	4	4	5	5	*4.5*
4. It would be useful to follow the RSMP	3	4	3	4	*3.5*

**Responses on 5 point likert scales; Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Table 8.22: RSMP^{SE} subjects' perceptions about usefulness of the RSMP after experiments

	B1	B2	B3	B4	M
1. The RSMP helped me to produce a better model than I otherwise would have	4	3	3	4	3.5
2. Using the RSMP brought discipline in my simulation practice	4	4	3	4	4
3. I found documentation guidelines of the RSMP helpful	4	4	5	5	4.5
4. I found it useful to follow the RSMP	4	3	3	4	3.5
5. I would like to use the RSMP in future	4	3	4	4	4

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Table 8.23: RSMP^{OR} subjects' perceptions about usefulness of the RSMP before experiments

	Y1	Y2	M
1. Using the RSMP for simulation modelling will improve the quality of the models I develop	4	4	4
2. Using the RSMP for simulation modelling is likely to bring discipline in the my simulation modelling practice	5	5	5
3. The documentation guidelines of the RSMP are helpful	3	4	3.5
4. It would be useful to follow the RSMP	3	3	3

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Table 8.24: RSMP^{OR} subjects' perceptions about usefulness of the RSMP after experiments

	Y1	Y2	M
1. The RSMP helped me to produce a better model than I otherwise would have	4	4	4
2. Using the RSMP brought discipline in my simulation practice	4	3	3.5
3. I found documentation guidelines of the RSMP helpful	5	4	4.5
4. I found it useful to follow the RSMP	4	4	4
5. I would like to use the RSMP in future	5	4	4.5

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Overall the RSMP subjects were able to produce better models in some aspects than the Non-RSMP subjects; while other aspects require further investigation.

- The client was satisfied with the models produced by two of the RSMP^{SE} subjects compared to one Non-RSMP^{SE} subject. The client was also satisfied with the models produced by both of the RSMP^{OR} subjects compared to none of Non-RSMP^{OR} subjects.

- The client was satisfied with the documentation produced by two of the $RSMP^{SE}$ subjects compared to none of the Non-RSMP subjects. Moreover, the client was satisfied with the documentation produced by the $RSMP^{OR}$ subjects compared to none of the Non-$RSMP^{OR}$ subjects

- From the maintainability perspective, the $RSMP^{SE}$ subjects scored better than the Non-$RSMP^{SE}$ subjects, and the $RSMP^{OR}$ subjects scored better than the Non-$RSMP^{OR}$ subjects.

- The RSMP subjects generally think that the RSMP helped develop better simulation models and in a disciplined manner.

Analysis of the experimental data suggests that RSMP is useful in certain areas such as model credibility, design, documentation, and maintainability of simulation models. The RSMP was also useful in bringing discipline into the simulation practice of the subjects.

8.5.4. Evaluating the RSMP: Summary of key findings

As stated earlier, the aim of these experiments was to answer my fourth research question:

> *RQ4: Will a simulation modelling process help novice software process simulation modellers to improve their simulation modelling?*

For a simulation modelling process to be useful it should be easy to understand by its audience and they should be able to use the process. A simulation modelling process is useful if it improves the simulation modelling practice of its target audience. To investigate whether the RSMP has helped novices improve their simulation modelling, the RSMP has been evaluated in terms of its understandability, usability and usefulness.

In terms of understandability, the RSMP subjects in both phases of the experiments

- found it easy to understand the RSMP

- found it easy to learn the RSMP

- found that the RSMP guidelines are clear to them

In terms of usability, most the RSMP subjects in both phases of experiments:

- went through all the tasks recommended by the RSMP foundation phase, however, they could not fully exercise the tasks listed in 2nd phase. They did not perform any of the tasks listed in the experimentation phase.
- maintained a high level of client contact as suggested by the RSMP
- produced documentation as per the RSMP guidelines for most of the tasks they performed in the foundation phase.
- found it easy to follow the RSMP guidelines

In terms of usefulness of the RSMP, in both sets of experiments:

- Simulation models produced by the RSMP subjects are generally better than those of Non-RSMP subjects in terms of scope and face validity than those of the Non-RSMP subjects.
- Simulation models produced by the RSMP subjects are generally better than those of Non-RSMP subjects in terms of modularity and clarity.
- Simulation models produced by the RSMP subjects are generally better in terms of their modularity and clarity than those of the Non-RSMP subjects.
- The documentation produced by the RSMP subjects is better than the Non-RSMP subjects
- The RSMP subject produced better models in terms of simulation model maintainability than their Non-RSMP counterparts.
- Most of the RSMP subjects found the RSMP helpful in producing better model, bringing discipline into their simulation practice, and producing better documentation.
- The results indicate that following a disciplined process has a potential to produce valid and credible models. The RSMP subjects typically had a better

approach to problem definition and disciplined modelling process due to which they produced more credible models compared to their counterparts.

The results from these experiments provide encouraging evidence as to the understandability, usability and usefulness of the RSMP for these subjects. The RSMP has also been useful to bring discipline in their simulation modelling. However, the results from these experiments are not generalisable beyond the experiment subjects.

RSMP is proposed as a process applicable to both discrete event and continuous simulation. However, it has been assessed only with a continuous simulation problem. Ideally, it should also have been assessed with a discrete event simulation problem; however, resources and time constrained the evaluation only to one technique. The RSMP should be assessed with a discrete event simulation problem in the future. The RSMP has been tested in a laboratory setting; ideally it should have also been applied in real world practice, where simulation modellers work on simulation studies over extended periods of time. Repeating these experiments in the future with different subjects and under different contexts would be a better test of usefulness of the RSMP.

8.6. Subjects' perspective on the experiments

Both Non-RSMP and RSMP subjects were provided with a questionnaire at the end of the experiments. This evaluates the experiments from subjects' perspectives. Tables 8.25 and 8.26 summarise the responses to this questionnaire.

Both groups seem generally happy with the experiments. Table 8.25 shows that the problem was clear to most of the SE subjects. Table 8.25 shows that all the $RSMP^{SE}$ subjects agree that the time given was enough to solve the problem, whereas two of the $Non\text{-}RSMP^{SE}$ subjects, A1 and A2, strongly disagree that the time given was enough to solve the problem. It can be argued that the RSMP subjects found it easier to solve the problem in the time because of the RSMP. Another reason could be that A1 and A2 were not satisfied with their models; therefore, they wanted to spend more time working on them.

Table 8.25: Experiment evaluation by the SE subjects

	Non-RSMP^SE group					RSMP^SE group				
	A1	*A2*	*A3*	*A4*	*M*	B1	B2	B3	B4	*M*
1. The problem I was asked to model was clear to me	*5*	*3*	*4*	*4*	*4*	3	5	5	4	*4.5*
2. Given time was enough to solve the problem	*1*	*1*	*4*	*4*	*2.5*	3	5	5	5	*5*
3. It was easy to access the client during the experiment	*4*	*4*	*4*	*5*	*4*	5	4	5	5	*5*
4. I wanted to spend more time with the client	*5*	*4*	*2*	*3*	*3.5*	4	3	1	1	*2*
5. Difficulty of given problem hindered me producing a good model	*1*	*2*	*1*	*2*	*1.5*	1	1	1	1	*1*

**Responses on 5 point likert scales; Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Table 8.26: Experiment evaluation by the OR subjects

	Non-RSMP^OR group			RSMP^OR group		
	X1	*X2*	*M*	Y1	Y2	*M*
1. The problem I was asked to model was clear to me	*4*	*3*	*3.5*	5	4	*3*
2. Given time was enough to solve the problem	*3*	*1*	*2*	1	3	*2*
3. It was easy to access the client during the experiment	*5*	*5*	*5*	5	5	*5*
4. I wanted to spend more time with the client	*4*	*2*	*3*	3	3	*3*
5. Difficulty of given problem hindered me producing a good model	*2*	*2*	*2*	2	1	*1.5*

**Responses on 5 point likert scales; Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = Median of the corresponding values

Having the client in easy access of the subjects was an important experimental protocol in this study. Table 8.25 shows that both groups in the SE experiments have general agreement that the client was easy to access. Table 8.25 shows that two of the Non-RSMP^{SE} subjects, A1 and A2, wanted to spend more time with the client; they spent 17 and 13 minutes respectively with the client (see Table 8.9). One reason may be that at the end of the experiment they realised that they should have spent more time with the client instead of trying to continue with the problem on their own.

A major weakness in these experiments was that none of the subjects was able to produce an error-free model. This limited the evaluation of the RSMP. The subjects indicated that they lacked proficiency with system dynamics modelling and the modelling tool as shown in Section 8.3.1. However, the difficulty of the given problem could also have affected the performance of the subjects. Table 8.25 shows that none of the subjects think that the difficulty of the problem hindered him/her in producing error-free models.

In the case of the OR experiments, Table 8.26 shows that the problem was clear to most of the subjects. In Table 8.26, all the OR subjects show dissatisfaction with the time given to solve the problem, which is one of the reasons they could not complete the model. This is quite contrary to the results of the SE experiments where all the subjects agreed that the given time was enough to solve the problem, while the reason indicated for not completing the model was lack of expertise with system dynamics and the modelling tool. However, the confidence of the OR subjects' was much higher regarding system dynamics modelling and the modelling tool. There is no apparent reason for this variation in perception. One possible reason could be that the subjects in SE and OR experiments were given two different problems; perhaps the SE problem was comparatively simpler than the OR problem, therefore SE subjects thought that the given time was enough, while OR subjects thought the time was not enough.

All the OR subjects say that the problem was not difficult enough to hinder them producing a good model. This is again similar to the responses of the SE subjects. In the OR experiments, Table 8.26 shows that both groups have general agreement that the client was easy to access. This is similar to the result of SE experiments where all the subjects show that client was in easy access.

In the experiment evaluation questionnaire, subjects were also asked open-ended questions to find out what they liked and disliked about the experiments. All of them found the experiment an exciting experience and showed satisfaction with the experimental setting. Results from the experiment evaluation questionnaire suggest that subjects in both phases were generally happy with the experiments and experimental setting. Although they could not produce error-free models, they were motivated, and satisfied with the experimental protocol.

8.7. Conclusion

In this chapter, I have reported the results of controlled experiments to evaluate the RSMP for its understandability, usability and usefulness which were aimed to answer my fourth research question. The experiments were conducted in two phases. The first phase of experiments was conducted with Software Engineering students at the University of Hertfordshire and the second phase was conducted with Operational Research students at Warwick Business School. The subjects in each phase were given a different problem for which to develop a simulation model.

The results show that the subjects in these experiments found the RSMP an easy to understand and easy to learn process. Moreover, they found that the guidelines provided by the RSMP are clear and understandable. Although most of the RSMP subjects were not confident in using the RSMP before the experiments, they indicated after the experiment that it was easy to use the RSMP.

The conclusion is that the RSMP has proved to be at least partially usable and useful for subjects of these experiments. Overall the RSMP subjects performed better than the Non-RSMP subjects in both the SE and OR experiments. The RSMP participants were able to demonstrate comparatively a rapid development approach than the Non-RSMP participants. The RSMP brings benefits in important areas such as problem formulation, documentation and maintainability. In the future the RSMP will be further evaluated by applying it in real-world simulation practice with novice software process simulation modellers.

The small sample size limits the generalisability of the results to the population of software process simulation modellers.

RSMP is a generalised process intended to be independent of discrete event and continuous simulation. However, it has been assessed only with a system dynamic modelling as yet. Ideally it should also be evaluated using a discrete event simulation; however, resources and time constrained me to test it only with one technique. Repeating these experiments in the future with different subjects and under different contexts would be useful in further evaluation of the RSMP.

9. Chapter nine: Evaluating the RSMP with experts

9.1. Introduction

In this chapter I present the results of an expert panel evaluation of the rapid simulation modelling process (RSMP). This expert panel evaluation forms the second stage in evaluating the RSMP evaluation. The expert panel evaluates the RSMP on the evaluation criteria previously established and described in Chapter 4. Chapter 4 also provides a detailed description of the expert panel questionnaire for which the results are now reported.

This expert panel evaluation has been conducted to contribute to answering the following research question:

> *RQ4: Will a simulation modelling process help novice software process simulation modellers to improve their simulation modelling?*

The overall aim of these experiments is to evaluate the RSMP on following five criteria:

- Scope of the RSMP
- Understandability of the RSMP
- Usability of the RSMP
- Utility of the RSMP
- Tailorability of the RSMP

Seven expert software process simulation modellers were invited to participate in this study. Five out of seven agreed to participate. These expert software process simulation modellers are different from those who participated in my interview study. An evaluation questionnaire was constructed and piloted as described in Chapter 4. The questionnaire was sent to the experts who agreed to participate in this study.

Table 9.1 shows the demographics of the experts. Overall the members of the expert panel have a substantial experience of working with simulation problems in the software engineering domain. They are active researchers and/or consultants in software process simulation modelling. Table 9.1 shows that the expert panel have an average experience of 9.8 years in simulation. Table 9.1 also shows that three experts have experience with both discrete event and system dynamics simulation. It also shows that the expert panel have experience of working with many problems related to software process improvement, project management, control and operational management of software processes, technology adoption, process understanding and process training.

Table 9.1: **Expert panel demographics**

	Experience	DE/SD	Professional role	Domain
E1	5 years	DE	Researcher	Software process improvement
E2	22 years	DE	Consultant/ Researcher	Software process improvement project management, control, and planning, training and education
E3	5 years	DE, SD	Consultant/ Researcher	Software process improvement, project management, control, and planning, training and education
E4	9 years	DE, SD	Researcher	Planning, technology adoption, process improvement
E5	8 years	DE, SD	Consultant/ Researcher	Project management, process understanding, technology adoption

DE = Discrete event, SD = System dynamics

The experts were asked to evaluate the RSMP in terms of its scope, understandability, usability, usefulness, and tailorability.

The chapter has been organised in 8 sections. Section 9.2 present the results of the RSMP scope evaluation; Section 9.3 evaluates the understandability of the RSMP; Section 9.4 presents results of evaluating the RSMP for its usability; Section 9.5 discusses the usefulness of the RSMP; Section 9.6 evaluates the tailorability of the RSMP; Section 9.7 provides a discussion of the expert panel evaluation of the RSMP, and Section 9.8 concludes the chapter.

9.2. Evaluation criteria 1: Scope of the RSMP

In Tables 9.2 and 9.3 the experts' responses to evaluate the scope of the RSMP are shown.

Table 9.2a shows that most of the experts think the process activities recommended by the RSMP are fairly general and likely to apply to most contexts of software process simulation modelling practice. However, E1 thinks differently regarding the applicability of the RSMP. Table 9.2 shows that most of the experts think that the RSMP is applicable to system dynamics and discrete event simulation; E1 does not respond to the question regarding applicability of the RSMP to system dynamics; E1 does not have any experience with system dynamics modelling.

Table 9.3 shows that all five experts believe that the RSMP is applicable to small simulation models; experts E2, E3, and E4 also indicate that the RSMP can be useful for developing medium simulation models. Expert E2, who is the most experienced, indicates that the RSMP can also be useful for simulation models of large size.

Table 9.2: Scope of the RSMP [from Part I of the questionnaire]

	E1	*E2*	*E3*	*E4*	*E5*	*M*
1. The activities recommended by the RSMP are general and likely to apply in most contexts	2	4	5	4	4	4
2. The RSMP framework is ***applicable*** to						
a. *System dynamics modelling*	-	4	4	5	4	4
b. *Discrete event simulation*	4	4	4	5	3	4

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

Table 9.2b shows that all five experts think that the RSMP is applicable to low complexity simulation models; similarly, all five experts also think the RSMP is applicable to medium complexity simulation models; only E2 and E4 think that the RSMP can also be useful for highly complex simulation models.

Table 9.3: Scope of the RSMP [from Part I of the questionnaire]

	E1	*E2*	*E3*	*E4*	*E5*
RSMP would be useful for ***what type*** of simulation models					
1. Small size	*X*	*X*	*X*	*X*	*X*
2. Mediums size		*X*	*X*	*X*	
3. Large size		*X*			
4. Low complexity	*X*	*X*	*X*	*X*	*X*
5. Medium complexity	*X*	*X*	*X*	*X*	*X*
6. High complexity		*X*		*X*	

In addition, expert E4 recommends that the RSMP tutorial document should include a clear statement showing the scope under which the RSMP should be used. The proposed change has been incorporated in the RSMP tutorial document shown in Appendix C1.

The overall response from the experts suggests that the RSMP is suitable both for discrete event and system dynamics simulation as it was the objective that the RSMP should be independent of a particular simulation technique. Moreover, the overall response of the experts also suggests that the RSMP is suitable for small/medium and low/medium complexity simulation models.

9.3. Evaluation criteria 2: Understandability of the RSMP

Table 9.4 shows that most of the experts agree that the RSMP has been clearly defined for novice software process simulation modellers. Expert E1 disagrees that the RSMP has been clearly defined; unfortunately, E1 does not provide any suggestions on how to improve the clarity of the RSMP's definition.

Table 9.4 also shows that most of the experts agree that the level of detail provided in the RSMP tutorial document is appropriate for novice modellers. Expert E1 again disagrees on the appropriateness of the level of detail but does not provide any suggestion to improve it; however, the median score for the response category is positive.

Table 9.4: Understandability of the RSMP [from Part II of the questionnaire]

	E1	*E2*	*E3*	*E4*	*E5*	*M*
1. The accompanying documentation ***clearly*** defines the RSMP for novice software process simulation modellers	2	4	4	5	4	4
2. The level of detail in the accompanying documentation of the RSMP is ***appropriate*** for novice software process simulation modellers	2	3	4	4	4	4
3. The RSMP is ***easy to understand*** by novice software process simulation modellers	2	4	4	3	3	3

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M *= Median of the scores*

Table 9.4 shows that only E2 and E3 agree that the RSMP is an easy to understand process for novice modellers; E2 disagrees and E4 and E5 chose the middle value which shows they are not sure. However, the experts have provided some advice on improving the wording and structure of the RSMP tutorial document.

Expert E2 identified an important deficiency in the RSMP documentation as following:

> *"There is little notion of iterating through the steps except for the arrows in Figures 1 and 2 and the initial statement. The iteration is not addressed again very clearly. It might appear to the novice that the steps are taken once and never repeated. Suggest stressing that the model becomes more elaborated and revised through multiple iterations of the modelling process."*

And E4 recommends that:

> *"Some of the steps in the RSMP are optional. It would be worthwhile making them obvious in the graphical representation of the process"*

The deficiencies identified by E2 and E4 are a major ones, which not only affects understanding of the RSMP but subsequently also its usability and usefulness. The changes recommended by the experts to improve understandability of the RSMP have been incorporated in the tutorial document.

9.4. Evaluation criteria 3: Usability of the RSMP

Table 9.5 shows that most of the experts think that the RSMP is a usable process for novices. There is a strong agreement that the RSMP provides a logical set of steps for novices to develop simulation models. Client contact, which is one key process area (KPA) of the RSMP, gets a median score of 4; most of the experts agree that the RSMP requires a realistic level of client contact for simulation model development; however, expert E5 identifies a major deficiency in the RSMP tutorial document as following:

> "*You emphasise heavy client contact in the introduction, yet there is little notion on what process activity the client would be in heavy contact. You should clearly state importance of client contact in the definition of each step which is client intensive, rather it would be even better to incorporate that in the figures*"

The recommendation by expert E5 has been incorporated in the RSMP tutorial document described in Appendix C1.

Table 9.5 shows that E2 and E4 strongly agree that the documentation required in the RSMP is appropriate; E3 and E5 choose middle value, and E1 disagrees. On the other hand, three out of five experts agree that the documentation guidelines provided by the RSMP would be easy to use by novices. However, none of the experts recommends any improvement in documentation guidelines.

Table 9.5 E1 and E2 disagree that the RSMP would be easy to follow; E3 and E4 choose middle values, and E5 agrees that the RSMP would be easy to follow by novices.

E2 says:

> "*The process might appear more simplistic than it is. The novice would find out otherwise when he/she actually gets into it. But then I guess it is same for any process, theory and practice is always different*"

On the other hand E4 says:

"It is very difficult to perceive because I think it [following the RSMPP] would depend on individual calibre of novices and how well actually they have been taught the process"

Moreover, E5 says:

"Ease of using a process is partially connected with the motivation of the modeller to use a process for modelling"

Table 9.5: Usability of the RSMP [from Part III of the questionnaire]

	E1	*E2*	*E3*	*E4*	*E5*	*M*
1. The RSMP provides a ***usable process*** for novice software process simulation modellers	4	4	3	4	4	4
2. The RSMP provides a ***logical set of steps*** for novice software process simulation modellers for simulation model development	4	4	4	4	5	4
3. The RSMP includes a ***realistic*** level of client contact	3	4	4	4	3	4
4. The documentation required in the RSMP is ***appropriate***	2	5	3	5	3	3
5. It would be ***easy*** for novice software process simulation modellers ***to use*** the RSMP documentation guidelines	3	4	3	4	4	4
6. It would be ***easy*** for novice software process simulation modellers ***to follow*** the RSMP	2	2	3	3	4	3

Responses on 5 point likert scales; **Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

The opinions of the experts suggest that there are several factors on which the ease of following the RSMP may depend, which includes individual motivation, calibre and the difference between theory and practice.

9.5. Evaluation criteria 4: Usefulness of the RSMP

Table 9.6 that there is a strong agreement amongst the experts that it is very useful for novice modellers to have a process view of simulation modelling practice. Most of the experts, except E1, agree that using the RSMP is likely to bring discipline into the simulation practice of novices. E2 says:

"It is good that you are trying to balance agility and discipline in the process."

Table 9.6: Usefulness of the RSMP [from Part IV of the questionnaire]

	E1	*E2*	*E3*	*E4*	*E5*	*M*
1. It would be ***useful*** for a novice software process simulation modeller to take a ***process view*** of simulation modelling practice	5	5	4	5	4	5
2. Using the RSMP is likely to ***bring discipline*** into the novice software process simulation modellers' practice	1	4	4	4	5	4
3. RSMP's emphasis on client contact will help the novice software process simulation modellers ***effectively define the problem***	5	5	3	4	5	5
4. Following the RSMP *Foundation* step guidelines, novice software process simulation modellers would be able to capture the ***scope of the problem better***	4	4	3	4	4	4
5. Identifying and defining inputs, outputs, and their interactions (*Foundation* step) in advance will help novice software process simulation modellers in producing ***better model design***	3	4	3	4	3	3
6. Identification of scenarios (*Foundation* step) in advance will help novice software process simulation modellers in ***designing the experiments better***	3	5	3	5	5	5
7. Designing the model structure in advance (*Construction* step), a novice software process simulation modeller would be able to produce a better model design in terms of						
a. Reusability	3	4	3	4	2	3
b. Modularity	3	5	3	4	4	4
c. Interoperability	2	4	3	2	2	2
8. Using the RSMP is likely to ***improve the validity*** of the simulation models produced by novice software process simulation modellers	2	5	3	3	3	3
9. Designing the experiments prior to conducting them is more likely to produce ***valid results***	2	3	4	5	4	4
10. Using the RSMP documentation guidelines, the novice software process simulation modellers would be able to produce ***better documentation***	3	5	4	4	5	4
11. Documentation produced following the RSMP guidelines will ***make it easier*** to understand the model	2	4	4	4	3	4
12. Documentation produced following the RSMP guidelines will ***help model maintenance***	4	5	4	4	3	4
13. Producing the documentation, as specified by RSMP, would need further cost/effort to simulation model development	3	3	4	5	5	4

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

There is again strong agreement that having heavy client contact will help to effectively define the problem. Table 9.6 also shows that most of the experts think that the RSMP's foundation step guidelines will help novices capture the scope of the problem better. However, Table 9.6 also shows that most of them are not sure whether identifying and defining model inputs, outputs and their interactions in advance will help produce a better model design.

Table 9.6 also shows that experts do not generally agree that planning the model structure would help reusability and interoperability of the model, but most of them think that it will help enhancing the modularity of the simulation model. However, reusability and interoperability may not be important in practice, as E2 says:

> *"Reusability and interoperability may not be important goals depending on the context"*

Table 9.6 also shows that most of the experts are not sure whether using the RSMP would enhance the validity of the simulation models developed by novices. However, most of the experts think that identifying experimental scenarios at the beginning of the simulation study would help to produce better experiments design, and designing the experiments before conducting them helps to produce valid experimental results.

Table 9.6 also shows that most of the experts think that the documentation produced following RSMP's documentation guidelines would make it easy to understand the simulation models, and in turn make it easier to maintain the models. However, most of them think that producing documentation introduces extra overheads of cost and effort.

9.6. Evaluation criteria 5: Tailorability of the RSMP

Table 9.7 shows that there is a strong agreement amongst experts that the RSMP can be tailored to individual needs. Similarly, Table 9.7 shows that most of the experts agree that it is easy to adapt the RSMP as needed. Moreover, most of them agree that it would be easy to extend process activities to specialise them to specific contexts. The RSMP has been designed at a fairly high level; a more detailed and prescriptive RSMP would have become less likely to be applicable to a wide variety of contexts.

The RSMP's potential for being adapted for individual needs appears to be a strength of the RSMP's design.

Table 9.7: Tailorability of the RSMP [from Part V of the questionnaire]

	E1	*E2*	*E3*	*E4*	*E5*	*M*
1. The RSMP can be ***tailored*** to suit an individual simulation modeller's needs	4	5	4	4	4	4
2. It would be easy to ***adapt*** the RSMP (e.g. add/remove/amend process activities)	4	5	4	3	4	4
3. It would be possible to ***extend*** each process activity to create specific guidelines and prescription in specific situations	3	4	4	3	5	4

Responses on 5 point likert scales;* ***Strongly Disagree 1 2 3 4 5 Strongly Agree*
M = *Median of the scores*

9.7. Discussion

The expert panel evaluation of the RSMP not only contributed to testing the validity of the RSMP but has also helped to improve the RSMP. It highlights strengths and weaknesses of the RSMP and helps determine the directions for further developments and evaluation of the RSMP.

The general attitude of most of the expert panel is supportive. Expert E1 is most critical of various aspects of the RSMP, unfortunately E1 does not provide any feedback which could explain his/her negative response or be used to improve the RSMP.

There is general consensus amongst the expert panel that the RSMP is applicable to both discrete event and continuous simulation and for developing simulation models of small/medium size and low/medium complexity. The expert panel results which test the scope of the RSMP supplement the results of the experiments, in which the RSMP was applied to a small and low complexity problem. The results from the experiments and the expert panel evaluation add confidence that the RSMP is applicable to the contexts it has been designed for.

Confidence in the understandability of the RSMP has been further strengthened by the results of this expert panel evaluation. The experimental results show that the RSMP is clear, easy to understand, and easy to learn for novices who participated in the experiments. This is further augmented by the general consensus amongst the experts that the RSMP has been defined clearly. However the experts are not sure whether the RSMP would be easy for novices to understand. The experts, however, have provided with valuable advice to improve the RSMP so as to make it more understandable.

Most of the experts generally believe that the RSMP is a usable process and provides a logical set of steps. Nevertheless, they are not sure how easy would it be for novices to follow the RSMP. This is because they believe that usability is not only a property of the RSMP but also depends on the users of the RSMP. The experts believe that the calibre, motivation, and circumstances of an individual modeller play a major part in the ease of using the RSMP. Although, according to the experts the RSMP documentation guidelines are easy to follow, they are not sure whether the rigour of documentation proposed by the RSMP is appropriate. However, they do not recommend any improvement in the documentation guidelines. This could be perhaps because the experts either do not consider the documentation very important or they think that documentation depends on the requirements of the project; if this is so, it would be similar to most of the expert simulation modellers who participated in my interview study who believe the rigour of documentation depends on various circumstances (as described in Chapter 6).

The experts generally believe that it is useful to have a process view of simulation modelling and that the RSMP is likely to bring discipline to the simulation practices of novices. This can be related to the experimental results, where most of the experiment subjects indicated that the RSMP brought discipline into their simulation modelling. There is a strong agreement amongst the experts that the RSMP would be helpful for novices in making them define the problem effectively. This can be related to my experiments results where the RSMP subjects defined the problem more effectively than the Non-RSMP subjects. The simulation literature also suggest that following a disciplined process to develop simulation models would be helpful to define problem effectively. [Rus et al. 2003, Robinson 2004, Nordgren 1995].

Although generally the experts are not sure whether identifying and defining simulation inputs, outputs and their interaction as suggested by the RSMP process activity would help designing better models, the RSMP subjects produced better model designs in the experiments.

Most of the experts believe that identifying experimental scenarios at the beginning of the simulation study and designing the simulation experiments prior to conducting them would help producing valid experimental results from the simulation. It was a limitation of my controlled experiments that the time did not allowed the subjects to conduct experiments on their models so that the RSMP could be fully tested. Expert panel evaluation, however, provides some confidence that the RSMP can be helpful in conducting effective experiments.

The usefulness of documentation guidelines gains considerable agreement from the expert panel. The expert panel views the RSMP documentation guidelines as helpful in producing better documentation of simulation models. Moreover, they think that documenting the simulation models makes it easier to understand and maintain models. This result adds strength to the experiment results in which the RSMP subjects performed better than the Non-RSMP subjects for the maintainability of simulation models; primarily because they provided documentation with their models.

It was an objective that the RSMP should be tailorable to individual needs. The expert panel evaluation suggests that the RSMP is an abstract and general process which can be easily tailored to individual needs.

The five criteria; scope, understandability, usability, usefulness, and tailorability of the RSMP has been evaluate to answer my fourth research question. The expert evaluation results suggest that the RSMP has the potential to be a useful process for novices to improve their simulation modelling.

A note on the evaluation process

It may have been potentially better if the expert panel evaluation was conducted prior to conducting the experiments. Because then the experiment subjects would have been trained in a process revised and improved by the experts.

The original plan was to conduct the expert panel evaluation after the first phase of the experimental study (SE experiments) and the second phase (OR experiments) would have been conducted after the expert panel evaluation with a revised version of the RSMP. This would have potentially allowed comparison of the results of two phases on two evolving versions of the RSMP and objectively assess the value the expert panel evaluation would have added to the RSMP.

However, the original plan could not be exercised as the experts took too long time return the questionnaire. Therefore the second phase of experiments had to be conducted with the earlier version of the RSMP.

9.8. Conclusion

This chapter seeks to answer my fourth research question:

> *RQ4: Will a simulation modelling process help novice software process simulation modellers to improve their simulation modelling?*

I have presented the results of an expert panel evaluation of the RSMP which was the second stage of the evaluation plan to answer this research question. In the second stage, the RSMP has been evaluated in terms of its scope, understandability, usability, usefulness and tailorability. The members of the expert panel who evaluated the RSMP are highly experienced and have developed models for many of the problems related to software engineering.

The results suggest that the RSMP may not be applicable to every kind of models (in terms of size and complexity). It is most likely to be applicable to small/medium size and low/medium complexity simulation models. The expert panel evaluation augmented by experimental results suggests that the RSMP has been defined clearly and is likely to be understandable by novices in SPSM. The expert panel generally believe that the RSMP is a usable process and is useful in various aspects such as better problem formulation, documentation, experimental design, and experimental results validity. Moreover, there is a high level of consensus amongst members of the expert panel that the RSMP is a process which can be tailored to individual needs.

Generally, the expert panel evaluation in conjunction with the experimental results strengthens the validity of the RSMP. However, the expert panel responses suggest that the RSMP is unlikely to satisfy everyone and cannot be fully evaluated in all aspects through these two studies. A separate study is needed to evaluate the effect of

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PART IV: CONCLUSION

10. Chapter ten: Conclusion and future work

This chapter summarises my work and presents conclusions from my research. It explains how the research findings relate to the research questions and how the questions address the hypothesis. The chapter explains how this research has contributed to the body of knowledge in software process simulation modelling (SPSM) in particular and simulation modelling in general. It also provides a critique of the research strategy used and potential extensions to this study are also explored.

10.1. Overview of the work

This thesis reports the development and evaluation of a simulation modelling process (RSMP) for novices in software process simulation modelling. Simulation modelling of software engineering processes has come into research and practice recently [Abdel-Hamid 1989] and there is a lack of literature available to guide novice software process simulation modellers. Moreover, there is very little debate in the SPSM literature about the simulation modelling process. The aim of this research project was to develop a simulation modelling process for novices in SPSM which embodies real world simulation practice.

The hypothesis of this study is:

A simulation modelling process will be helpful to novice software process simulation modellers to improve their simulation modelling.

The hypothesis has been addressed using the following three research questions:

1. What are the modelling contexts of simulation modellers?
2. What are the practices of simulation modellers?
3. What process emerges by investigating the contexts and practices of simulation modellers?
4. Will a simulation modelling process help novice software process simulation modellers to improve their simulation modelling?

The objectives of developing a simulation modelling process for novices were:

I. Provide novices software process simulation modellers with a simulation modelling process which is close to real world simulation practice

II. Develop a simulation process which is independent of a particular simulation technique (i.e. discrete event and system dynamics)

The study resulted in the development of the RSMP through an empirical investigation of the contexts and practices of expert simulation modellers (as reported in Chapters 6 and 7). Two groups of simulation modellers were studied in this research; software process simulation modellers and operational research simulation modellers. The participants in both groups of simulation modellers were a mix of researchers and consultants and had experience with discrete event simulation and system dynamics. An empirical investigation of the practices of expert simulation modellers allowed the development of a simulation modelling process which embodies real world simulation practice; and a mix of discrete event simulation and system dynamics modellers allowed the development of a simulation modelling process which is independent of a particular modelling technique. A comparison of the RSMP with other simulation modelling processes (Chapter 7, section 7.4) adds confidence that the objectives of the RSMP.

The RSMP has three core phases and two key process areas (KPAs). The RSMP core phases guide a novice software process simulation modeller through the process of developing a simulation development; the RSMP client contact KPA emphasises a heavy contact with the client; and the RSMP documentation guidelines help novices produce the documentation to support the simulation models they develop.

The RSMP has been evaluated with novice software process simulation modellers through two sets of controlled experiments. In each set of experiments, novices were divided into two groups, one of which used the RSMP, while the other used their own process to develop simulation models. The results of these experiments show that the RSMP has the potential to deliver focused benefits to simulation modelling for novices in SPSM. The RSMP has also been evaluated by an expert panel for its scope, understandability, usability, usefulness, and tailorability. The results of the expert panel not only increased confidence in the usefulness of the RSMP for novices but feedback from the expert panel also helped improve the RSMP. The results from evaluating the RSMP are encouraging; however, I do not claim that these results are generally applicable as they are based on a non-random and small size sample.

10.2. Summary of research findings

10.2.1. RQ1: What are the contexts of simulation modellers?

To answer the first research question the following main findings have been drawn from the interview participants:

- Most simulation models (both in SPSM and OR) are developed for short-term use (see Chapter 6, Section 6.3.1)
- Most simulation models (both in SPSM and OR) are of small or medium size (see Chapter 6, Section 6.3.4)
- Most simulation models (both in SPSM and OR) are of low or medium complexity (see Chapter 6, Section 6.3.5)
- The size and complexity of models are interrelated i.e. typically the larger the model, the greater the complexity
- The size and complexity of models is dependent on the problem size, complexity, and the level of detailed needed in a simulation model
- There are no generally agreed measures for simulation model size and complexity; and most participants do not consider it important to measure size and complexity
- Use of simulation tools or language selected to develop a simulation model may affect simulation size and complexity (see Chapter 6, Section 6.3.2)
- Most simulation models are developed by an individual modeller. However, the modeller has to interact with clients, users and/or domain experts to develop the simulation model (see Chapter 6, Section 6.3.6)

10.2.2. RQ2: What are the practices of simulation modellers?

In an attempt to answer the second research question, the following main findings from the interview participants are presented:

- Most participants emphasise heavy client contact and rapidness in the simulation modelling process (see Chapter 7, Section 7.2.1)

- The simulation modelling process of most participants is highly iterative (see Chapter 7, Section 7.2.1)

- There should not be a strict order in the activities related to problem understanding and formulation (see Chapter 7, Section 7.2.1)

- Most participants have three overlapping phases in their simulation model development process; in which phase-I involves heavy client contact during the work related to problem understanding and formulation; phase-II consists of the technical work of model building and has relatively lower client contact; and phase-III again has an equal amount of client contact and technical work of experimentation. (see Chapter 7, Section 7.2.2)

- Simulation model documentation depends on many factors, which include the type of simulation study, the size and length of simulation study, model life, time and budget constraints, model users, and relationship with the client (see Chapter 6, Section 6.4.1)

- Most of the participants think that simulation model maintenance is not an issue if a model is to be maintained by its authors (see Chapter 6, Section 6.4.2)

- The participants think that if a simulation model has to be used and maintained in the long-term, it should be provided with good documentation; the most important aspect of which is providing comments within the model. Other documentation suggestions include clearly stating the model objectives, questions, defining inputs and outputs, and model working (see Chapter 6, Section 6.4.2)

- Simulation model validation is the core activity for model evaluation and client satisfaction is single biggest indicator of model evaluation (see Chapter 6, Section 6.4.3)

- Although the simulation modelling processes of the SPSM and the OR participants are quite similar, the main difference is experimentation; where as compared to the OR participants most of the SPSM participants do not explicitly mention experimentation as part of their process.

10.2.3. RQ3: What process emerges by investigating the contexts and practices of simulation modellers?

To answer the third research questions, the following main findings have been drawn:

<u>The RSMP</u>

The RSMP has been developed by analysing the empirical data collected from expert simulation modellers

- A rapid simulation modelling process (RSMP) consisting of three core phase and two key process areas (KPAs); client contact and documentation

- The RSMP core phases are foundation, construction, and experimentation which are based on the three phases identified from the analysis of participants' simulation modelling processes

- The RSMP client contact KPA emphasises heavy client contact;

- The RSMP documentation guidelines consists of general recommendations for documenting a simulation study

- The RSMP is for individual simulation modellers, intended to be independent of a particular simulation technique (e.g. discrete event or system dynamics), and for developing simulation models of small/medium size and low/medium complexity; because the RSMP is based on an empirical investigation of simulation modellers who most of the time develop simulation model individually, develop both discrete event simulation and system dynamics models, and their models are mostly of small/medium size and low/medium complexity.

10.2.4. RQ4: Will a simulation modelling process help novice software process simulation modellers to improve their simulation modelling?

The RSMP has been evaluated with novice software process simulation modellers through controlled experiments and also through expert panel evaluation. The criteria used in this evaluation were established prior to developing the RSMP as described in Chapter 4. The RSMP evaluation criteria include scope, understandability, usability, utility, usefulness, and tailorability.

To answer the fourth research questions, following I summarise the key findings.

The RSMP has been evaluated with novice software process simulation modellers for its understandability, usability, and usefulness as detailed in Chapter 8. The results of evaluating the RSMP with novices are summarised as following:

- Novice software process simulation modellers indicate that they find it easy to understand and learn the RSMP (see Chapter 8, Section 8.5.1)
- Results suggest that the RSMP is a usable process as novices followed the RSMP guidelines at least for the first two phases. However, they could not perform experimentation. They also maintained heavy client contact as suggested by the RSMP. They also produced documentation for most of the tasks they went through (see Chapter 8, Section 8.5.2)
- Results also suggest that the RSMP proved to be a useful process for novices in SPSM to improve their simulation modelling. Overall the models produced by the RSMP subjects in the experiments are better and more maintainable than the Non-RSMP subjects, and the documentation produced by the RSMP subjects is better than the Non-RSMP subjects (see Chapter 8, Section 8.5.3)

The RSMP has also been evaluated for its scope, understandability, usability, usefulness, and tailorability by a panel of experts. The expert panel results suggest that:

- The RSMP is suitable for its intended scope i.e. simulation models of small/medium and low/medium complexity; and both for discrete event and system dynamics modelling (see Chapter 9, Section 9.2)

- The RSMP is clearly defined and the level of detail provided in the RSMP tutorial is appropriate. However, the expert panel is not sure whether it is easily understandable by novices in SPSM (see Chapter 9, Section 9.3)

- The expert panel think that the RSMP provides a usable logical set of steps for simulation model development, requires a realistic level of client contact, and it would be easy for novice software process simulation modellers to follow the RSMP documentation guidelines. However, the expert panel is not sure whether it would be easy for novices to follow the RSMP (see Chapter 9, Section 9.4)

- The expert panel think that it is useful to provide a process view for simulation model development; that the RSMP is likely to bring discipline to modeller work; the RSMP is likely help define the problem better; help capture the scope of the problem better; and design the model better. Moreover, they think that the RSMP guidelines may help design better experiments, produce valid simulation results, produce better documentation, and enhance the maintainability of simulation models. However, the expert panel is not sure whether the RSMP will be useful in improving the validity of simulation models (see Chapter 9, Section 9.5)

- The expert panel think that the RSMP is fairly general and can be tailored easily to suit individual needs and can be extended in each process activity to create specific guidelines (see Chapter 9, Section 9.6)

The evaluation results of the RSMP provide encouraging evidence of its scope, understandability, usability, usefulness, and tailorability. The evaluation results are specific to the subjects of the study and cannot be generalised to a larger population. The answers to these research questions provide some confidence in testing the hypothesis, "*A simulation modelling process will be helpful to novice software process simulation modellers to improve their simulation modelling.*"

10.3. The contribution to knowledge

I have empirically studied the contexts and practices of experienced simulation modellers in the field of software engineering and operational research to develop a simulation modelling process (RSMP). The RSMP has been evaluated by novice and expert software process simulation modellers.

My contribution to knowledge is a simulation modelling process that guides novice software process simulation modellers to develop simulation models. It offers guidelines of the three general phases that should be followed during a simulation study; it emphasises heavy client contact, and provides guidelines to document simulation studies. This research project makes the following contributions to knowledge:

- An empirical study that investigates the contexts and practices of simulation modellers coming from two distinct backgrounds (SE and OR)
- A study in that provides novice software process simulation modellers with a simulation modelling process close to real world simulation practice and intended to be independent of a particular simulation technique

The RSMP has been developed using empirical data collected from expert simulation modellers. It has been compared for its validity with the modelling processes reported previously in the literature. While the RSMP marks a fundamental difference from the simulation modelling processes reported in the SPSM literature, the RSMP shares similarities with the simulation modelling processes reported in the general simulation literature. Comparing the RSMP with other processes provides evidence to its validity and extends its generalisability to simulation modelling discipline in general.

The SPSM is a very young and small community [Raffo 1998] because simulation modelling was used in research and practice only around 15 years ago [Abdel-Hamid 1989]. So far the SPSM community has been isolated from the general simulation community for unknown reasons. Moreover, the mainstream simulation community seems to be unaware of SPSM research. For example, hardly any papers related to software process simulation can be found in the proceedings of the Winter Simulation Conference (WSC) or the European Conference on Modelling and Simulation

(ECMS), which are the biggest research events in simulation modelling. This situation potentially limits the SPSM community from learning from the mainstream simulation community. In this study expert simulation modellers have been interviewed both from SPSM and OR simulation backgrounds. This study may prove to be a bridge between the software process simulation modelling community and the mainstream simulation community.

10.4. Critique of the research methodology

This section presents a critique of the methodology adopted for this study. It identifies how this research could be done differently and adopting other methods could add to the findings of this study.

10.4.1. Use of interview data only

I have used only the interview data for developing the RSMP. Consequently the data collected consists largely of perceptions of the participants regarding their contexts and practices. These perceptions have not been verified directly. It is therefore possible that what modellers perceive they do may be different in practice. Ideally this perception data should be augmented by observational data from practices.

An alternative approach to exploring the simulation modelling process is to conduct field studies of simulation modellers as they work on a simulation study. Another possible way to explore their simulation modelling processes is to conduct experiments with them using a think aloud protocol as Willemain [1995] did, in which simulation modellers are given a problem to develop model for. Both of these approaches might have effectively augmented the interview data. However, both of these approaches could not be taken because:

- The participants involved in the interviews are geographically dispersed across Europe and America which poses an accessibility problem
- Both approaches would have required a longer time period and more resources than were available for this study.

10.4.2. One to one interview as opposed to focus group discussions

Another possible approach for data collection from expert simulation modellers could be focus group discussions. Prior to deciding the approach to be undertaken for data collection I considered focus groups. The simulation literature suggests that most simulation models are developed by individuals [Robinson 2002]. Therefore, individual modellers have been studied through one-to-one interviews. Focus group discussions would have been useful if the aim of the research was to explore the simulation modelling process of the participants from an organisational and teamwork perspective. However, it would have been useful if focus group discussions including of simulation modellers, client, model users, and domain experts could be conducted. This would have allowed exploration of the facets of the simulation modelling process associated with client interactions. However, the short timescale of the project, geography, and resource constraints did not allow the adoption of such an approach.

10.4.3. A large scale survey followed by the interviews

A possible approach to generalise interview results is to conduct a large scale survey with simulation modellers after having developed a simulation modelling process from interview data. Such a survey would have allowed the exploration of the simulation modelling process of a large sample of modellers. However, given the short time scale of this project, conducting such a survey would not have allowed time to evaluate the RSMP through controlled experiments with novices. A lack of a sampling frame of simulation modellers also limits taking this approach.

10.4.4. The RSMP evaluation

The participants in the interview study come from both system dynamic and discrete event simulation backgrounds. The RSMP is a generic process, consolidated from the data gathered from system dynamics and discrete event modellers. Therefore, RSMP is intended to be generically applicable to both system dynamics and discrete event simulation. The results from controlled experiments indicated that the RSMP is usable and useful for system dynamics modelling, however, the RSMP's usability and usefulness remains to be established for discrete event simulation. There is promising feedback from the expert panel that the RSMP can be applicable to system dynamics modelling as well as discrete event simulation, nevertheless, establishing RSMP's applicability to discrete event simulation remains an area for further research. Therefore, I intend to repeat the experiments with discrete event simulation in the future.

10.5. Future work

This section outlines possible extensions to this work. An empirical investigation of practices of simulation modellers provides a foundation for future work in similar areas. I discuss how the RSMP can be further developed, validated and generalised and what other methodological issues can be further explored based on the findings from this study.

10.5.1. Further development of the RSMP

A large scale survey of simulation modellers

The interview study with expert simulation modellers revealed their contexts, practices, and a set of process activities which they perform to develop simulation models. To generalise these findings a large scale survey of simulation modellers aiming to explore similarities and difference in the process activities of simulation modellers would be useful. Such a survey could be conducted not only with software process simulation modellers but also with simulation modellers from other domains, and with varying degree of experience, to generalise the results. This would potentially add to the validity of the findings from this research.

A field study with novices to evaluate the RSMP

The RSMP has been evaluated with novice software process simulation modellers in a laboratory situation. To effectively evaluate and improve the RSMP, a field study with novices in SPSM should be conducted where the novices will work on a real w#orld simulation problem(s) over an extended period of time. This will help evaluate the RSMP in the aspects which could not be covered through laboratory study.

Moreover, the RSMP has been evaluated only for system dynamics modelling for a problem which has to be solved in two hours in a laboratory situation. A field study involving novices working both discrete event and system dynamics models with a real modeller-client environment have more potential to evaluate the RSMP.

10.5.2. Other methodological issues

A field study of conceptual modelling practices of simulation modellers

The RSMP has been developed only through perception data collected from expert simulation modellers. In this study, the dominant part of the discussion in most of the interviews has been conceptual modelling or problem formulation. There is a lack of reporting in the software process simulation literature on how simulation modellers go about doing conceptual modelling in the real world. A field study with simulation modellers has the potential to unravel the conceptual modelling practices of simulation modellers. This will help understand the effective techniques for conceptual modelling and subsequently improve conceptual modelling practices.

A study of simulation modellers' interaction with client/user/domain experts

A recurring theme in the interviews with simulation modellers has been client contact and interaction with the client, users, and domain experts. The simulation modelling literature generally emphasises the importance of communication with the client [Paul 2003, Taylor 2000, Robinson and Pidd 1998], yet no studies can be found which explore the dynamics of client communication. Similarly, there is little or no literature available in software process simulation modelling which takes the client aspects of simulation modelling into account. An in-depth study of simulation modellers' interactions with clients will help improve understanding and may lead to improved practice.

Developing an approach for simulation model documentation

Foss et al. [1998] say that most simulation models are poorly documented; therefore, they are rarely reused and difficult to maintain. Although the RSMP provides guidelines based on data collected from the simulation modellers who participated in this study, the documentation guidelines are very basic. Studying the documentation produced by modellers during real world simulation studies will add depth to an understanding of effective documentation. The only study regarding documenting simulation models have been conducted by Gass [1978] but that study recommends a documentation approach based on an investigation of large scale simulation models' documentation. A documentation approach developed by an in-depth study of the documentation practices of simulation modellers would potentially help software process simulation modellers to produce effective documentation for the kind of they develop.

FINAL WORD

By developing a simulation modelling process based on an empirical investigation, I have attempted to fill a gap found in the current-state-of-the-art in software process simulation modelling. Several processes have been reported in the literature, however, none reports on how the authors have formulated a process model for simulation. This study shows an empirical way to formulate a simulation modelling process. In developing the RSMP I have utilised expert insights into simulation modelling in the real world. The RSMP framework is holistic and tailorable and is based on best practices of expert modellers. The results of evaluating the RSMP demonstrate that the RSMP can be useful in improving the simulation modelling practices of novice software process simulation modellers. Although it is difficult to formally show the impact of using the RSMP on the validity of models, generally following the discipline of the RSMP has the potential to produce better models.

(The End)

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Appendices

Appendix A1: Glossary of terms and acronyms

Acronym	Meaning in full
CMM	Capability maturity model
GT	Grounded theory
KPA	Key process area
OR	Operational research
RSMP	Rapid simulation modelling process
RUP	Rational unified process
SPSM	Software process simulation modelling

Term	Related words	Definition
Abstraction		The principle of ignoring/suppressing the information that is not relevant to the current purpose in order to concentrate more fully on those that are [Coad and Yourdon, 1990].
Agile methods	Extreme programming, pair programming	Agile methods emphasise the non-technical aspects of developing software where software development is viewed as a highly social activity. Agile approaches are related to inspecting and adapting engineering approach where cycles and feedback loops are short [Cohn and Ford 2003].
Best Practice		"*A [proven] tactic or method chosen to perform a particular task and/or to meet a particular objective*" [Beecham 2003]
Client contact	Simulation modeller	Interaction of a simulation modeller with the client in order to conduct a simulation study
Computer science		*"Computer science is concerned with the theories and methods which underlie computers and software systems (whereas software engineering is concerned with practical problems of producing software)."* [Sommerville 2001]
Conceptual modelling	Simulation modelling	*"A non-software specific description of the simulation model that is to be developed, describing the objectives, inputs, outputs, content, assumptions and simplifications of the model"* [Robinson 2004]
Consultant		People actively involved in developing simulation models in industry
Context(s)	Simulation modeller	The particular environment within which a simulation modeller develops simulation models e.g. simulation techniques, tools, models size and complexity, nature of teams etc.

Customer/client		*"The person, or persons who pay for the product and usually (but not necessarily) decide the requirements. In the context of this and the IEEE [1998] recommended practice the customer and the supplier may be members of the same organization. The individual, group, organisation that commissions the development of the system"* [Loucopoulos and Karakostas 1995].
Engineering		*"Engineering is the use of principles to find designs that will meet multiple competing objectives, within limited resources and other constraints, under conditions of uncertainty."* [Gilb 1996].
Expert(s)	Expert evaluation	The expert software simulation process simulation modeller who participated in the panel to evaluate the RSMP
Framework		An essential supporting or underlying structure [Camb. 2005]
Goal Question Metric	GQM	A paradigm proposed by [Basili and Rombach 1988] that is used to help decide what measurements should be taken and how they should be used.
Helpful (from hypothesis)		Providing assistance or serving useful function. Giving support. Being of service or assistance. [dictionary.com]
Improve (from hypothesis)		To raise to a more desirable or excellent quality; make/become better To increase productivity or value To put to good use; use profitably [dictionary.com]
Item	In questionnaires, also questions	*"The term ,item™ is used to mean the question and all its associated results; i.e. the row of results"* [El Emam and Jung 2001]
Life cycle	System	*"The period of time that begins when a system is conceived and ends when the system is no longer available for use"* [IEEE 1999]
Model		*"A model is an external and explicit representation of part of a reality as seen by the people who wish to use that model to understand, to change, to manage and to control that part of reality"* [Pidd 1996]
Novice		*"A person who is not experienced in a job or situation"* [Camb. 2005]
Participants(s)	Interviews	The simulation modellers who participated in the interview study of this research
Population	Statistics Sampling	A generic term denoting any well defined class of people or things [Everitt, 1998]

	frame	
Practice(s)	Simulation modeller	A particular activity performed by a simulation modeller in order to develop a simulation model and related artefacts such as documentation, reports, user manuals etc.
Process		A collection of activities with entity flows among them (Yu and Mylopoulos 1997) or particular method of doing something, generally involving a number of steps or operations.
Requirement		*"A condition or capability that must be met or possessed by a system or system component to satisfy a contract, standard, specification, or other formally imposed documents. A documented representation of a condition or capability"* [IEEE 1999]
Researcher		Academics who are involved in developing simulation models for research purposes
Resources		*"This relates to time, costs, investment in tools and people. Timescales and estimates given at beginning of project to be managed with allocation of adequate resources (staff time/training/costs of new tools) to include long-term software improvement activities."* [Beecham 2003]
Respondent(s)	Preliminary survey	The software process simulation modellers who participated in the preliminary survey of this research
Simulation model		A simulation model is a dynamic or executable model of a real or conceptual system/process [Kellner et al. 1999]
Simulation modelling		*"The process of designing a model of a real system and conducting experiments with this model for the purpose of either of understanding behaviour of the system or of evaluating various strategies (within the limits imposed by a criterion or set of criteria) for the operation of the system"* [Shannon 1975]
Software engineering		*"Software engineering covers the development of software systems. Software engineers focus on applying systematic, disciplined, and quantifiable approaches to the development, operation, and maintenance of software. When you select software engineering for your model, the model will contain the Process Management, Project Management, Support, and Engineering process areas. Discipline amplifications specific to software*

		engineering are provided to help you interpret specific practices for software engineering" [SEI 2002].
Subject(s)	Experiments	The students at University of Hertfordshire and Warwick Business School who participated in the experiments to evaluate the RSMP
User	Simulation user	An individual or group who uses a simulation model or the results/recommendation gained from a simulation study to understand, control, manager or change a system or process
Validation		the process of ensuring that the model is sufficiently accurate for the purpose at hand", Carson [1986]
Verification		Davis [1997] states, *"Verification is the process of ensuring that the model design (conceptual model) has been transformed into a computer model with sufficient accuracy"*

Appendix A2: Preliminary survey questionnaire

Questionnaire

Thank you for participating in this questionnaire. Your personal information will be kept confidential and will be used only for the purpose of this survey.

Personal Information:

Name: ____________________

Address: ____

____

Phone No.: ____________________

Email Address: ____________________

Experience in modelling (years): ____________________

Position (Academic or Industry): ____________________

Job Title: ____________________

There are six sections. Please circle the appropriate choice for each question.

I. Please describe yourself as a modeller:			
1.	Theoretical	1 2 3 4 5 6	Applied
2.	Value elegance	1 2 3 4 5 6	Value comprehensiveness
3.	Intuitive	1 2 3 4 5 6	Methodical
4.	Value creativity	1 2 3 4 5 6	Value practicality
5.	Generalist WRT subject area	1 2 3 4 5 6	Specialist
II. Please describe the models you make			
1.	Each model unique	1 2 3 4 5 6	All basically identical
2.	Only you use them	1 2 3 4 5 6	Many others use them
3.	Goal is insight	1 2 3 4 5 6	Goal is quantities
4.	Dynamic in behaviors	1 2 3 4 5 6	Static
5.	One unified model	1 2 3 4 5 6	Many linked sub-models
6.	Small no. of variables (say 10-30)	1 2 3 4 5 6	Large no. of variables (say 100+)
7.	Data based	1 2 3 4 5 6	Theory based
8.	Descriptive	1 2 3 4 5 6	Prescriptive
9.	Deterministic	1 2 3 4 5 6	Probabilistic

III. Please describe the problems you model:		
1. System that exist	1 2 3 4 5 6	System only imagined
2. Vague objectives	1 2 3 4 5 6	Specific objectives
3. Simple systems	1 2 3 4 5 6	Complex systems
4. Large problems	1 2 3 4 5 6	Small problems
5. Immediate relevance	1 2 3 4 5 6	Long-term relevance
6. Model a product	1 2 3 4 5 6	Model a process
IV. Please describe the most typical way you develop your models:		
1. Look for analogies	1 2 3 4 5 6	Start from scratch
2. Start small and add content	1 2 3 4 5 6	Start big and subtract content
3. Work in one short burst	1 2 3 4 5 6	Work over extended time
4. No client contact	1 2 3 4 5 6	Heavy client contact
5. Make single model	1 2 3 4 5 6	Make alternative models and compare results
6. Work alone	1 2 3 4 5 6	Work collaboratively with others
V. Please describe your modelling process:		
1. Systematic process	1 2 3 4 5 6	Ad hoc process
2. Assess feasibility as first step	1 2 3 4 5 6	Don't assess feasibility
3. Define model scope at all levels	1 2 3 4 5 6	Scoping isn't a big concern
4. Define problem sufficiently	1 2 3 4 5 6	Insufficient problem definition
5. Always document formally	1 2 3 4 5 6	Never document formally
6. Follow a life cycle approach	1 2 3 4 5 6	No life cycle approach
7. Value modular structure	1 2 3 4 5 6	Develop model in one view
8. Concern usability	1 2 3 4 5 6	Usability isn't of much concern
9. Review model at each step	1 2 3 4 5 6	Review at the end
10. Evaluate formally	1 2 3 4 5 6	No formal evaluation
11. Concerned with model maintainability	1 2 3 4 5 6	Maintainability is not an issue

VI. Urgent issues to be addressed in your opinion

A. In your opinion what is the most urgent issue to be addressed for modelling in software engineering?

a. Modelling process
b. Evaluation
c. Validation
d. Modelling notations
e. Modelling tools or model development environments
f. Formal education and training (for model developers)
g. Other (please specify) ____________________

B. In your opinion what area of modelling process needs more attention?

a. Model requirements analysis (scope, problem definition, inputs and outputs definition etc)
b. Model design
c. Formal documentation
d. Maintenance
e. Other (please specify) ____________________

C. We welcome any comment which you think might be helpful for our research.

____

____

____

Appendix A3: Results of spearman's correlation test on survey data

The tables in this appendix show the correlation between various variables of the preliminary survey questionnaire.

Spearman rho's correlation test is used with non-parametric ordinal data to measure the strength of relation between two variables.

The null hypothesis for a correlation problem is r = 0 (the hypothesis of no relationship) and the alternative hypothesis can take one of three forms depending on the problem.

- H_1: r > 0 (hypothesizing a significant positive correlation between the two variables - a one tailed test)
- H_1: r < 0 (hypothesizing a significant negative correlation between the two variables - a one tailed test)

The value of a correlation coefficient can vary from minus one to plus one. A minus one indicates a perfect negative correlation, while a plus one indicates a perfect positive correlation. A correlation of zero means there is no relationship between the two variables. When there is a negative correlation between two variables, as the value of one variable increases, the value of the other variable decreases, and vise versa. In other words, for a negative correlation, the variables work opposite each other. When there is a positive correlation between two variables, as the value of one variable increases, the value of the other variable also increases.

			Q1.3	Q4.1
Spearman's rho	Q1.3	Correlation Coefficient	1.000	-.671(**)
		Sig. (1-tailed)	.	.002
		N	17	17
	Q4.1	Correlation Coefficient	-.671(**)	1.000
		Sig. (1-tailed)	.002	.
		N	17	17

** Correlation is significant at the 0.01 level (1-tailed).

			Q1.3	Q5.1
Spearman's rho	Q1.3	Correlation Coefficient	1.000	-.582(**)
		Sig. (1-tailed)	.	.007
		N	17	17
	Q5.1	Correlation Coefficient	-.582(**)	1.000
		Sig. (1-tailed)	.007	.
		N	17	17

** Correlation is significant at the 0.01 level (1-tailed).

			Q1.3	Q5.5
Spearman's rho	Q1.3	Correlation Coefficient	1.000	-.679(**)
		Sig. (1-tailed)	.	.001
		N	17	17
	Q5.5	Correlation Coefficient	-.679(**)	1.000
		Sig. (1-tailed)	.001	.
		N	17	17

** Correlation is significant at the 0.01 level (1-tailed).

			Q1.3	Q5.7
Spearman's rho	Q1.3	Correlation Coefficient	1.000	-.417(*)
		Sig. (1-tailed)	.	.048
		N	17	17
	Q5.7	Correlation Coefficient	-.417(*)	1.000
		Sig. (1-tailed)	.048	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q1.3	Q5.8
Spearman's rho	Q1.3	Correlation Coefficient	1.000	.622(**)
		Sig. (1-tailed)	.	.004
		N	17	17
	Q5.8	Correlation Coefficient	.622(**)	1.000
		Sig. (1-tailed)	.004	.
		N	17	17

** Correlation is significant at the 0.01 level (1-tailed).

			Q2.2	Q5.2
Spearman's rho	Q2.2	Correlation Coefficient	1.000	-.518(*)
		Sig. (1-tailed)	.	.017
		N	17	17
	Q5.2	Correlation Coefficient	-.518(*)	1.000
		Sig. (1-tailed)	.017	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q2.2	Q5.6
Spearman's rho	Q2.2	Correlation Coefficient	1.000	.440(*)
		Sig. (1-tailed)	.	.039
		N	17	17
	Q5.6	Correlation Coefficient	.440(*)	1.000
		Sig. (1-tailed)	.039	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q2.6	Q5.4
Spearman's rho	Q2.6	Correlation Coefficient	1.000	-.431(*)
		Sig. (1-tailed)	.	.042
		N	17	17
	Q5.4	Correlation Coefficient	-.431(*)	1.000
		Sig. (1-tailed)	.042	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q2.6	Q4.3
Spearman's rho	Q2.6	Correlation Coefficient	1.000	.480(*)
		Sig. (1-tailed)	.	.026
		N	17	17
	Q4.3	Correlation Coefficient	.480(*)	1.000
		Sig. (1-tailed)	.026	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q2.6	Q4.4
Spearman's rho	Q2.6	Correlation Coefficient	1.000	.425(*)
		Sig. (1-tailed)	.	.045
		N	17	17
	Q4.4	Correlation Coefficient	.425(*)	1.000
		Sig. (1-tailed)	.045	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q3.2	Q5.3
Spearman's rho	Q3.2	Correlation Coefficient	1.000	-.494(*)
		Sig. (1-tailed)	.	.022
		N	17	17
	Q5.3	Correlation Coefficient	-.494(*)	1.000
		Sig. (1-tailed)	.022	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q3.2	Q5.10
Spearman's rho	Q3.2	Correlation Coefficient	1.000	-.490(*)
		Sig. (1-tailed)	.	.023
		N	17	17
	Q5.10	Correlation Coefficient	-.490(*)	1.000
		Sig. (1-tailed)	.023	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q4.4	Q5.2
Spearman's rho	Q4.4	Correlation Coefficient	1.000	-.544(*)
		Sig. (1-tailed)	.	.012
		N	17	17
	Q5.2	Correlation Coefficient	-.544(*)	1.000
		Sig. (1-tailed)	.012	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q4.4	Q5.3
Spearman's rho	Q4.4	Correlation Coefficient	1.000	-.690(**)
		Sig. (1-tailed)	.	.001
		N	17	17
	Q5.3	Correlation Coefficient	-.690(**)	1.000
		Sig. (1-tailed)	.001	.
		N	17	17

** Correlation is significant at the 0.01 level (1-tailed).

			Q4.4	Q5.4
Spearman's rho	Q4.4	Correlation Coefficient	1.000	-.533(*)
		Sig. (1-tailed)	.	.014
		N	17	17
	Q5.4	Correlation Coefficient	-.533(*)	1.000
		Sig. (1-tailed)	.014	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q4.4	Q5.9
Spearman's rho	Q4.4	Correlation Coefficient	1.000	-.542(*)
		Sig. (1-tailed)	.	.012
		N	17	17
	Q5.9	Correlation Coefficient	-.542(*)	1.000
		Sig. (1-tailed)	.012	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

			Q4.4	Q5.10
Spearman's rho	Q4.4	Correlation Coefficient	1.000	-.536(*)
		Sig. (1-tailed)	.	.013
		N	17	17
	Q5.10	Correlation Coefficient	-.536(*)	1.000
		Sig. (1-tailed)	.013	.
		N	17	17

* Correlation is significant at the 0.05 level (1-tailed).

Appendix B1: Interview questionnaire sent to the participants

We are conducting empirical research into how people go about developing simulation models of software processes. This study develops on from our preliminary survey of software process simulation modellers' practices, conducted at ProSim03. The objective of this study is to find out:

- The modelling context of the modellers
- The way simulation modellers go about developing their models.

It will take approximately 45 minutes to complete the interview. Thank you very much for dedicating some time for this interview. All information collected from you will be treated in strict confidence.

Interview Questionnaire

The interview questionnaire consists of two parts. Part I consists of questions related exploring your modelling context and Part II consists of questions related to the way you develop your simulation models.

Part I: Modelling context

1. What kind of simulation models do you develop?
2. What modelling techniques do you use to develop a simulation model?
3. How big are the simulation models you develop?
4. How complex are the simulation models you develop?
5. What problems do you face if you develop simulation models with other modelers?

Part II: Modelling approach and practices

6. Can you describe the way you develop your simulation models?
7. How do you document your simulation models?
8. How do you take care of your simulation models' maintainability?
9. How do you evaluate your simulation models?
10. How effective is the way you develop simulation models?

Appendix B2: Interview script used during the interview

This appendix describes the script for used during semi-structured interviews conducted with expert simulation modellers. The script lists each step and wording to be followed during the interview session. I indicate some of the probes to use when needed and the possible follow up questions depending on the interviewee's response.

Interview Script

Thank you very much Mr/Ms <Name of interviewee> for sparing some time for this interview. I am conducting these interviews as a part of my doctoral research. The aim of this research project is to find out the state of the art in simulation modellers' practices. On the basis of my finding I aim to propose a set of best practice guidelines in software process simulation modelling.

The interview consists of two parts. In Part I, I will ask questions related to your background and modelling context. And in part II, I will ask questions related to the development of simulation models. I expect to finish the interview in 45 minutes. Your responses on the questions are very important to this research. As I cannot trust on my memory to keep a record of your response, would you mind if I record them?

<Tape recorder is turned on depending on the interviewee's response>

Introductory Questions

a. Would you like to ask me something before I start the interview question formally?

b. Would you like to tell about your simulation experience and educational background?

Part I

Question 1

<Would you like to tell me about>

Q.1. What kind of models do you develop?

Probe: overall aim of the models you develop. Strategic, managerial decision making, process improvement, long-term or short-term etc

Question 2

<Alright, so the next question I would like to ask is >

Q.2. What modelling techniques do you use to develop simulation models?

Probe: discrete event, continuous, analytical, combined etc.

Question 3

Q.3. How big are the simulation models you develop?

Follow up: What do you mean by big model? How do you measure size?

Question 4

Q.4. How complex are the simulation models you develop?

Follow up: What do you mean by complex model? How do you measure complexity?

Question 5

Do you develop simulation models alone or with a group of modellers?

<If alone>

Follow up: Why is it? Is it that the models are too small to be developed in a group?

<If in a group>

Q.5. What problems do you face when working in a group?

Part II

Now that I have learned quite a lot about your modelling context, I would like to move on to the next part of the interview that is your approach towards simulation model development. So the first question is:

Question # 6

Q.6. Can you please describe the way you develop your simulation models?

Probe: your approach. The steps you take. Also probe the interviewee on different activities of his model development process and their relation with his/her context.

Question # 7

<Would you like to tell something about>

Q.7. How do you document your simulation models?

Probe: Notes within model. Separate manuals for users and developers etc.

Question # 8

<Now I would like to discuss about maintenance of simulation models you develop. First question is>

Do you need to change your models?

<If No>

Follow up: Why is it? Are the models for very short-term use?

<If Yes>

Follow up: How easy do you find it to change your model?

<If difficult>

Follow up: Why do you find it difficult?

Probe: Modelling tools, techniques or notations do not provide enough support to change models. Or model size and complexity.

<Alright! So would you mind telling>

Q.8. What do you do in your model building to make future changes easy?

Question # 9

<Now I would like to move on to 2nd last question that is>

Q.9.How do you evaluate your simulation models?

Follow up: Who else evaluates your models? Customer or third party?

<I suppose interviewee may talk about validation and verification upon asking this question>

Follow up: How do you differentiate between validation, verification and evaluation?

Question # 10

<So Mr/Ms <name> we are almost at the end of our discussion. Would you like to tell>

Q.10.How effective is the way you develop your simulation models?

Follow up: In your opinion, what should be an ideal process for simulation model development?

<If the described ideal process is different than modeller's actual process>

Follow up: What stops you from using your ideal process?

The End

Thank you very much for your feedback on these questions. Your comments are very valuable and will contribute immensely to this research.

Appendix B3: Skirmish test questionnaire

The questionnaire consists of two parts. Part I consists of questions related to exploring your modelling context and Part II consists of questions related to the way you develop your simulation models.

Each question's validity is determined with three question marked as *a, b, c.* Please circle as appropriate.

Part I: Modelling context

Q1	What kind of simulation models do you develop?	High						Low
a.	How Confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Q2	What modelling techniques do you use to develop a simulation model?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Q3	How big are the simulation models you develop?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Q4	How complex are the simulation models you develop?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Q5	What problems do you face if you develop simulation models with other modelers?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Part II: Modelling approach and practices

Q6	Can you describe the way you develop your simulation models?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Q7	How do you document your simulation models?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Q8	How do you take care of your simulation models' maintainability?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Q9	How do you evaluate your simulation models?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

Q10	How effective is the way you develop simulation models?	High						Low
a.	How confident are you that you *understand* this question.	1	2	3	4	5	6	7
b.	To what extent you have *knowledge* to answer this question	1	2	3	4	5	6	7
c.	How *relevant* is this question to the subject of simulation modelling	1	2	3	4	5	6	7
d.	If you are not satisfied about the way the question is asked, please suggest how this question should be asked							

We would welcome any comments or suggestions that you think might be beneficial for our research.

Appendix B4: Inter-coder reliability test: Applying Cohen's Kappa statistic

This appendix presents results of Inter-coder reliability test performed on category system of qualitative data collected in my interview study. Inter-coder reliability test is used to gain a level confidence whether coding scheme for qualitative data, established by one researcher matches with another researcher's perceptions [Bernard 2000]. Cohen's Kappa statistic is commonly used to check inter-coder reliability. *"Kappa statistic measures how much better than chance the agreement is between a pair of coders on the presence or absence of binary (yes/no) themes in texts"* [Bernard 2000]. Following the application of Kappa statistics has been presented.

2. Process

This qualitative data consisted of interview transcripts conducted with expert simulation modellers to investigate their practices and processes for simulation model development. There were 20 transcripts in total containing 878 marked quotes. The categories system consisted of a hierarchy of 38 categories. Time constraints did not allow the other researcher to test each quote against its relative category. Therefore an arbitrary set of 60 quotes were extracted from all 20 transcripts, which makes up 6% of 878 quotes. The selected 60 quotes belonged to 3 categories chosen from 20 transcripts and they were placed in random order.

Cohen Kappa test was performed in two iterations. In first iteration (iteration A) 60 quotes were chosen falling in three categories; 'Analysis', 'Complexity' and 'Neither', where 'Neither' category was collection of quote falling in any other category of the category system but not in 'Analysis' and 'Complexity'. The kappa value obtained from first iteration was .724. Kappa agreement value, .7 is acceptable to most of the researchers [Bernard 2000]. But some researchers such as Krippendorrf [1980] consider .80 a reliable value for Kappa agreement. To ensure further reliability, I performed 2nd iteration (iteration B) of Kappa test. This time, I modified my method and replaced 'Neither' category with 'Maintainability'. The Kappa agreement value obtained in iteration B was 0.9, which satisfies requirements for category system.

Section 3 and 4 provide the details of both iterations and Section 5 concludes the discussion.

3. Iteration A

Research 1 established the category system

Researcher 1 chooses 60 quotes falling in following three categories

1. Analysis
2. Complexity
3. Neither.

Each of these categories has been defined in figure A1.

Researcher is provided with collection of quotes and definition of categories.

Researcher 2 identifies and marks occurrence of categories 1, 2 and 3 in the provided collection of quotes.

See Table A1 for comparative perceptions of the two researchers for selected quotes, numbered from 1 to 60.

Figure A1: Category definition

Analysis
Analysis is, gaining the understanding the problem at hand. Problems can be organisation's processes. Analysis is also referred as "*Conceptual Modelling*" which may include drawing the understood problem on a piece of paper or computer to ensure that the concepts grabbed during problem recognition are correct. Analysis also includes meetings with the customer, reading customer documents, visiting sites etc. It also has been discussed in the context of preparing requirements specifications

Key words

Analysis, conceptual modelling, understanding the problem, understanding process/processes, meeting the customer, visiting customer site, looking into details, scoping, identifying data requirements, determining boundaries.

Complexity
The theme of complexity occurs when complexity of simulation models is discussed. How does a participant measure complexity? How does he consider a model big, small, simple or complex? Many times this theme has occurred as the amount of time taken to complete the project.

Keywords

Size, Big, Small, Number of variables, Number of interaction, Number of blocks, Number of workstations, Networks, time taken, interactions

Neither
Any quote that does not fall in any of above two categories.

Table A1 : Coders perceptions

Quote#	R1	R2	Quote#	R1	R2
1	3	3	31	2	2
2	3	3	32	3	3
3	1	3	33	1	1
4	3	1	34	3	3
5	2	3	35	3	3
6	3	3	36	1	1
7	1	1	37	2	2
8	2	2	38	3	3
9	1	1	39	3	3
10	2	1	40	2	2
11	3	3	41	1	1
12	3	3	42	2	2
13	1	1	43	2	2
14	3	1	44	1	1
15	2	2	45	1	3
16	3	1	46	1	1
17	1	1	47	3	3
18	2	2	48	1	1
19	1	1	49	2	1
20	2	2	50	1	2
21	2	2	51	1	3
22	3	3	52	1	1
23	3	3	53	3	3
24	1	1	54	3	3

25	1	1	**55**	3	3
26	2	2	**56**	2	2
27	2	2	**57**	3	3
28	1	3	**58**	3	3
29	2	2	**59**	1	1
30	2	2	**60**	2	2

Table A1a shows the number of quotes falling in each category according to Researcher 1 and Researcher 2.

Table A1a: Number of quotes falling in each category according to R1 & R2

	R1	**R2**
Analysis	20	20
S & C	19	17
Neither	21	23

The two researcher's perceptions have been recorded in Agreement matrix tables A3 and A4. Table A2 provides the agreement matrix scheme.

Table A2: Agreement Matrix

Res		**Analysis**	**Complexity**	**Neither**
	Analysis	**A**	A1	A2
	S & C	B1	**B**	B2
	Neither	C1	C2	**C**

Agreement matrix arranged in table A3 shows that:
'*Analysis*' = 20 agreements
R1 '*Analysis*' quote that are in R2 '*Complexity*' = 1 disagreement
R1 '*Analysis*' quote that are in R2 '*Neither*' = 4 disagreement

'*Complexity*' = 16 agreements
R1 '*Complexity*' quotes that are in R2 '*Analysis*' = 2 disagreements
R1 '*Complexity*' quotes that are in R2 '*Neither*' = 1 disagreements

'*Neither'* = 18 agreements
R1 '*Neither'* quote that are in R2 '*Analysis'* = 3 disagreement
R1 '*Neither'* quote that are in R2 '*Complexity'* = 0 disagreement

Table A3: Agreement Marix

R1 x R2		**Analysis**	**Complexity**	**Neither**
	Analysis	**15**	1	4
	S & C	2	**16**	1
	Neither	3	0	**18**

Agreement matrix arranged in table A4 shows that:
'*Analysis*' = 20 agreements
R2 '*Analysis*' quote that are in R1 '*Complexity*' = 2 disagreement
R2 '*Analysis*' quote that are in R1 '*Neither*' = 3 disagreement

'*Complexity*' = 16 agreements
R2 '*Complexity*' quotes that are in R1 '*Analysis*' = 1 disagreements
R2 '*Complexity*' quotes that are in R1 '*Neither*' = 0 disagreements

'*Neither*' = 18 agreements
R2 '*Neither*' quote that are in R1 '*Analysis*' = 4 disagreement
R2 '*Neither*' quote that are in R1 '*Complexity*' = 1 disagreement

Table A4: Agreement Matrix (original scheme)

R2 x R1	**Analysis**	**Complexity**	**Neither**
Analysis	15	2	3
S & C	1	16	0
Neither	4	1	18

Cohen Kappa statistics can be performed with SPSS statistic tool after having the data matrix arranged. Data arranged in Table A5 was put in SPSS for calculation of Kappa statistic automatically. Table A6 shows SPSS output.

Table A5: data put in SPSS to calculate Kappa statistic

Res1	**Res2**	**Frequency**	**Table A3 Matrix reference**
1	1	15	Agreement A
1	2	1	Disagreement A1
1	3	4	Disagreement A2
2	1	2	Disagreement B1
2	2	16	Agreement B
2	3	1	Disagreement B2
3	1	3	Disagreement C1
3	2	0	Disagreement C2
3	3	18	Agreement C

Table A6: SPSS output

		Value	Asymp. Std. Error(a)	Approx. T(b)	Approx. Sig.
Measure of Agreement	Kappa	**.724**	.075	7.938	.000
N of Valid Cases		60			

Kappa agreement value obtained for iteration A: .724

4. Iteration B

Research 1 established the category system

Researcher 1 chooses 60 quotes falling in following three categories

4. Analysis
5. Complexity
6. Maintainability

Each of these categories has been defined in figure B1.

Researcher is provided with collection of quotes and definition of categories.

Researcher 2 identifies and marks occurrence of categories 1, 2 and 3 in the provided collection of quotes.

See Table B1 for comparative perceptions of the two researchers for selected quotes, numbered from 1 to 60.

Figure B1: Category definition

Analysis

Analysis is, gaining the understanding the problem at hand. Problems can be organisation's processes. Analysis is also referred as "*Conceptual Modelling*" which may include drawing the understood problem on a piece of paper or computer to ensure that the concepts grabbed during problem recognition are correct. Analysis also includes meetings with the customer, reading customer documents, visiting sites etc. It also has been discussed in the context of preparing requirements specifications

Key words

Analysis, conceptual modelling, understanding the problem, understanding process/processes, meeting the customer, visiting customer site, looking into details, scoping, identifying data requirements, determining boundaries.

Complexity

The theme of complexity occurs when complexity of simulation models is discussed. How does a participant measure complexity? How does he consider a model big, small, simple or complex? Many times this theme has occurred as the difficulty and amount of time takes to complete the project.

Keywords

Size, Big, Small, Number of variables, Number of interaction, Number of blocks, Number of workstations, Networks, time taken

Maintainability

Changing a model during or after model development due to customer request, changing requirements, reuse, or bug fix.

Keywords

Maintain, Change, Alter, Modify, Modification, Adjust, Adjustment, Amend, Amendment, Alteration, Revise, Revision, Rework, Rewrite, Correct, Correction, Adapt, Adaptation, Transform, Transformation, Improve, Improvement, Renovate, Renovation, Convert, Conversion, Upgrade, Up gradation, Reuse, Use again, Recycle, adapting a model, future use

Table B1 : Coders perceptions

Quote#	R1	R2	Quote#	R1	R2
1	3	3	**31**	3	3
2	3	3	**32**	1	1
3	1	1	**33**	3	3
4	3	3	**34**	3	3
5	2	2	**35**	1	1
6	3	2	**36**	2	2

7	1	1	**37**	3	3
8	2	2	**38**	3	3
9	1	1	**39**	2	2
10	2	2	**40**	1	1
11	3	3	**41**	2	2
12	3	1	**42**	2	2
13	1	1	**43**	1	1
14	2	2	**44**	1	1
15	3	3	**45**	1	1
16	1	1	**46**	3	3
17	2	2	**47**	1	1
18	1	1	**48**	2	1
19	2	2	**49**	2	2
20	2	2	**50**	1	1
21	3	3	**51**	1	1
22	1	1	**52**	3	1
23	3	3	**53**	3	3
24	1	1	**54**	3	3
25	2	2	**55**	2	2
26	2	2	**56**	3	3
27	1	1	**57**	3	3
28	2	2	**58**	1	1
29	2	2	**59**	2	2
30	2	2	**60**	3	3

Table B1a shows the number of quotes falling in each category according to Researcher 1 and Researcher 2.

Table B1a: Number of quotes falling in each category according to R1 & R2

	R1	R2
Analysis	19	22
S & C	20	20
Maintainability	21	18

The two researcher's perceptions have been recorded in Agreement matrix tables B3 and B4. Table B2 provides the agreement matrix scheme.

Table B2: Agreement Matrix

Res	**Analysis**	**Complexity**	**Maintainability**
Analysis	**A**	A1	A2
S & C	B1	**B**	B2
Maintainability	C1	C2	**C**

Agreement matrix arranged in table B4 shows that:
'*Analysis*' = 19 agreements
R2 '*Analysis*' quote that are in R1 '*Complexity*' = 0 disagreement
R2 '*Analysis*' quote that are in R1 '*Maintainability*' = 0 disagreement

'*Complexity*' = 19 agreements
R2 '*Complexity*' quotes that are in R1 '*Analysis*' = 1 disagreements
R2 '*Complexity*' quotes that are in R1 '*Maintainability*' = 0 disagreements

'*Maintainability* = 18 agreements
R2 '*Maintainability*' quote that are in R1 '*Analysis*' = 2 disagreement
R2 '*Maintainability*' quote that are in R1 '*Complexity*' = 1 disagreement

Table B3: Agreement Marix

R1 x R2		**Analysis**	**S & C**	**Maintainability**
	Analysis	19	0	0
	S & C	1	19	0
	Maintainability	2	1	18

Agreement matrix arranged in table B3 shows that:
'*Analysis*' = 19 agreements
R1 '*Analysis*' quote that are in R2 '*Complexity*' = 1 disagreement
R1 '*Analysis*' quote that are in R2 '*Maintainability*' = 2 disagreement

'*Complexity*' = 19 agreements
R1 '*Complexity*' quotes that are in R2 '*Analysis*' = 0 disagreements
R1 '*Complexity*' quotes that are in R2 '*Maintainability*' = 1 disagreements

'*Maintainability*' = 18 agreements
R1 '*Maintainability*' quote that are in R2 '*Analysis*' = 0 disagreement
R1 '*Maintainability*' quote that are in R2 '*Complexity*' = 0 disagreement

Table B4: Agreement Matrix (original scheme)

R2 x R1		**Analysis**	**S & C**	**Maintainability**
	Analysis	19	1	2
	S & C	0	19	1
	Maintainability	0	0	18

Cohen Kappa statistics can be performed with SPSS statistic tool after having the data matrix arranged. Data arranged in Table B5 was put in SPSS for calculation of Kappa statistic automatically. Table B6 shows SPSS output.

Table B5: data put in SPSS to calculate Kappa statistic

Res1	Res2	Frequency	Table B3 Matrix reference
1	1	19	Agreement A
1	2	0	Disagreement A1
1	3	0	Disagreement A2
2	1	1	Disagreement B1
2	2	19	Agreement B
2	3	0	Disagreement B2
3	1	2	Disagreement C1
3	2	1	Disagreement C2
3	3	18	Agreement C

Table B6: SPSS output

Symmetric Measures

		Value	Asymp. Std. Error(a)	Approx. T(b)	Approx. Sig.
Measure of Agreement	Kappa	.900	.048	9.906	.000
N of Valid Cases		60			

Kappa agreement value obtained for iteration B: .900

5. Conclusion

The Kappa agreement value obtained for iteration A was .724 on the provided data. Kappa agreement value, .7 is acceptable to most of the researchers [Bernard 2000]. But some researchers such as Krippendorrf [1980] consider .80 a reliable value for Kappa agreement.

To ensure further reliability, Kappa test method was slightly modified in iteration B. The Kappa value obtained for iteration B is .900 on the provided data, which is higher than .80.

In conclusion Kohen Kappa agreement gives confidence to the reliability of coding scheme established by researcher 1.

Appendix B5: Indexing the interview transcripts

A8-1: Can I have introduction to your background and experience?
I have developed software for about 35 years and I went back to do my masters and doctorate in engineering and management... software modelling is the part of my doctoral research... I also used the models for industrial applications...

A8-2: Simulation models or other models...?
Simulation models of oil and gas pipelines and things like that...

A8-3: What was your PhD about...?
I developed a hybrid model of software development process... and combined SD model of Abdel-Hamid with a discrete model of the process so I had the ability to look at different software process within the context of dynamic environment...

A8-4: So was this model with some industrial collaborator...?
I did both, first I modelled the ISPW6... that's a hypothetical process... so I modelled that within Abdel-Hamid model which is again a theoretical component...
A8-4a: then I did work with company called Northern Braman which had a sophisticated software process... I modelled their process...

A8-5: Did you model the whole process or some part of the process?
I modelled everything up to system test... there were 72 steps... when they got for of their integration testing where they start testing their hardware, I stopped there... so from the definition up to system test...

A8-6: What was the overall aim of the software process model you developed...?
Well, primarily what I was interested in creating a tool that would allow us to examine process questions...
A8-6a: and you know after Abdel-Hamid's model in 1990, that made such a strong argument that structure of the dynamic factors, you know control of what happens, explain the behaviour that it seemed like you cant really ignore the dynamic factors in the project... so you have to have that in your model...
A8-6b: if you really want to explain what's goin on in the project... when you take SD as a tool and you try to understand process steps, like what's going on in inspection... that's very difficult to do in SD because you have to represent everything as flow or level...2nd thing that was a problem in SD model is that you have no attributes... so you cant talk about modules of different size or resources of different capabilities...
A8-4c: so my goal in my research was to create a tool that allows to ask questions that couldn't be answered or asked by these other models...
A8-4d: so I did a discrete model which could also handle attributes or queuing, so it had the resolution to model the SD interactions...
A8-4e: if you model in discrete event you may not see the granularity of feedback loops... so that was I did, to create a tool that would allow us to represent things mode accurately...

Appendix B6: An example of open coding

Advantages of tools

B1-6a: Witness is quite *flexible* and *provides what we need*...
B2-9: I think that's why Witness particularly good... *because you have the front-end, you can build from the designer elements*... and if you go behind that you can use Witness's own *command language*...
B2-11c: I think it [witness] is *very good when it comes extracting the numerical results* would obviously need most of the times...
B5-20a: It [ModSim] is *beautifully object oriented*... it is a pleasure to write... the *libraries are well designed*... they have picked good abstractions... so you haven't got this problem that I get with Java where you have got a vast array of library modules and the API and you have got the *problem of having someone to show your way to libraries*...
B7-5b: I have used Simul8 quite a lot for students' projects... in fact *later versions of Simul8* are much better for dealing this sort of things but I have obviously developed a library of routines...
B8-8a: Because... we used to work with other tools as well but mainly *Witness is good*... we got a *good relationship and support from the supplier* and it seems to be working very well... it is just suitable for us...

Disadvantages/problems of tools

B1-45a: I think there might be a *need to incorporate Witness with other software easier*... there are some *problem with undo function* in Witness...
B2-11a: I think one of the problem with Witness is similar to what I had or would have with any other simulation package, that is sometimes *the graphical side*, presenting the model in an attractive manner which is easy to communicate with non simulation specialist *does take a lot of time*...
B2-11b: it [Witness] is *not as easy* to draw as it is in drawing package... now that functionality has developed and it has improved but it still can take sometime to produce attractive results...
B2-11d: it is very important to be able to communicate with the people in their own terms who don't have knowledge about the software and simulation and to do that I think *a good graphical interface is needed, which can be difficult to achieve...*
B4-1d: because Witness is build in a generic manner to solve all kind of problems, they r *not very good at solving specific problems*...
B4-16a: We have never actually used Witness in a project because of the *cost of licensing*... we are looking at a project of sort of 40-50k... within that budget there isn't awful lot of space for a 10k license...
B4-16c: now *Simul8* has an optimisation capability but we didn't ever used it because it is *too slow*...
B4-16e: you find that *Simul8 or Witness are not fast* enough to do simulation optimisation...
B4-16g: because running simulation isn't particularly interesting, more interesting is to put optimisation and find optimum parameters and restructure the simulation dynamically at runtime... these are the sort of thing that customer would be really like to be able to do... *but current packages don't do that [optimisation]*
B4-41b: Its just *performance* side of things that we miss in *commercial tools*...
B7-5a: For my own work I tend to code it from scratch in Pascal...or Borland Delphi... mainly because healthcare models are so complex and there are so many parallel and interrupted activities that individuals have to be given quite complicated attributes that determines what happens to them... that's *most of the packages, certainly the ones we can afford couldn't do it*...
B8-30b: *Witness doesn't support analysis and design* for simulation model development... you have to build the model directly...

Appendix B7: Example of axial coding

Following an example of axial coding is shown. Axial coding aims to find out relationships between different categories of themes in data. Figure 1 shows the relationships and Table 1 identifies which participant at which place in the interview transcript has talked about a particular relationship.

Figure 1: Relationship between simulation model documentation and maintainability with other categories

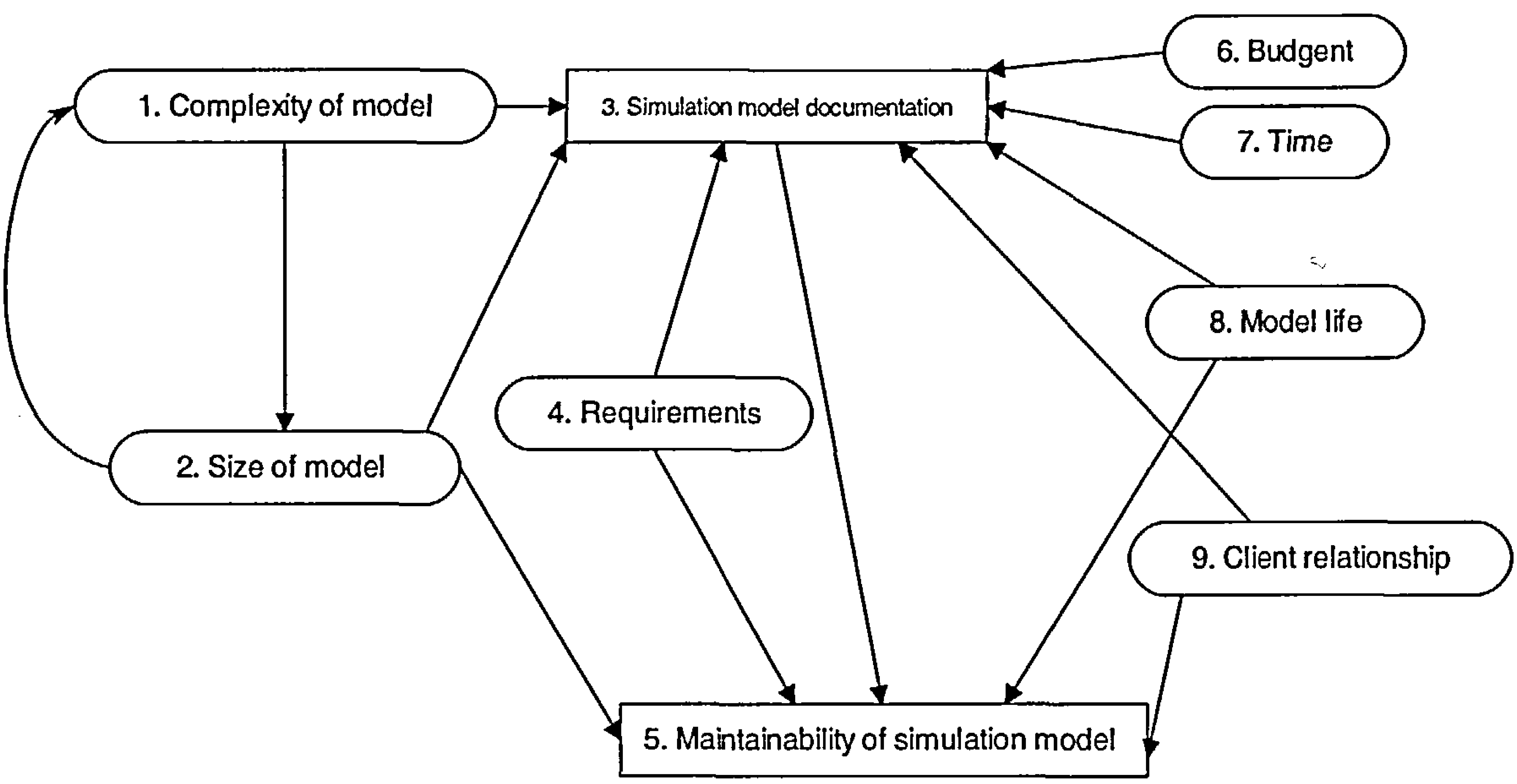


Table 1: Themes relationship matrix

	1	2	3	4	5	6	7	8	9
1		[A3, 21, 36][B2, 10, 11, 22]	[B3, 36, 37]						
2	[A7, 15, 16], [A9, 12, 15]		[B3, 32, 27][A1, 38]		[A5, 25, 55][A6, 45][B8, 51, 53]				
3					[A4, 23, 48, 49][A6, 33, 39, 40][A10, 55][B5, 21, 59, 60] [B10, 42]				
4			[A2, 49, 51][B3, 36, 37]		[A4, 25][B3, 44, 45]				
5									
6			[A8, 67][A10, 52, 53] [B4, 29, 32][B7, 45]						

7			[A6, 33][B4, 44] [B10, 56]						
8			[A2, 10, 28][A4, 43] [B8, 35, 36]		[B6, 34]				
9			[A8, 66][B2, 71]		[A8, 61, 62]				
[X, #] = [Participant, Quote number]									

Appendix B8: Definition of themes identified from interview transcripts

Themes	Definition	Keywords
1. Researcher	A person who works fulltime as a researcher (not necessarily only on simulation)	Researchers
2. Consultant	A person who works full time as a simulation consultant in the industry	Consultant, practitioner, industry
3. Researcher cum Consultant	A participant who divides his/her time between simulation research and consultancy	Researchers, Consultant, practitioner, industry
4. Education	Participant's education in simulation modelling	Diploma, bachelor, masters, PhD.
5. Experience	Number of years of experience	
6. Aim of model	The purpose for which a simulation model is developed by a simulation modeller	Insights, studying and decision making cost, quality, and schedule, resource allocation and planning, process improvement, understanding, performance analysis,
7. Application area	The application area for which a simulation model is developed by a simulation modeller.	Process improvement, understanding, project management, operational management, planning, control, technology adoption, education and training
8. Problem domain	The problem domain for which a simulation model is developed by a simulation modeller	Software process, rational unified process, CMM, software reliability engineering, software inspections, software evolution, airport processes, manufacturing, call centres, telecom, defence, financial sector, healthcare, mines
9. Model's life	The amount of time a model is used for the purpose it has been developed	Short-term, long-term
10. Simulation technique	A simulation technique using which a simulation model is developed by a simulation modeller	Discrete event simulation (DES), system dynamics (SD), state based, agent based, monte carlo simulation
11. Simulation tool	A computer software or	Witness, Arena, Extend,

	programming language using which a simulation model is developed using a particular simulation technique	SPSS, GPSS, Excel, visual basic, C#, java, ModSim, SimScript, Vensim, PowerSim, SimuLink, iThink,
12. Advantages of tools	Advantage of using a simulation tool or programming language as mentioned by the interview participants	
13. Disadvantages/problems in tools	Problem or disadvantage of using a particular simulation tool	
14. Model size	The size of a simulation model as perceived by the interview participants	Small, medium, big, large
15. Development time	The time it take to develop a simulation model	
16. Number of variables	The number of variables in a simulation model in the context of simulation model size and/or complexity	
17. Entities/activities/processes/	Entities, processes, or activities modelled in a simulation model when discussed in the context of simulation model size and/or complexity	
18. Blocks	Block in tool (e.g. Witness, Extend) that represent a particular activity, process, or entity in a simulation model when discussed in the context of size and complexity	
19. Lines of code	The number of lines of codes when discussed in the context of simulation model size and/or complexity	
20. Amount of input data	The amount of input data provided in a simulation model when discussed in the context of simulation model size and/or complexity	
21. Complexity of models	The level of difficulty a simulation modeller faces to develop or understand a simulation model	Low, medium, high
22. Interactions	The link or relationship that occurs between variables or blocks in a problem or simulation model when discussed	

	in the context of simulation model complexity	
23. Feedback loops	The relationship between factors in a simulation model or problem that occurs in a feedback manner, when discussed in the context of complexity	
24. Questions	The questions which are needed to be answered by a simulation model in the context of complexity	
25. Complexity in data	The level of difficulty in understanding data and its relationships in a simulation model	
26.		
27. Individual work	When a simulation modeller works alone	Alone, individual, individually, in isolation
28. Teamwork	When a simulation modeller works with a team of modellers	Team, group, colleague, peer
29. Collaboration	When simulation modeller collaborate with other modellers/domain experts/client to develop a simulation model	Group, collaboration, collaborative,
30. Documentation time	The time it takes to document a simulation model	Documentation, time
31. Model user	The person who conducts experiments with the a simulation model in order to get the results	User, client, customer, decision maker
32. Domain expert	The person who understands the problem domain and provides with expert insights	Expert, domain expert, subject matter expert
33. Client	The person for whom a simulation model is developed	Client, customer, user
34. Maintenance	*Changing a model during or after model development due to customer request, changing requirements, reuse, or bug fix.*	Maintain, Change, Alter, Modify, Modification, Adjust, Adjustment, Amend, Amendment, Alteration, Revise, Revision, Rework, Rewrite, Correct, Correction, Adapt, Adaptation, Transform, Transformation, Improve, Improvement, Renovate, Renovation, Convert, Conversion, Upgrade, Up gradation, Reuse, Use

		again,
35. Reuse	Using some part (code, component) of old model in a new model Using experience and learning from an old simulation study	Reuse, reusable, components, code, experience and learning
36. Model structure	The way in which parts (variables, blocks, components) of a model are arranged and related in order to form a simulation model	Structure, design, simple, complex, arrangement, composition
37. Modularity	The property of a model being modular, i.e. it is arranged in the form of independent modules or units	Modularity, modular, structure, ease of understanding, ease of changing, simple, coupling, cohesion, cohesive
38. Interoperability	The property of a simulation model which makes it easy to be connected with other simulation model	Interoperable, interoperability, communication, communicate, exchange
39. Evaluation	To examine or judge a simulation model on various criteria in order to ensure that it fulfils the requirements for which it has been built	Validate, Validating, Validation, Validity, Accuracy, Faithfulness, Truthfulness, Reliability, Acceptability, Accreditation, Calibration, Quality, Usability, Utility, Verify, Verification, Verifying, Confidence, Soundness, Accurate, Acceptable, Admirable, Brilliant, Consistent, Correct, Credible, Exact, Excellent, Exceptional, Faithful, Good, Outstanding, Prefect, Precise, Reliable, Right, Satisfactory, Sound, Superb, Tremendous, True, Truthful, Trustworthy, Usable, Valid, Worth, Awful, Bad, Erroneous, Imprecise, Invalid, Improper, Inaccurate, Incorrect, Inexact, Poor, Rubbish, Terrible, Unacceptable, Useless, Valueless (of no value), Worthless, Wrong,
40. Validation	The act of assessing whether the model is a right model	Validate, validity, validation, credible, credibility, face validity, evaluation, assessment, judging, sensitivity analysis
41. Verification	The act of assessing that the model behaves as intended	Verify, verification, debugging, right,
42. Testing	Verifying and validating	

	a simulation model	
43. Usability	The ease of using a simulation model	Usable, usability, ease of use,
44. Utility	Usefulness of a simulation model	Advantage, disadvantage, answering simulation questions, value
45. Performance	How much computing resources a simulation model takes	Performance, quick, optimisation, resources
46. Client contact	The act of communicating with the client in order to develop a simulation model	Contact, communication, meeting, interview
47. Simulation goals/objectives	The purpose for which a simulation model is developed	Goals, objectives
48. Simulation questions	The questions for which answers are needed from a simulation model	
49. Requirements gathering/analysis	Requirement is the description of what a simulation model should do. Requirement defines the features or characteristics of simulation model along with the goals and questions of a simulation model	Performance/optimisation /usability requirement, goals, questions
50. Model inputs	The input factors identified by a modeller in which will be fed into a simulation model in order to get the desired results	Inputs, data, factors
51. Model outputs	The output factor identified by a modeller which will be the result of providing a model with the inputs and running the model	Output, data, results, factors
52. System/problem understanding/ Analysis	The act of analysing a problem situation and developing an understanding of the problem under consideration for which a simulation model is to be developed. Identifying the factors and their relationships	Problem analysis, system analysis, understanding, relationship, feedback loops, interactions,
53. Problem scope	Defining the parts/features of a problem/system which are to be modelled	Scope
54. Conceptual model	*A non-software specific description of the simulation model that is to be developed,*	Conceptual model, diagram

	describing the objectives, inputs, outputs, content, assumptions and simplifications of the model".	
55. Influence diagram	A diagram that shows interactions between different factors in a system	Influence diagram, CASE tools, relationships between factors
56. Prototyping	An early description of simulation model showing model structure and relationships	Prototype, prototyping
57. Technical feasibility	Checking whether building a model for a particular problem is technically feasible using a particular technique	Feasibility
58. Model Design	Planning the structure of a model on paper or using a tool	Design
59. Basic design	The high level description of a model design	
60. Detailed design	The low level description of a model structure	
61. Experiment	Running a simulation model in order to get answer to the questions to be answered	Experiment, running the model
62. Experimental scenarios	An outline of supposed sequence of activities under which a model is to be run	Scenario, assumption
63. Experimental design	The design of an experiment describing assumption, sequence of activities	Experimental design
64. Results analysis	Analysing and interpreting the results gained from running experiments on a simulation model	Results analysis
65. Model Implementation	Building a model in a simulation tool or language	Construct, construction, building, build, implement, implementation, coding
66. Results implementation	Implementing the recommendation or learning from the simulation model results, or day to day use of simulation model for decision maker	Implementation, recommendation, decision making, using learning an insights

Appendix B9: Graphical representation of simulation modelling processes of interview participants

Figure. S1: Participant A1's process

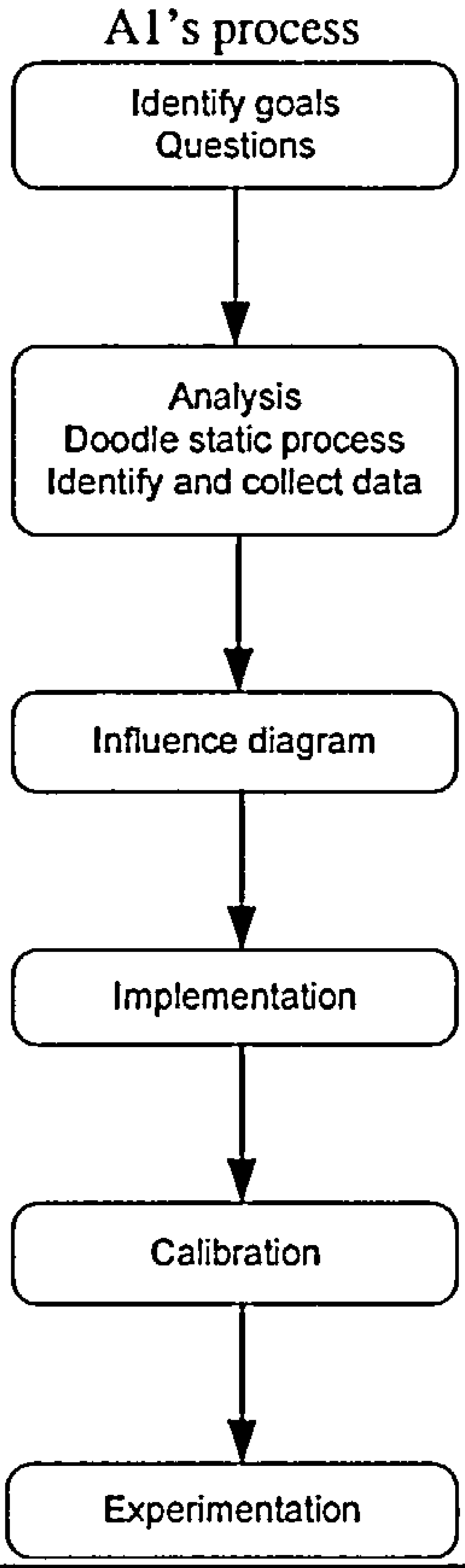


Figure. S2: Participant A2's process

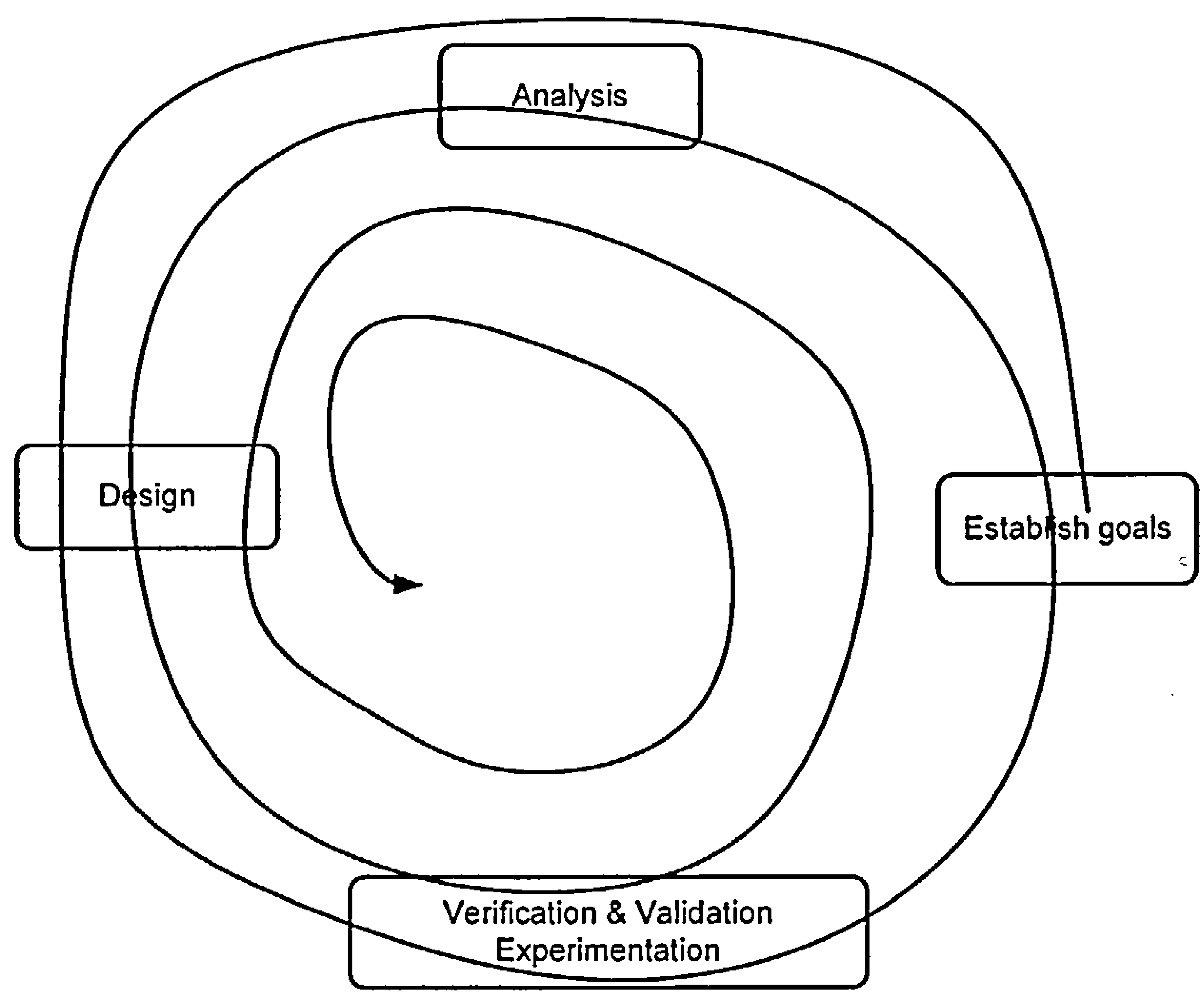


Figure. S3: Participant A3's process

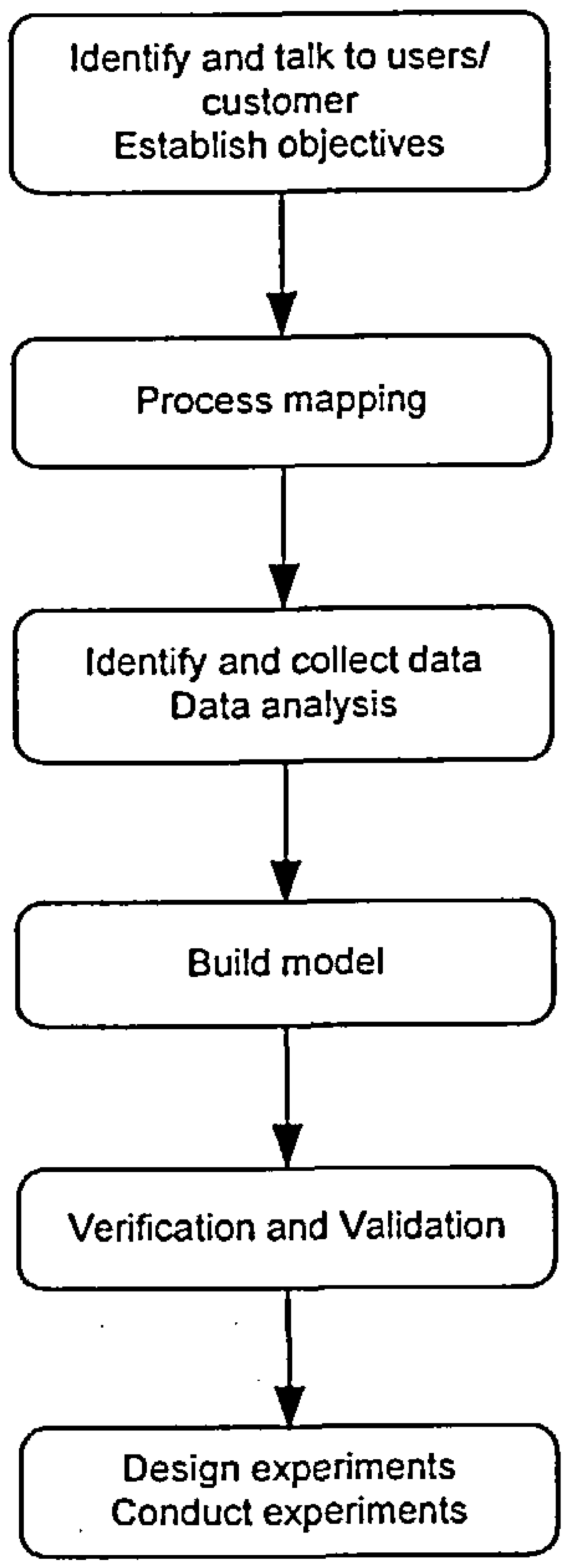


Figure. S4: Participant A4's process

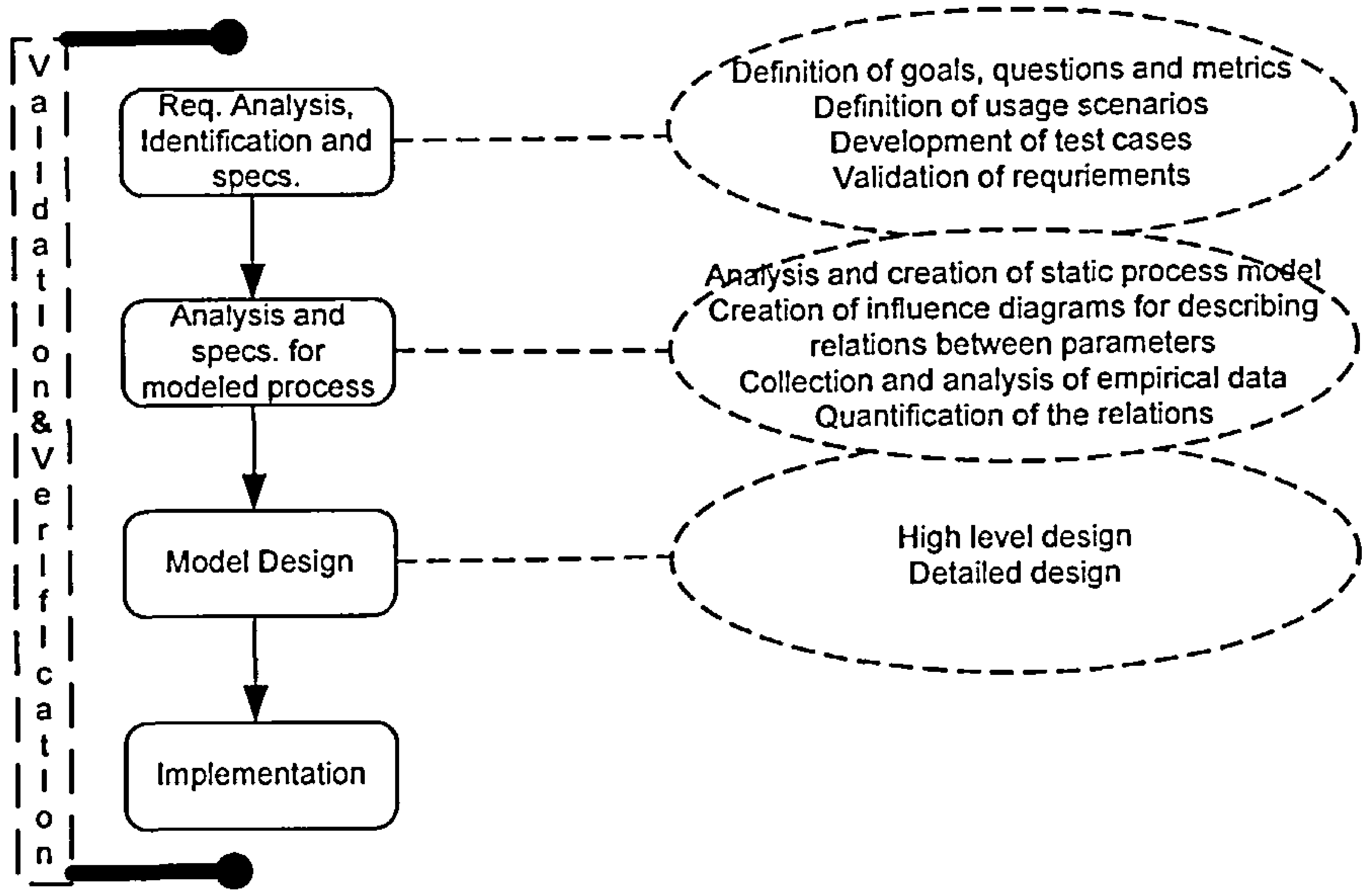


Figure. S5: Participant A5's process

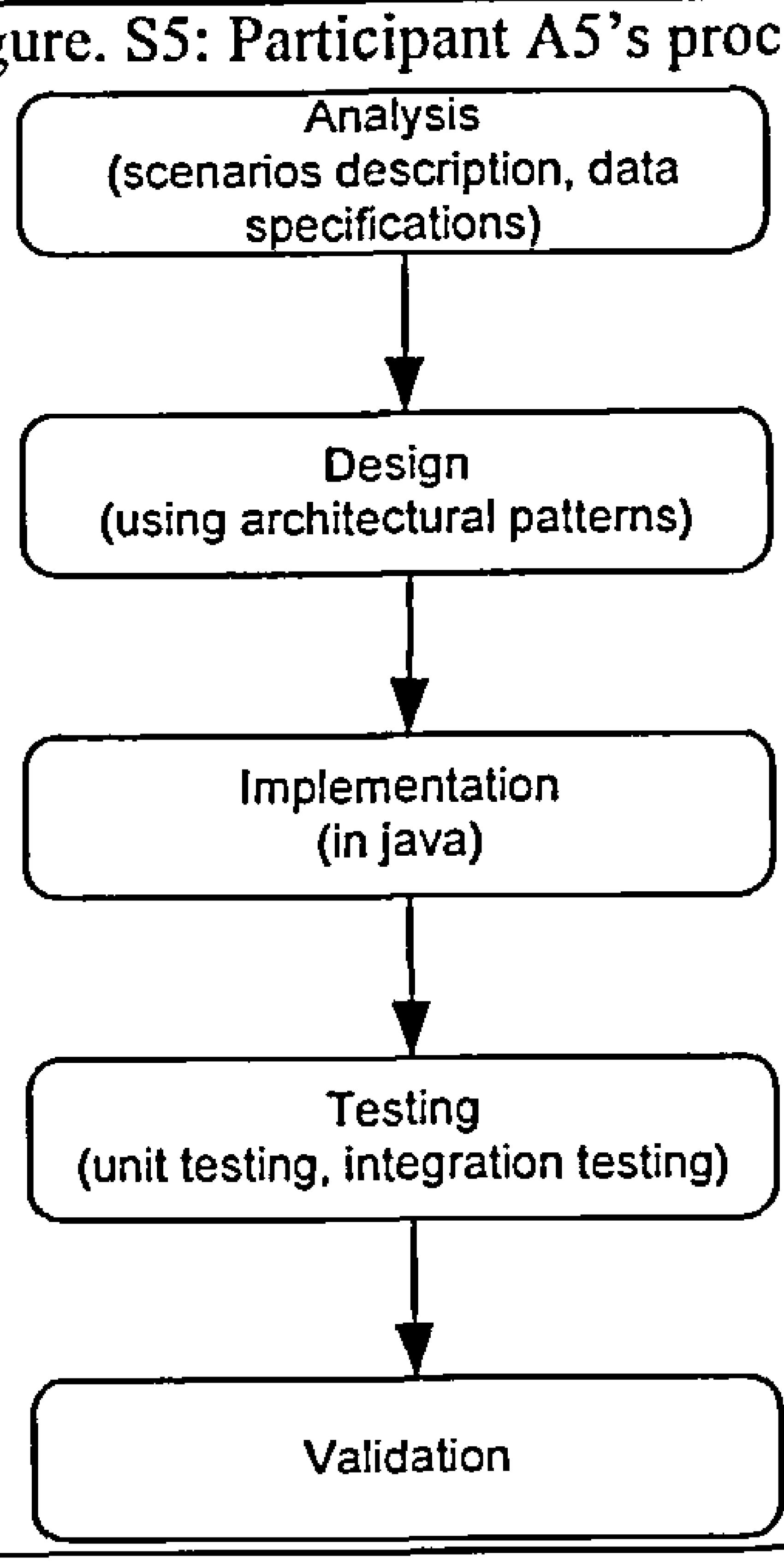


Figure. S6: Participant A6's process

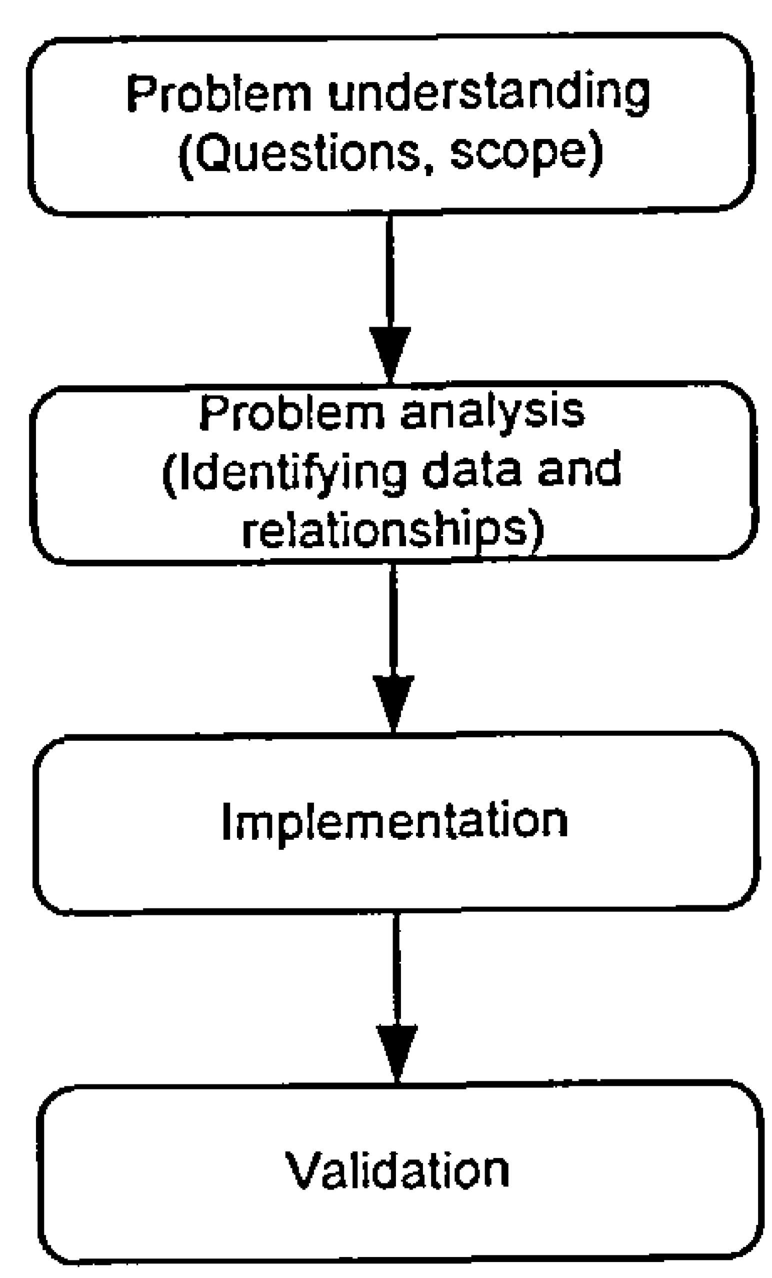


Figure. S7: Participant A7's process

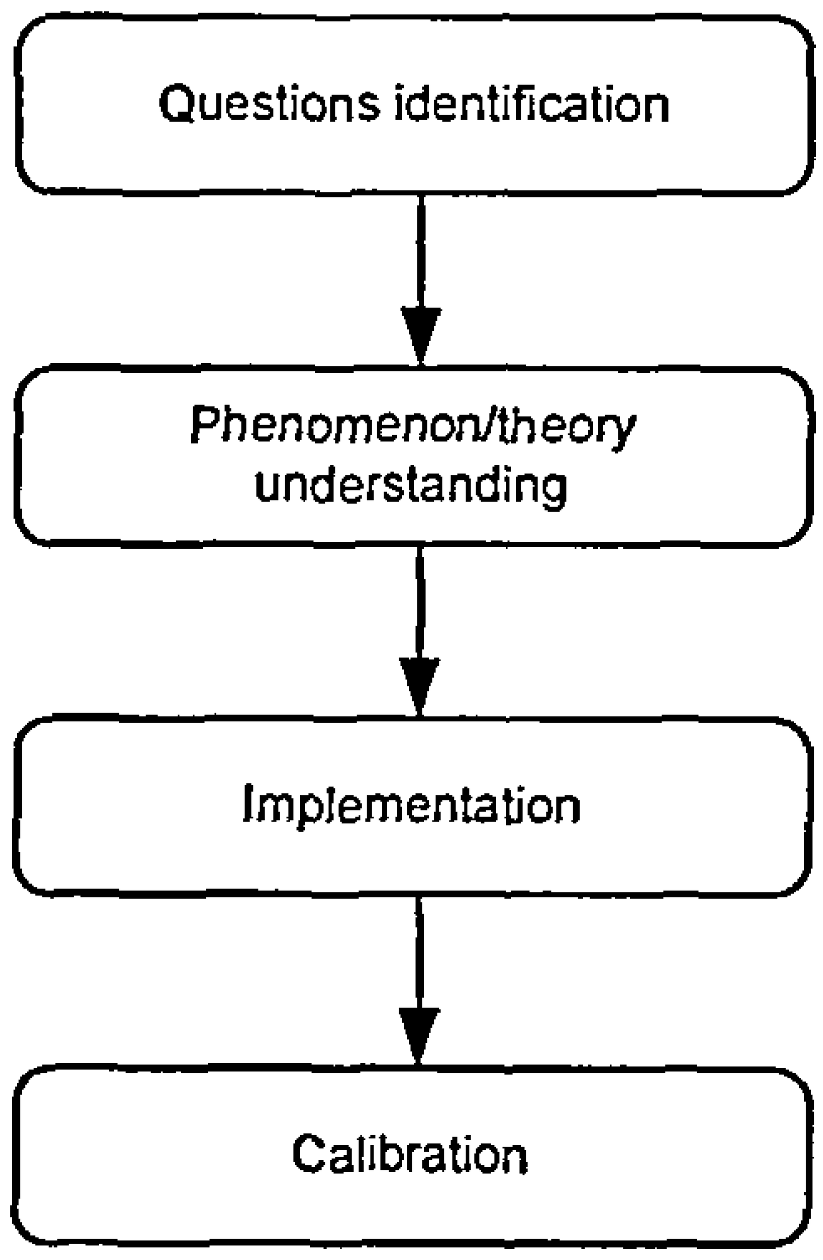


Figure. S8: Participant A8's process

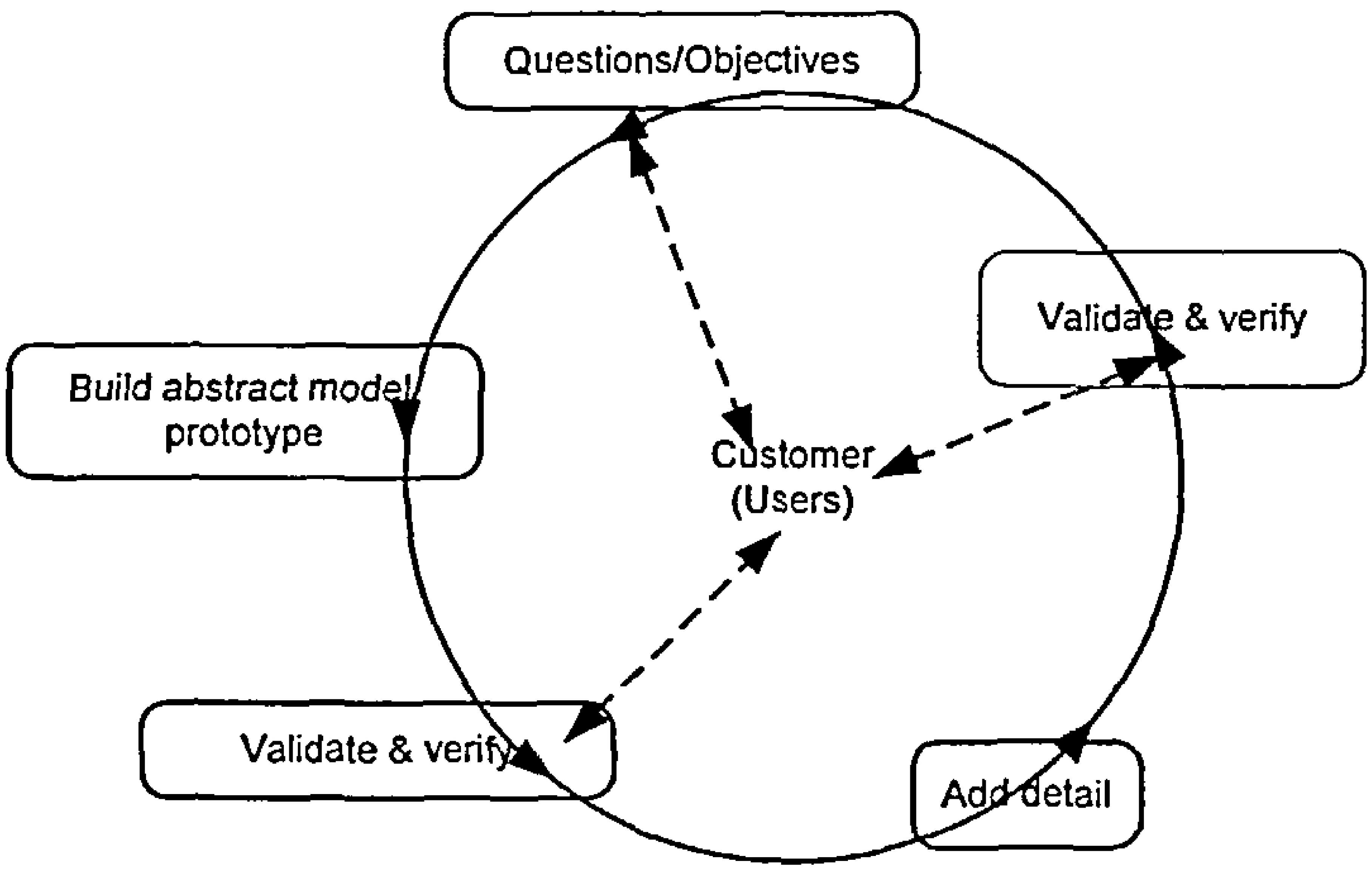


Figure. S9: Participant A9's process

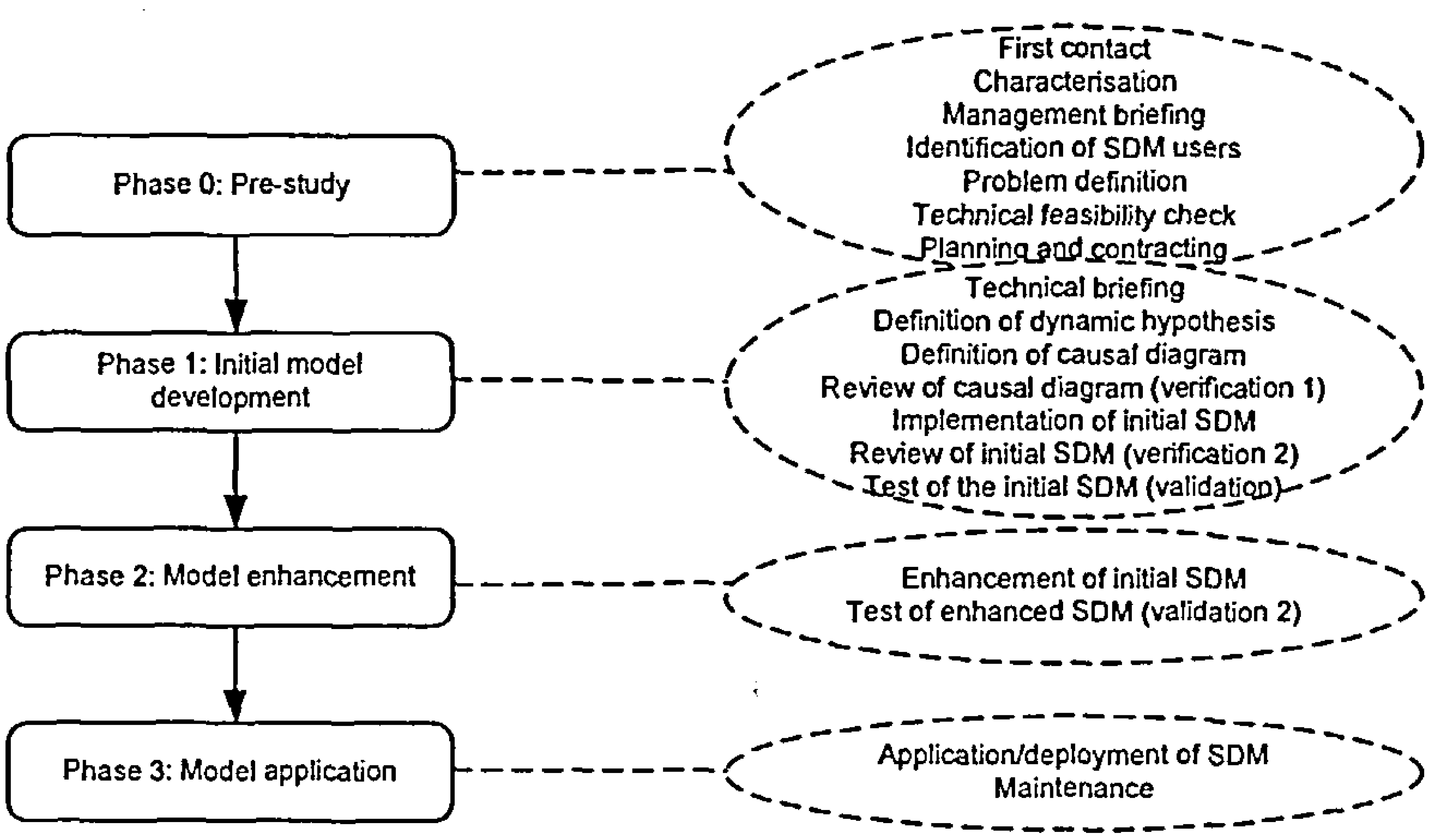


Figure. S10: Participant A10's process

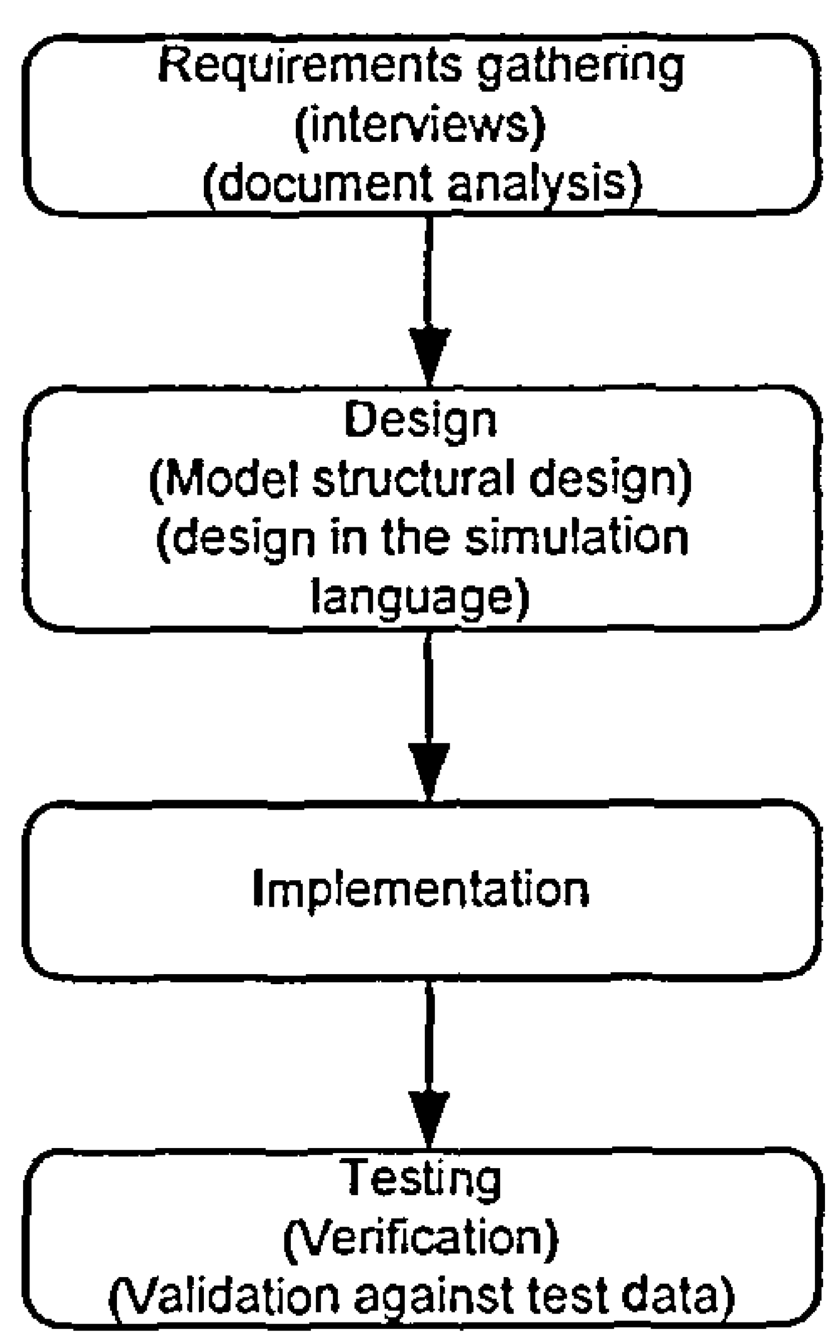


Figure. R1: Participant B1's process

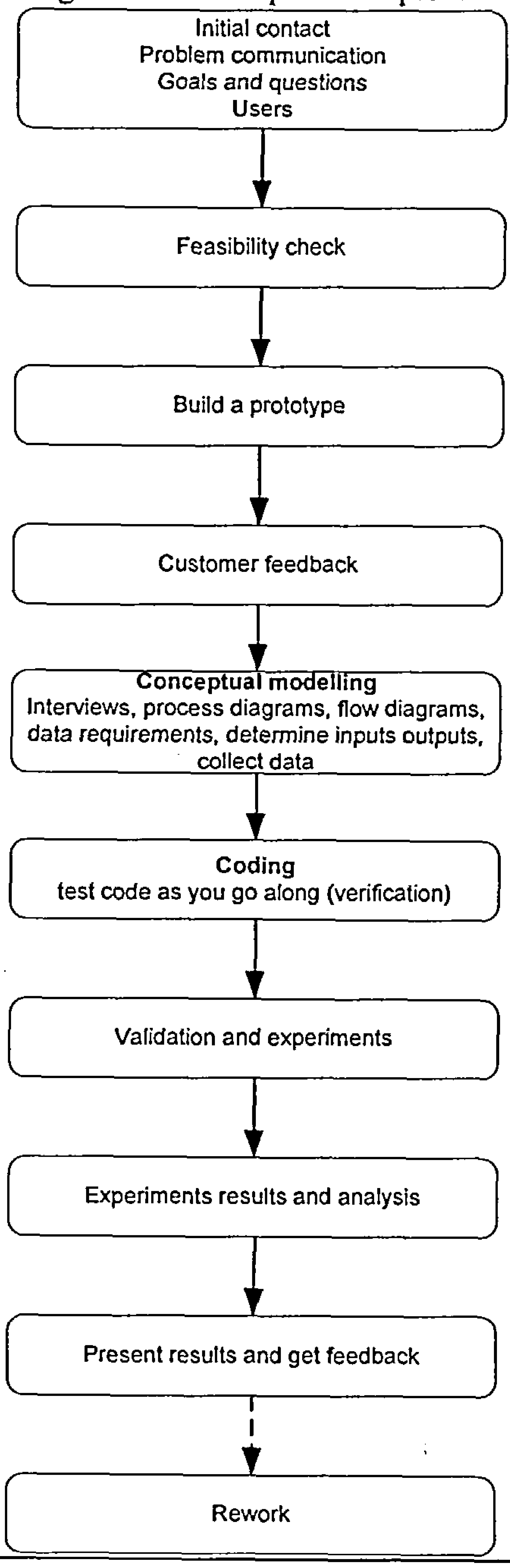


Figure. R2: Participant B2's process

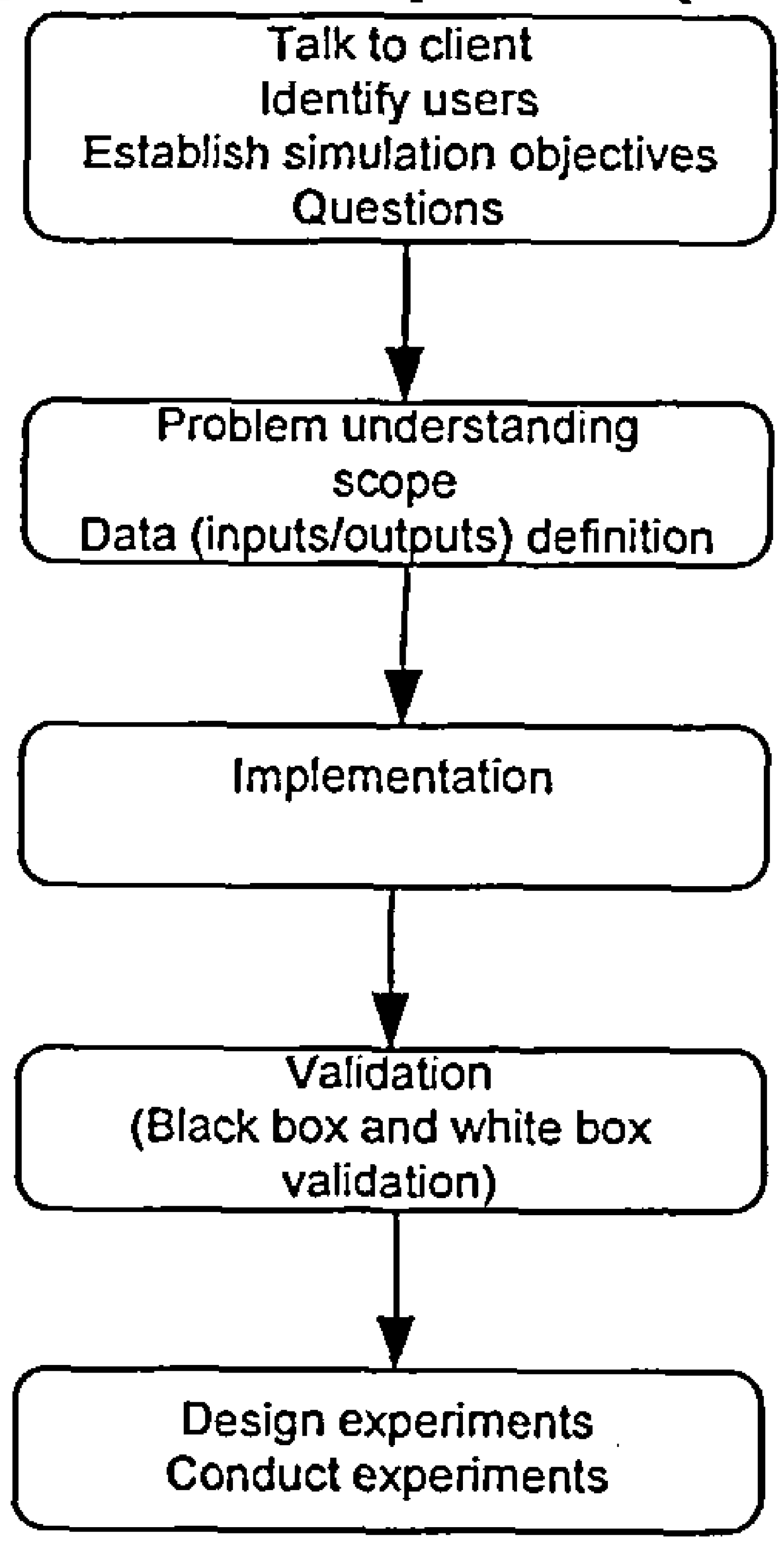


Figure. R3: Participant B3's process

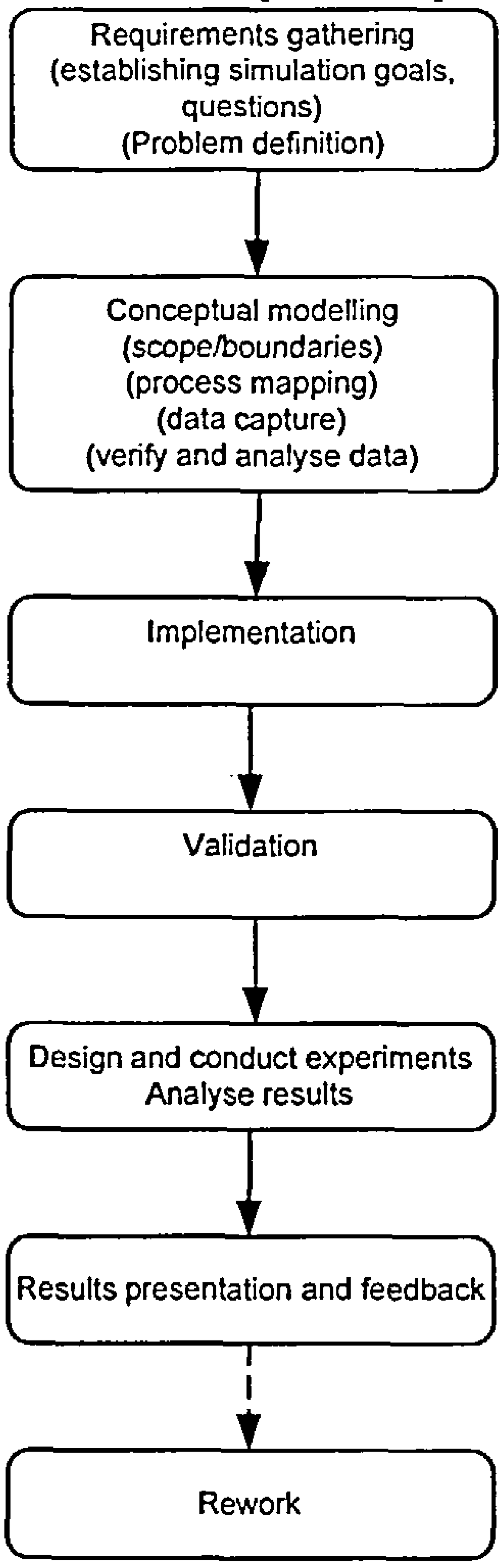


Figure. R4: Participant B4's process

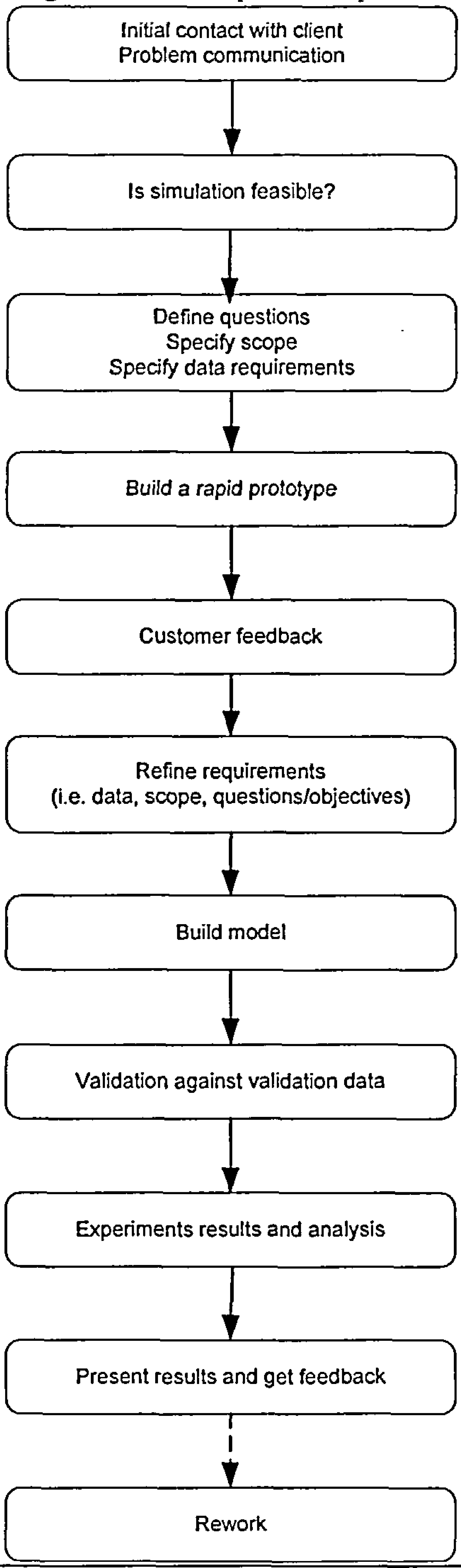


Figure. B5: Participant B5's process

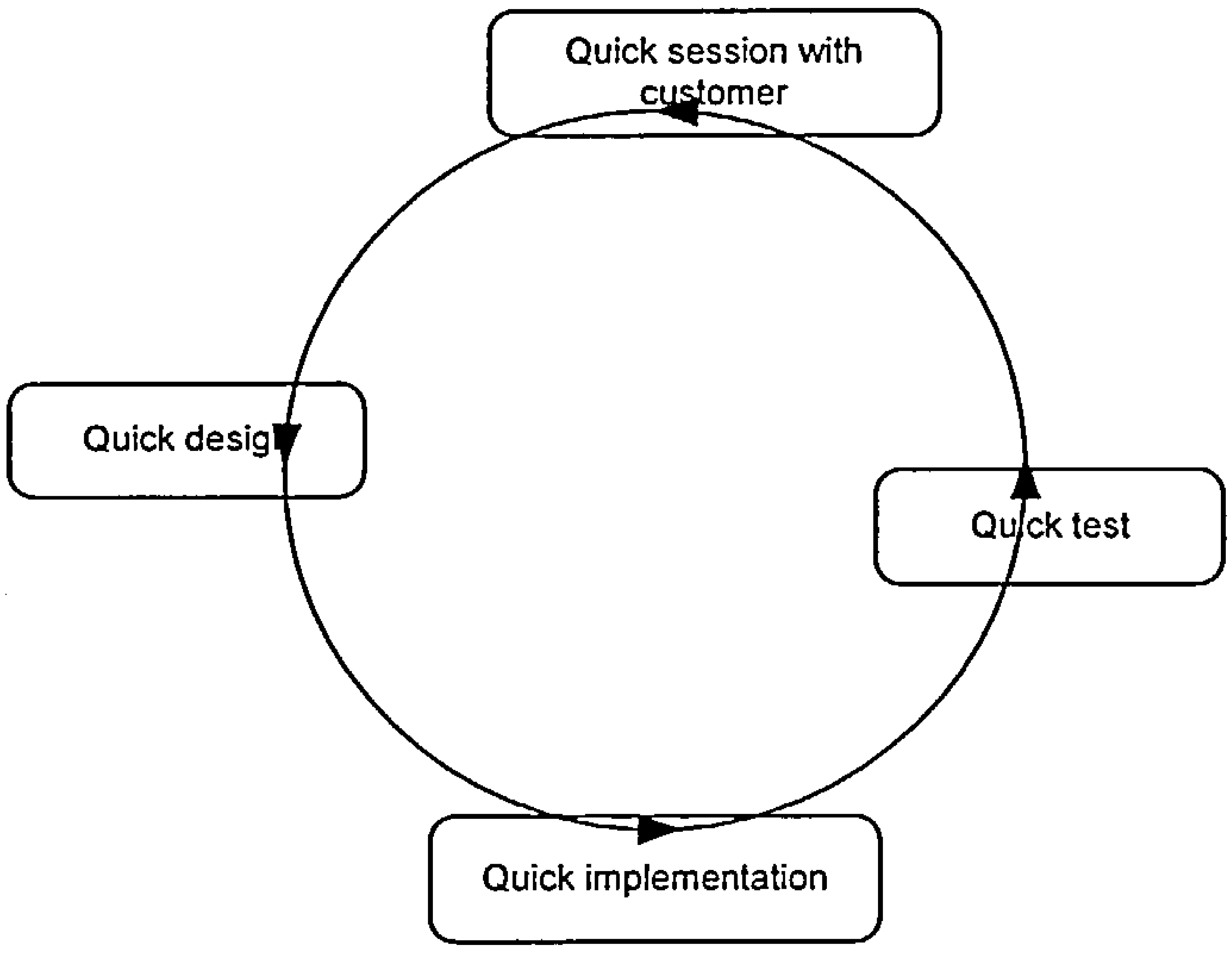
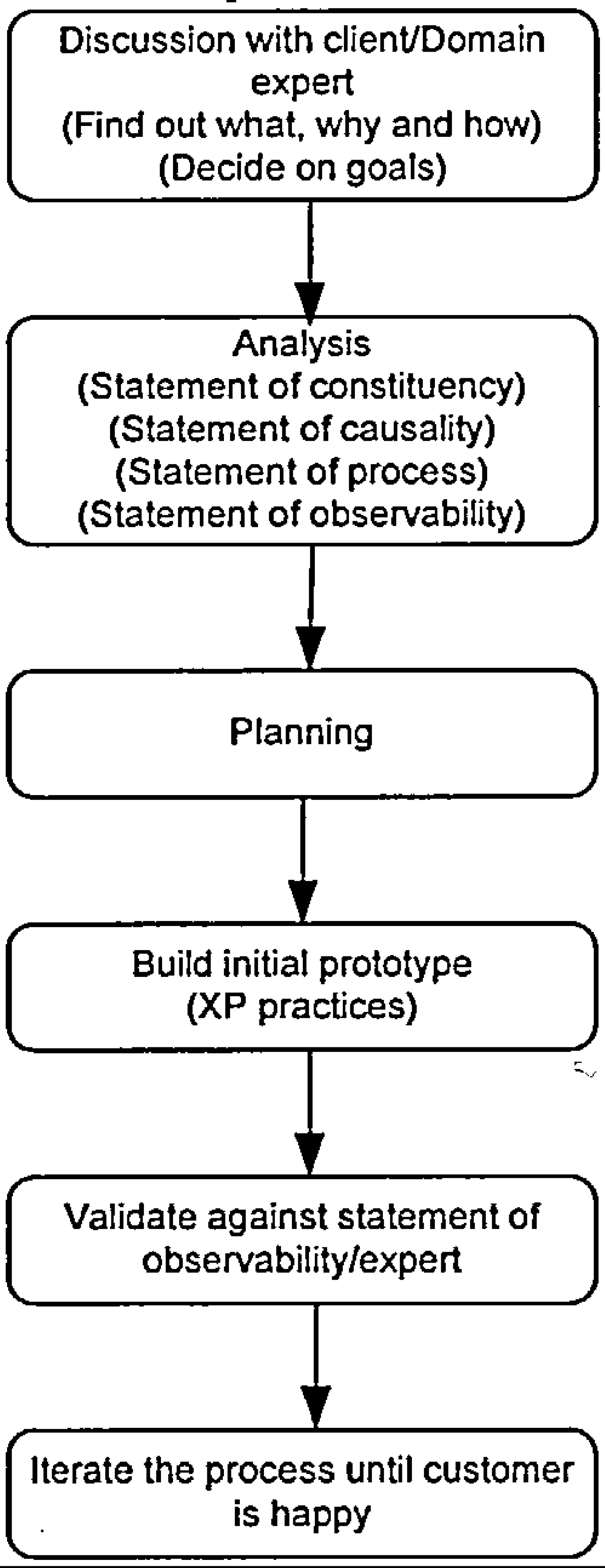


Figure. B6: Participant B6's process



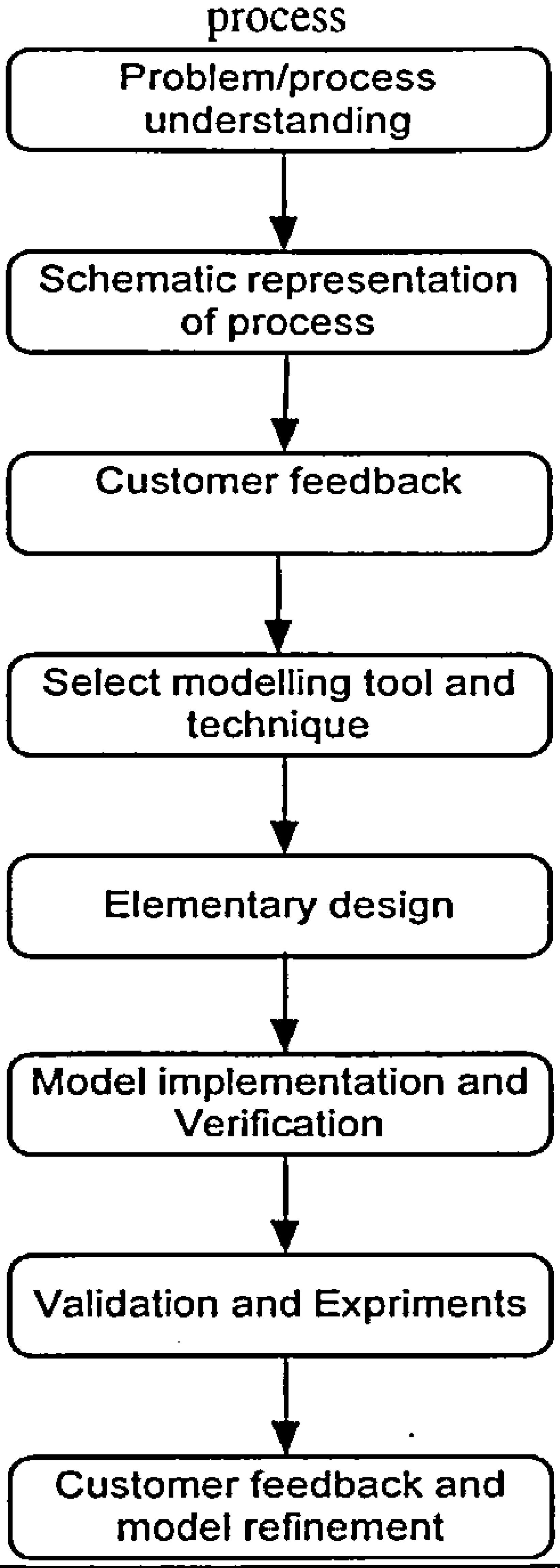


Figure. R7: Participant B7's process

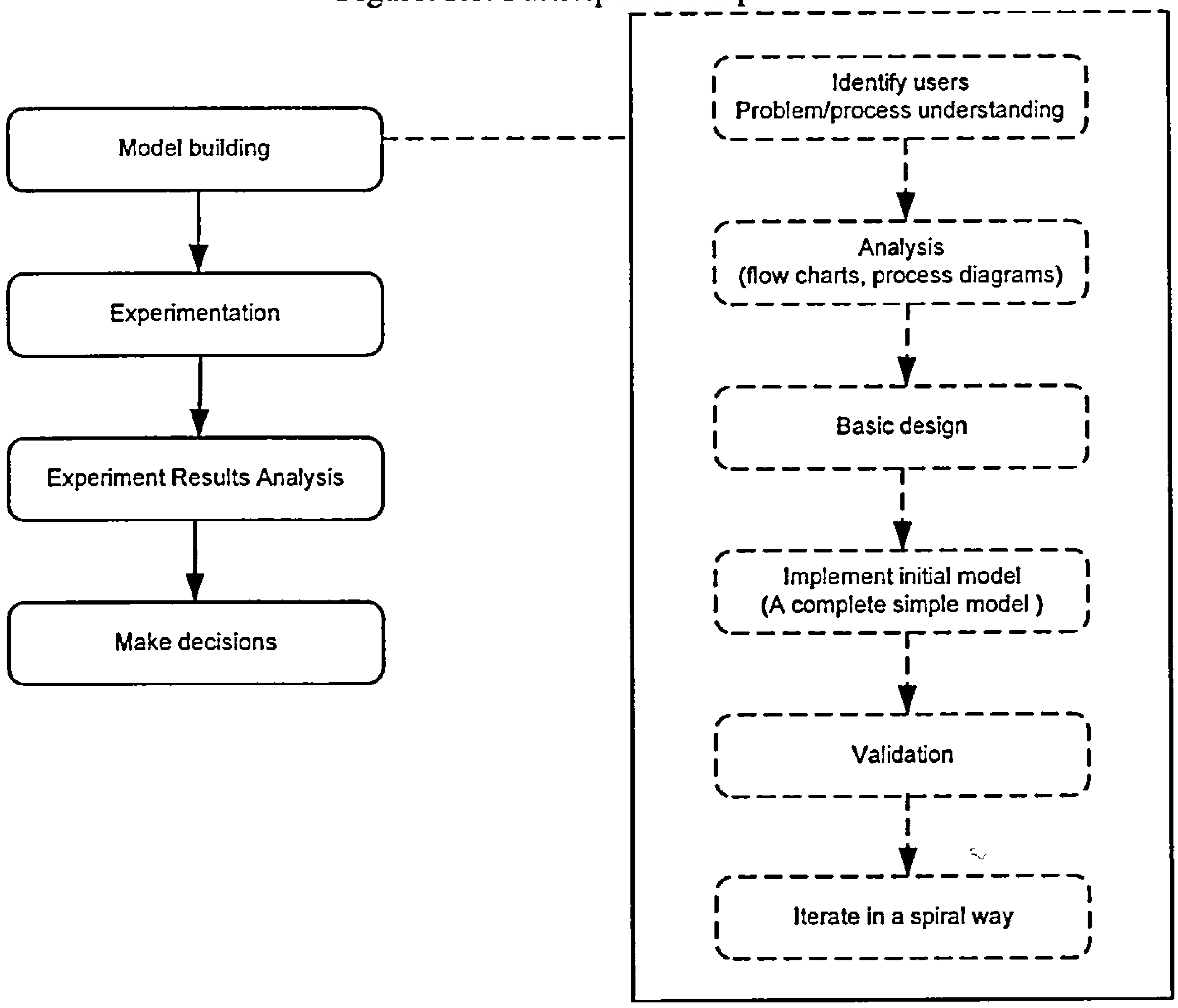


Figure. R8: Participant B8's process

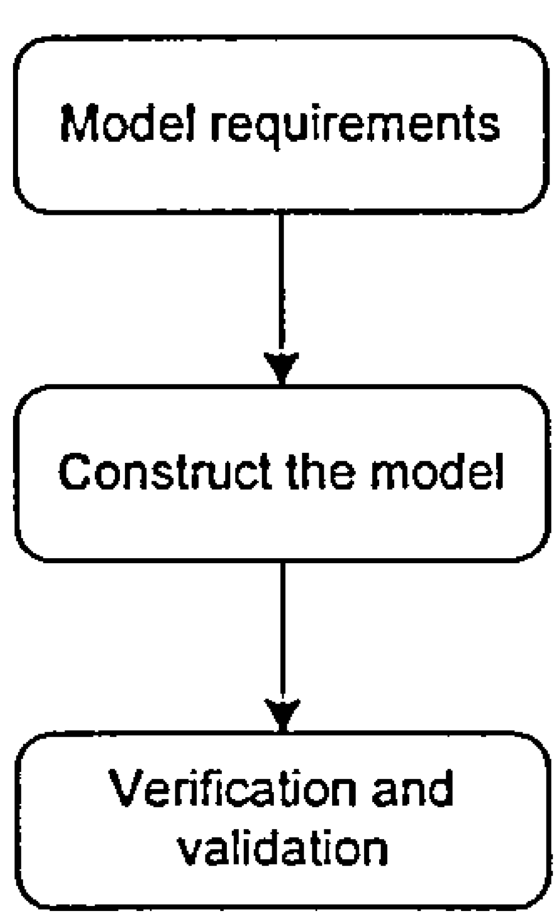


Figure R9: Participant B9's process

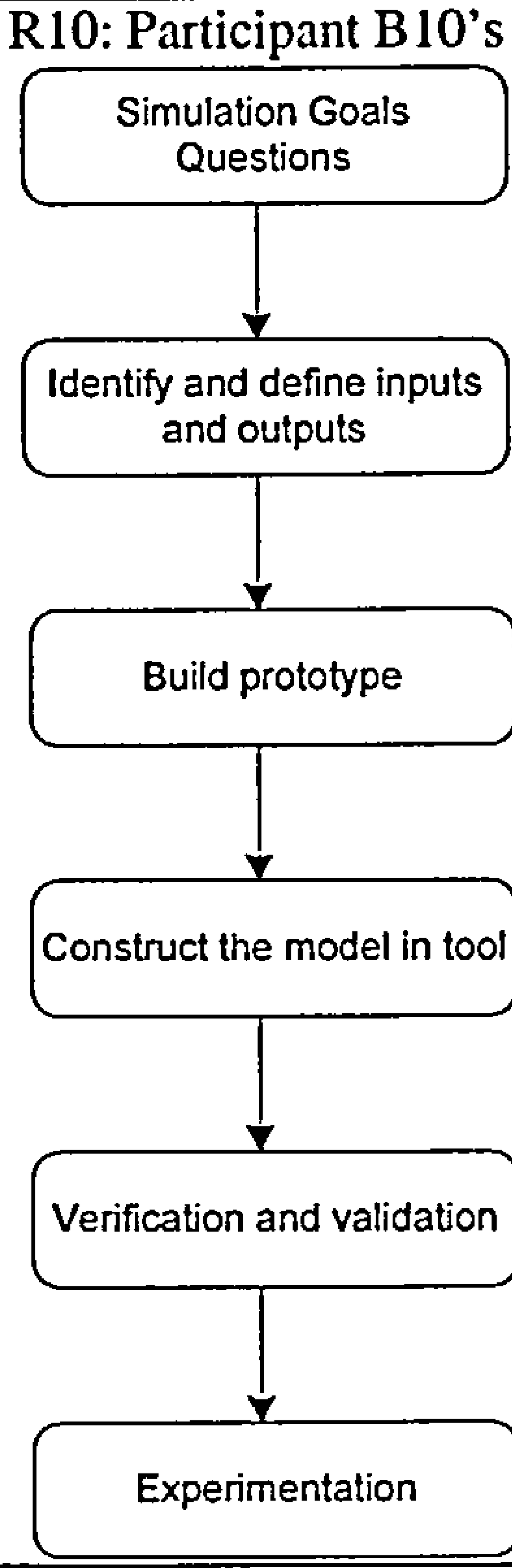


Figure R10: Participant B10's process

Appendix C1: The RSMP tutorial document

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The Rapid Simulation Modelling Process (RSMP)

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Contents

Purpose of this document

The Rapid Simulation Modelling Process (RSMP) aims to train and improve the simulation modelling practice of novice simulation modellers. It has been developed through an empirical study of simulation modellers' practices. The RSMP has been designed for rapid and iterative development of simulation models and is based on heavy client contact. The aim of the RSMP is to bring discipline in simulation modelling practices. This document provides guidelines for novice simulation modellers to use the RSMP.

This document has three parts. Part-I introduces the RSMP and provides a detailed description of each step to be followed for simulation model development. Part-II contains templates providing guidelines for documenting the simulation models. Part-III contains an example of problem definition following the RSMP.

Part-I: Rapid simulation modelling process (RSMP)

1. Overview and scope of the RSMP

The RSMP has three core phases that you should follow for the development of a simulation model. The RSMP is an incremental and iterative process for simulation model development; movement is possible from one phase to any other phase in the process of simulation model development. You may have to go through each phase of the RSMP in multiple iterations during the simulation model development. The RSMP has three phases as following:

- Foundation
- Construction
- Experimentation

Each of these phases will be discussed in detail in Section 2.

The RSMP key process areas (KPAs)

In addition to the core phases, the RSMP has two key process areas (KPAs) which should be implemented throughout development of the simulation model. The two KPAs are:

- Client contact
- Documentation

Client contact is the first key process area of the RSMP. Simulation modelling is an exercise of communication between the simulation modeller and the client. The aim of heavy client contact in the RSMP is to ensure continuous validation and verification of simulation modelling activities. Therefore, simulation modellers are expected to be in close contact with the client during the entire simulation project. The foundation phase would typically have the highest level of client contact. The construction phase will have a relatively lower level of client contact. The experimentation phase will again have a higher level of client contact.

Documentation is the second key process area of the RSMP. The RSMP provides documentation guidelines in Part-II of this document. The RSMP does not make it mandatory for simulation modellers to strictly adhere to the documentation guidelines; however, they provide a recommended framework for documentation. This is because the rigour of documentation required in every simulation study is different based on various factors such as budget, time, and resources. The RSMP recommends that model documentation should be continued in parallel to developing the simulation model.

Scope of the RSMP

Before describing the RSMP in detail, it is important to describe the scope under which RSMP should be used.

- The RSMP is for individual modeller. If multiple modellers are working on the same simulation project, the RSMP as it stands may not be appropriate.
- The RSMP has been developed for use by novice software process simulation modellers.

- The RSMP has been designed for use in small/medium simulation projects with low/medium complexity.
- The RSMP is independent of particular simulation techniques (i.e. it is not specific to discrete event or continuous simulation).

Each core phase of the RSMP is defined in the next three subsections. Figure 1 gives a high level graphical representation of the RSMP. Figure 2 gives a detailed graphical representation of the RSMP. In Figure 2, the mandatory activities of the RSMP are shown with a grey background, and the optional activities are shown with a white background. In figure 2, round boxes represent activities, cornered boxes represent products of the process activities, diamonds represent actions, hard lines show main flows, and dotted lines show secondary flows.

The worked example contained in Part-III will be referenced through out this text.

.

Figure 1: High level structure of the rapid simulation modelling process (RSMP)

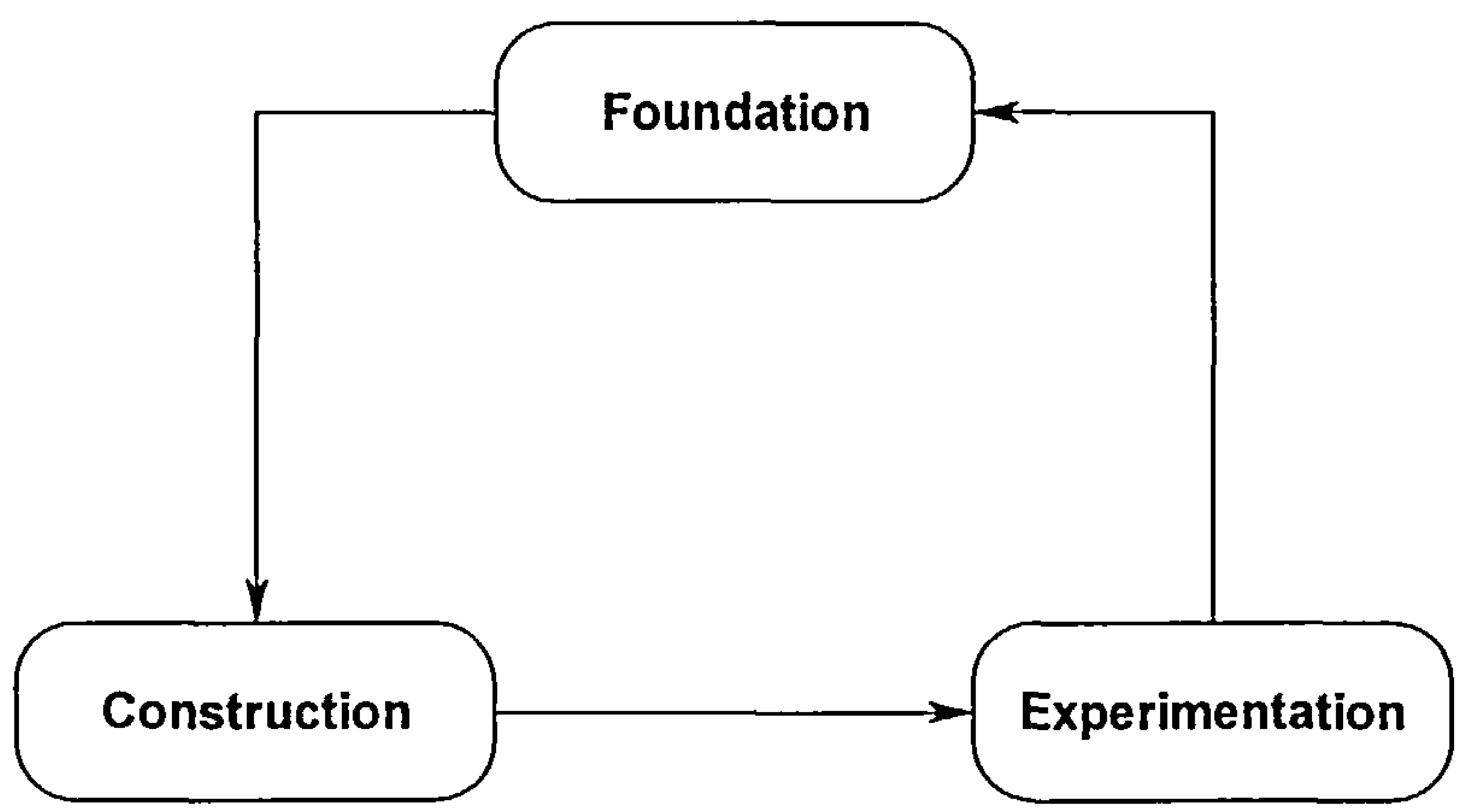
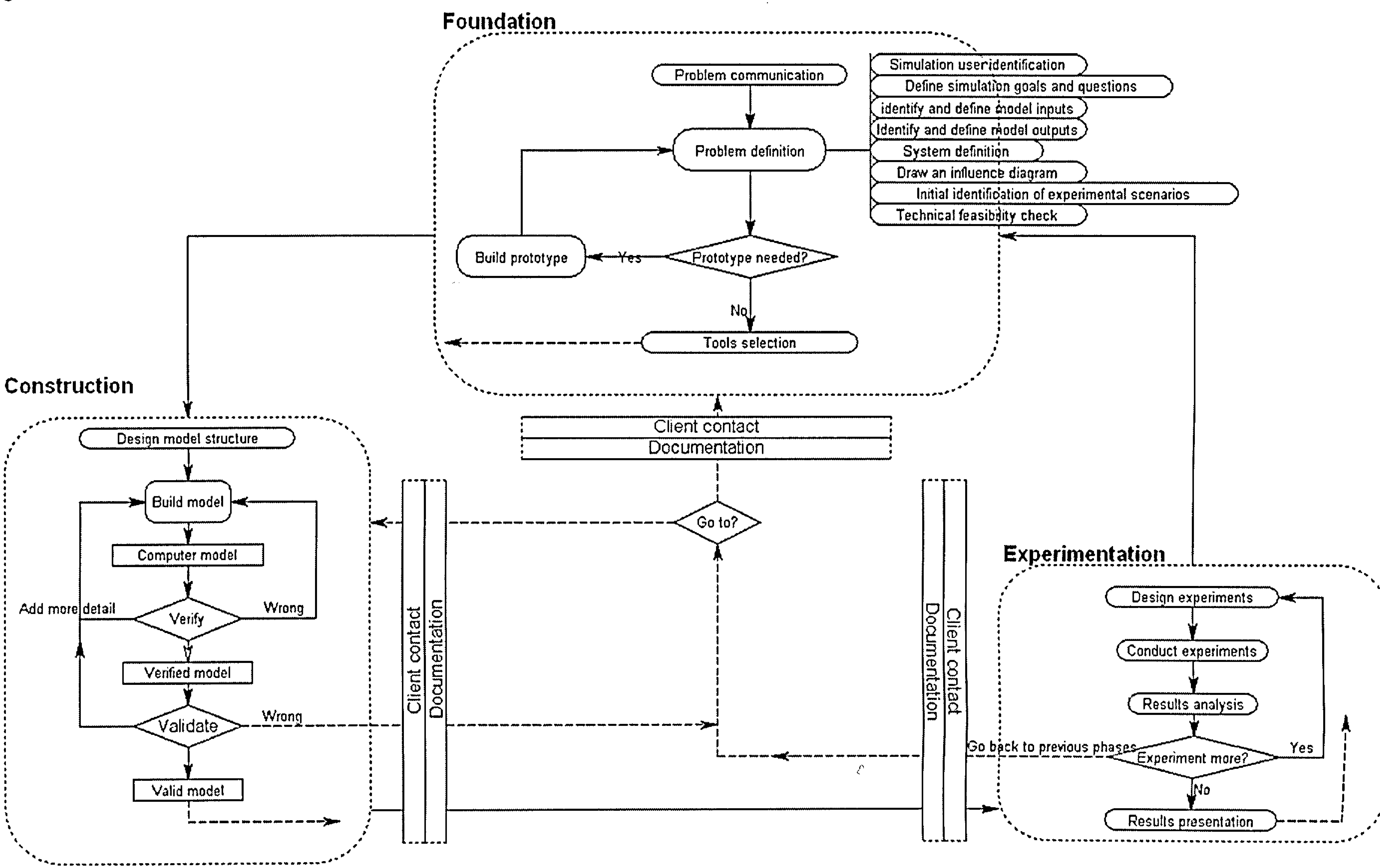


Figure 2: Detailed structure of rapid simulation modelling processes (RSMP)



2. The RSMP description

This section provides a detailed description of each phase of the RSMP.

2.1. Foundation

This phase sets up the foundation of the simulation study. The foundation phase comprises of:

- Problem communication
- Problem definition
    - ✓ *Simulation user(s) identification*
    - ✓ *Define simulation goals* and questions
    - ✓ *Identify and define model inputs*
    - ✓ *Identify and define model outputs*
    - ✓ *System definition (model scope, problem understanding)*
    - ✓ *Draw an influence/process diagram*
    - ✓ *Initial identification of experimental scenarios (optional)*
    - ✓ *Technical feasibility check*
- Initial prototyping
- Tool selection

2.1.2. Problem communication

The client may have a problem for which he/she needs a solution. The client contacts you and communicates the problem to you. The problem can be communicated through different means such as meetings with the client, phone conversations and email correspondence. Part-III provides an example of a typical problem.

2.1.3. Problem definition

Based on the problem communication, the simulation modeller defines the problem in consultation with the client. Problem definition is augmented by the problem communication. This step is highly iterative and client intensive. There are several tasks in the problem definition step. Following a strict order of activities in problem definition is neither necessary nor practical. However, the identification of simulation users and/or domain experts should normally be the first step. The rest of the activities are not mutually exclusive, in fact they inform each other. In a practical context, you may be doing some of these tasks in parallel or you may go from one task to another without any sequence. However, it is very helpful to have a distinct understanding of each task for simulation model development.

Simulation user(s) identification: The first and foremost task in defining the problem is identifying the users and/or domain expert with whom you will liaise to develop the simulation model. They may be project managers or team leaders or may be the client.

Simulation users/domain expert provide the information needed for the tasks involved in the problem definition. A simulation model developed without consulting the potential users is unlikely to be of any value or use to its users.

Setting the goals and questions: This is the most important task in a simulation study. The whole simulation project is driven by these goals. You need to define the agreed goals clearly and upfront. There can be single or multiple goals of a simulation study. On the basis of simulation goals, you will define the questions for which the client needs answers. Goals and questions may also change over the course of model development. Therefore, it is very important to have a clear vision of goals and questions by maintaining a heavy contact with the client. An example of goals and questions definition can be found Part-III.

Identify and define model inputs: The reliability of your simulation study largely depends on the reliability of input data. Identifying proper and relevant input variables is very important to simulation. Precise and accurate data increase confidence in the results from a simulation study. You must clearly identify and state to the client, what kind of data is needed to gain results from the simulation model. Along with defining the system boundaries and scope, you must identify the data requirements to run the simulation. See Part-III for an example of input data definition.

Identify and define model outputs: The analysis of outputs from a simulation model answers the questions for which the simulation study has to be carried out. Therefore outputs needed from a simulation model must also be defined. Again see Part-III for an example of outputs definition.

System definition: This clearly defines which part of the process or system is to be simulated. The system definition entails understanding the system. Clarification should be obtained from the client on the parts of the system or the development process that needs to be modelled. Is it for the whole development process or for some particular phase of development such as analysis, design, coding and testing? System definition leads to defining the scope and the boundaries of the system that is to be simulated. Discuss and define with the client the assumptions under which the simulation is to be developed. See Part-III for an example of scope refinement

System definition also includes gaining an understating of the problem by analysing the process to be modelled. There may be several ways to analyse the process or the system. You may conduct interviews with simulation users, read their documents, and observe their practices. After gaining an understanding of the process or problem to be modelled, you should discuss your understanding with the client. Various diagramming methods, such as UML or data flow diagrams, that are understandable to the client can be used to agree upon system definition.

Draw an influence diagram: While identifying the model scope, inputs and outputs and their relationship with each other, you should draw an influence or process diagram that shows how different factors in the system/process relate with each other.

There is no strict order when you should draw the influence diagram. Identifying inputs and outputs, system definition and drawing the influence diagram complement each other. Normally you will start drawing influence diagram as soon as you identify a small number of factors; the drawn influence diagram may lead to identify more factors interacting in the system.

Initial identification of experimental scenarios (optional): Definition of model objectives, scope, inputs and outputs provides the modeller with an opportunity to identify the scenarios under which the simulation model will be experimented. It is good practice to identify these scenarios in advance in discussion with the simulation users and then refine them later when performing the experiments. See Part-III for an example of using scenarios.

Technical feasibility check: It is important for a simulation that you ensure that it is technically feasible to develop a simulation of the problem under study. There may be several reasons why a simulation may not be feasible for a problem. For example, data may not be available to run the simulation or data available may not be precise enough. In such a case, you must ensure, in consultation with the client, that the precision of the available data does not affect the model goals. If the client is looking for concrete answers, then imprecise data may make it technically infeasible to carry out a simulation study. In another case data may not be available at all and you have to rely on expert opinion for model input values. Again in such a case simulation models may not provide concrete answers. However, in such cases simulation can be helpful to gain an understanding of the process.

2.1.4. Prototyping

Once the problem has been defined, it is always a good idea to build an initial prototype of the potential simulation model and discuss it with the client. This prototype can be a high level abstraction of the process to be simulated. Building an initial prototype helps gain a better understanding of the problem and removes confusion between you and the client. It may also help in deciding which tool to use for simulation model development. A prototype is normally developed on computer, however paper based prototyping can also be helpful.

2.1.5. Tool/technology selection

Sometimes the selection of tools/technology can be crucial to the success and timely delivery of a simulation study. The selection of an inappropriate tool or programming language may lead a simulation project to chaos. You should choose a tool that is most appropriate for the problem under investigation.

Result: The result of the foundation phase should be a document that contains the problem definition, which includes:

- Simulation goals/objectives definition
- Definition of questions
- Scope definition
- Definition of inputs
- Definition of outputs
- Initial identification of experimental scenarios

The simulation modeller (you) and the client should agree on this document, this would serve as validation of foundation phase tasks, such as simulation goals, system definition, inputs outputs and their relationships.

2.2. Construction

The construction phase has four steps. The steps for construction are shown in figure 2. Each step has been defined as follows:

- Plan model structure
- Build model
- Verify model
- Validate model
  - ✓ Face validity
  - ✓ Sensitivity analysis
  - ✓ Comparison with the real system

2.2.1. Plan model structure

Before starting to develop the simulation on computer it is always a good idea to design the structure of the model on a piece of paper. Different modellers may have different ways to structure the model. The RSMP does not insist that you produce a detailed design of the simulation model. You may plan the structure of the model on a piece of paper or you may use CASE (computer aided software engineering) tools to design the structure of the model, depending on the nature of the problem. This step is to ensure that you have thoroughly thought out a structure of the model which will be a road map for building the model.

When planning the model structure, three aspects should be taken care of:

- Reusability

  The structure of the model should be planned in a way that it should be easy to reuse the whole model or some part of the model in future.

- Modularity

  The model should be structured in a modular fashion, where relevant factors/variables should be put together in one block/module.

- Interoperability

  Model structure should be planned in a way that it should be easy to interoperate the model with another model if needed.

2.2.2. Build model

In the construction phase, the physical simulation model is generated on computer using a simulation tool or a programming language. This may be one sub-model or part of a model. It may be based on the initial prototype produced in Foundation phase. Model development should adhere to the goals of simulation study. It should initially capture the basic flows and logic of the system/process. Then more detail should be added after verifying and validating each part of the model. It is important to keep in mind that a simulation model is an abstraction of the system/process under study not the system itself. Therefore, the detail in the model should be feasible and should not make the model overly complex. An executable computer model will be the result of building the model.

When building the model

- Provide meaningful variable names so as to make it easy to understand the model.
- Provide detailed comments in the computer model so that if you or some other modeller has to revisit the model later sometime, it will be helpful to understand the model.

2.2.3. Verify model

As model building progresses, the executable model should be verified. Verification is a micro level check on model behaviour i.e. you will check that correct logic has been employed. The purpose of verification is to ensure that model elements exhibit the correct behaviour as intended. It is similar to software code testing and debugging.

If any problem is found in the model, you have to go back to the previous step and make changes in the computer model. For example, you have to ensure that you have put the right equations in the right places in the model. Check all the equations and check that directions of all the relationships are correct.

You may also have to refer back to the client to ensure you have put the correct logic in the model or confirm that the relationships between different variables in the model are correct.

2.2.4. Validate model

After the model has been verified, the next step is validating the model. Validation checks whether you have built the right model. Validation is a macro level check on the model. The purpose of validation is to ensure that the model behaves correctly overall and adheres to simulation goals. There are two dimensions to model validity; one from the modeller's perspective and the other from the client's perspective (often called credibility). In any model validation the client must be heavily involved.

There are several methods to model validation such as:

Face validity: If the simulation model has some graphical features in it, face validity checks the model conformance of the graphical model with the real process or system. Face validity is performed by obtaining the opinion of the people who are knowledgeable about the system that how reasonably the simulation model matches with the real system.

Sensitivity analysis: Sensitivity analysis checks how well the model behaves if certain values of inputs are given to the model. A simulation model may be sensitive to certain input values and may behave unexpectedly.

Comparison with the real system: Another way to check model validity is to compare its outputs with the real historical data. It is also called replication of reference modes, in which the model is provided with specific inputs and outputs when are matched with historical data collected from previous projects.

Validation is a very important step of simulation modelling. If the model is found to be invalid, you would need to return to the previous steps or phase to produce a valid model.

Results: Result from this phase of the process will be

- A document describing the model structure and working
- A verified and validated, well commented simulation model

2.3. Experimentation

The objective of simulation modelling is to facilitate analysis of the given problem so that decisions can be made. Experimentation allows you to provide the client/user with the information he/she wants from the simulation study. The aim of experimentation is to run as many scenarios as needed to a give the client a robust outcome of the study. The rigour of experimentation depends on the goals and scope of the problem. The steps for experimentation have been shown in figure 2. There are 4 steps in this phase:

- Design experiments
- Conduct experiments
- Results analysis
- Present results

2.3.1. Design experiments

The experimental design is driven by the goals, questions and scope of the problem in the simulation study. Different simulation run scenarios are discussed with client, under which simulation has to be performed.

Experiments are designed on the basis of these scenarios. The client is asked what outputs are required and how they should be presented. Identification and definition of scenarios start from the Foundation phase and are refined in the experimentation phase. The RSMP does not insist on a strict order to follow for scenario definition, however, best practice recommends that it should start in the Foundation phase.

2.3.2. Conduct experiments

Experiments are conducted on pre-defined scenarios. Conducting experiments can sometimes be a very time consuming task depending on the nature of the problem.

2.3.3. Results analysis

The results obtained from the experiment runs are analysed and communicated to the client for their validation. At this point some change may have to be made in the simulation model depending on the kind of results obtained.

2.3.4. Present results

Once the results have been analysed they are put in a presentable format to facilitate the clients decision making. Results may be put in graphical or tabular formats. Any statistical analysis is discussed and conclusion provided.

Result: A document detailing the experimentation scenarios, results, analysis and conclusion.

Part-II: Simulation modelling project documentation template

This part provides a template for documenting the simulation projects.

<<Project title>>

Author(s): <<Name of the document Authro(s)>>
Modeller(s): <<Name of the modeller(s)>>
Date: <<date>>

1. **Modeller** <<state the modeller(s) name who took part in the study>>

2. **Client** <<client and his/her company>>

3. **Users/domain experts of the simulation** <<state name of the users of the simulation model being developed and also the domain experts>>

4. **Problem definition**

4.1. Simulation goals/objectives definition

4.2. Definition of questions

4.3. Scope definition

4.4. Definition of inputs

Name	Type	Definition
......	....	....

4.5. Definition of outputs

Name	Type	Definition
......	....	.....

4.6. Influence diagram <<Draw influence diagram and describe how different factors interrelate and affect each other>>

4.7. Initial identification of experimental scenarios (optional) <<discuss the scenarios initially identified under which model is to be experimented>>

5. **Model structure** (optional) <<show model structure in a diagram and describe how the model works>>

6. **Experimentation**

6.1. Experiment # X <<Name or number of the experiments>>
6.1.1. Scenarios <<describe the scenario under which experiment is to be performed>>

6.1.2. Assumptions <<describe assumption if there is any>>
Assumption #1:
Assumption #2:
Assumption #3:
....

6.1.3. Initial input values <<initial values of the input variables>>

	Variable 1	Variable 2	Variable 3	......
Experiment run 1				
Experiment run2				
....				
....				

<<Repeat the structure of section 6.1 for every experiment>>

6.2. Results <<present results in tabular format and/or chart representation>>

6.3. Analysis <<analyse and discuss the results>>

6.4. Conclusion and recommendations <<present the conclusion and provide the client with the recommendations justified by your analysis>>

Part-III: Example of problem definition

Here we discuss a sample problem

Problem communication

Client states the goal of simulation:

"*Develop a simulation model for decision support. The model should help to plan resource allocations in a project, such that tradeoffs between duration and cost can be analysed and most suitable plan for resource allocation can be devised*".

The client wants answers to the following questions in the context of the above stated goal:

Q1: How many people will be needed to finish a project within a given time?

Q2: What will be the effect on cost and/or duration if more people are added to the project?

Q2: Can the cost of the project be reduced by increasing project duration?

Definition of outputs

The simulation modeller analyses the questions and concludes that 3 outputs are needed from this simulation study

i. No of developers

ii. Duration of the project phase (decide unit, let's say hours)

iii. Cost of the project phase (decide currency, let's say pounds)

Definition of inputs

The simulation modellers analyses the input data requirements, discusses it with the client and defines them as following:

i. No. of available developers (10)

ii. Developers' competencies levels

   a. Intermediate (4)

   b. Advance (6)

iii. Amount of functionality to be coded (100 KLOC)

iv. Given time (1000 hrs)

v. Avg. Performance of the developers

   a. 200 LOC/hr for intermediate

   b. 300 LOC/hr for advance

vi. Cost per hour work (in pounds) depending on the competencies level of the developer

   a. £25/hr intermediate

   b. £40/hr advance

System definition

Discussion with the client, (goal, questions, scope and relationships)

You discuss the stated goal with the client and ask several questions to refine the stated goal.

- Which part of the project life cycle is to be planned?
- Do resources mean only people or does it include hardware/software and office resources as well?

After discussion between you and the client the goal and questions are refined as follows:

"*Develop a simulation model for decision support. The model should help to plan resource (developers) allocations for the coding phase of the software development project, such that tradeoffs between duration and cost can be analysed and the most suitable plan for resource allocation can be devised*".

The client want answers to the following questions in the context of above stated goal:

Q1: How many people will be needed to finish the coding phase of the project within a given time?

Q2: What will be the effect on cost and/or duration if given different number of developers working in the coding phase of the project?

Q2: Can cost of the project be reduced by increasing the duration of coding?

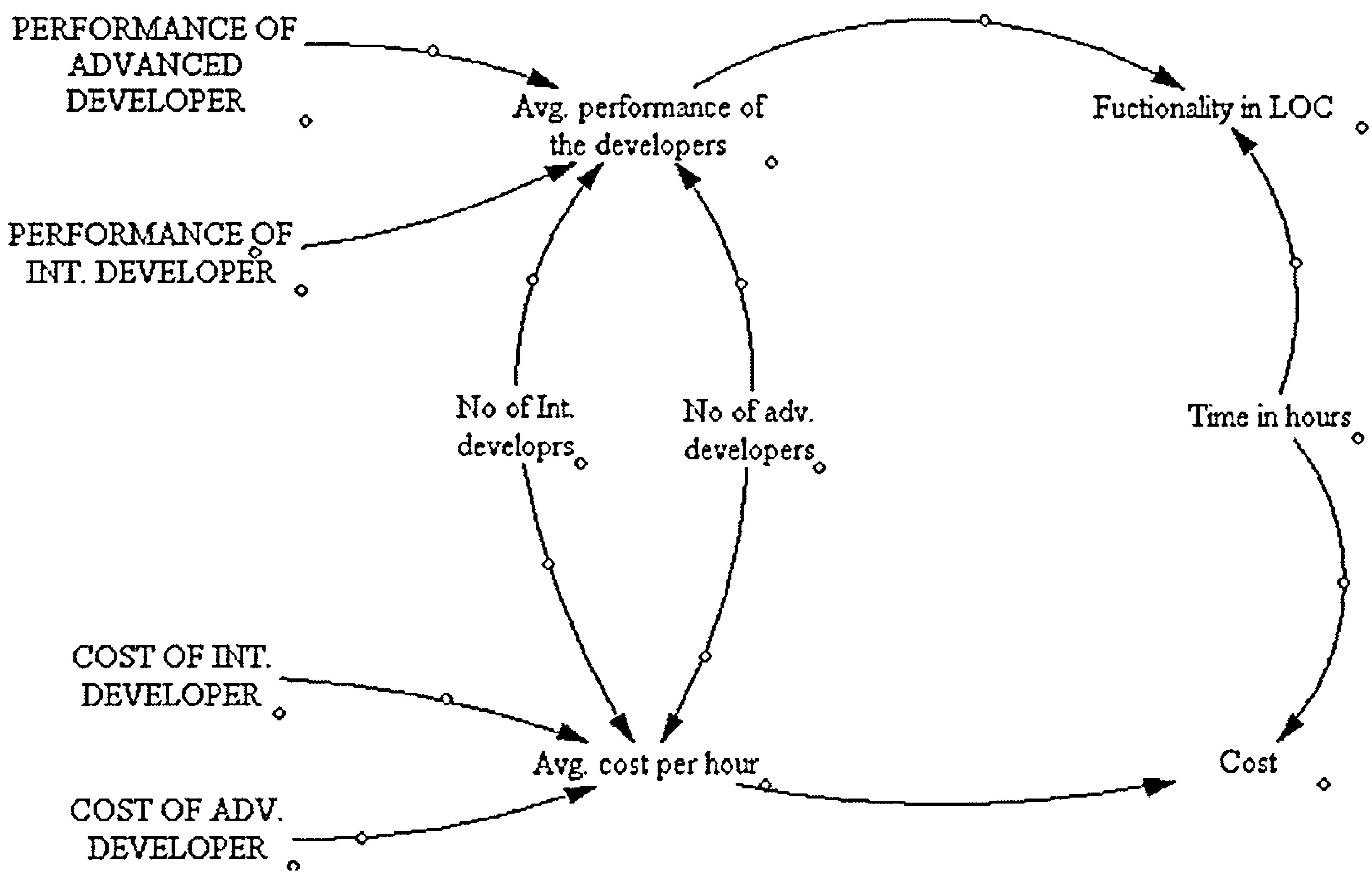
You will further discuss the problem with the client and identify the outputs and inputs needed to accomplish the simulation. You will gain an understanding of cause and effect relationships between different parameters in the process. An example of a cause-effect relationship is shown in figure A. The simulation must feasibly take care of all possible factors contributing in the system.

Influence diagram

Having identified the inputs and outputs and their relationship with each other, you should draw an influence/process diagram that shows how different factors in the system affect each other. The diagram shown in figure A depicts relationships of between different parameters of the above problem. 'Functionality' and 'cost' are the two main output parameters in which we are interested. Both 'functionality' and 'cost' is affected by 'time'. Functionality is affected by 'average performance of the developers', while 'average performance of the developers' depends on the number of developers and the performance of different kinds of developers. Similarly, 'cost' is affected by 'avg. cost per hour', while 'avg. cost per hour' depends on the number of developers working and the cost of different kinds of developers.

There is no order to when you should draw the influence diagram. Identifying contributing factors and drawing the influence diagram complements each other. Normally you will start drawing the influence diagram as soon as you identify a few factors and on the basis of the diagram you will identify more factors contributing to the system.

Figure 1: Influence diagram of the factors and their relationships



Scenarios for experimentation

There may be a number of scenarios under which a client may want you to run experiments with the developed simulation model. Here are two example scenarios.

Scenario 1: You have 5 advanced and 5 intermediate level developers. For code of 1000KLOC, devise a developer allocation policy such that coding could be finished within 1000 person hours.

Assumption1: Performance of the developers is constant

Assumption 2: Cost of a developer per hour is constant

Scenario 2: You have a budget of 15,000 pounds, devise a developer allocation policy such that project could be finished within given budget. The size of the functionality to code is 1000KLOC.

Assumption 1: Performance of the developers is constant

Assumption 2: Cost of a developer per hour is constant

Scenario 3: The functionality of 1000KLOC is to be finished in 1000 person hours. Devise a developer allocation policy such that coding can be finished in the given time.

Assumption 1: Performance of the developers is constant

Assumption 2: Cost of a developer per hour is constant

Assumption 3: Any number of developers is available

Appendix C2: Problem statement for the SE experiments

Introduction
Project managers at Wizzy Solutions, a small software company, are considering introducing Extreme Programming for their future projects. Extreme programming has been used in couple of projects in the past at Wizzy Solutions and some historical data is available from those projects. Developers who took part in those projects are still working at the company. Project managers want to identify factors and relationships that affect productivity in an extreme programming environment.
**See Appendix A for an introduction to Extreme Programming*

Objective
The objective of this simulation study is to compare the *productivity* of a *pairs* under variety of circumstances. Productivity of pairs depends on two factors,

- *Pair familiarity* (the extent members of a pair are familiar with each other)
  Pair familiarity is inversely proportional to pair unfamiliarity and there may be other factors affecting pair familiarity and unfamiliarity.
- *Task learning* (pairs are switched between different tasks in a project).
  Task learning is inversely proportional to task unfamiliarity and there may be other factors affecting task learning and task unfamiliarity.

Develop a system dynamics model that models the calculation of pair productivity under following circumstances:

1. Members of the pair are new to each other and they are working on a new task.
2. Members of the pair are new to each other but one or both of them has worked on the task before.
3. Members of the pair have worked together in the past but the task is new to both of them.
4. Members of the pair have worked together in the past and they have worked on the given task as well in the past.

Road map
Discuss the scope and requirements of the problem with the client; find out specific questions the client wishes to be answered; identify the contributing factors and their relationship within the problem. Use your system dynamics knowledge to develop the simulation model.

Show productivity output comparison of the four scenarios on a chart representation in Vensim. Discuss and analyse your results in the context of the questions provided by the client.
Please provide appropriate documentation for the simulation model developed.

Extreme programming
Extreme programming is a programming paradigm based on an evolutionary software development process. Extreme programming is characterized by several key practices, the most prominent of those are:

1. Constant customer interaction as feedback from the customer helps keep the project on the right track and improves the quality of the product.
2. Development is in short and small iterations, typically not longer than two weeks, so that the customers are constantly fed tangible value increments.

3. Pair programming; programmers work in a pairs, rather than individually. This provides inherent inspection capabilities and thus improves the quality of the product, albeit at the expense of a slight reduction in productivity.
4. Frequent task switching between programmer pairs, so that all programmers know all the details of the application. In addition, this practice contributes to the feeling of collective code ownership, which has been singled out as an important psychological factor.

Appendix C3: Problem statement for the OR experiments

Introduction

Project managers at Wizzy Solutions, a small software company, want to study the dynamics of their software projects. Project managers want to understand the interrelationships between human resource planning and those control functions that affect software production.

Objective

The objective of this simulation study is to study the rate of software production under a variety of circumstances. The software production function contributes to the on going software development activity. Important factors to consider are process losses, productivity, and effects of error generation.

There are three main functions of software project management related to the software production function, these are:

1. Human resource function

   The human resource function deals with the hiring, training, assimilation, and transfer of human resources. Projects teams typically are a mix of newly hired and experienced employees. The skills of project teams have a direct effect on the productivity of the project team.

2. Software project planning function

   The planning function of software project is responsible for initial project estimates (e.g. completion date, staffing, and effort). These estimates are then revised, as necessary, throughout the project life cycle.

3. Software project control function

   The software project control function deals with information which is used to keep the project in control. This information is based on projected outcomes and the current status of the project.

The relationships between these functions are that:

- Software production depends on the factors associated with the human resource function and planning function of the software project
- Software project planning function depends on control function. Planning function also affects human resource function.
- Control function is also affected by the software production function

Road map

Discuss the scope and requirements of the problem with the client; find out specific questions the client wishes to be answered; identify contributing factors, their relationship within the problem and any feedback mechanisms. Draw an influence diagram and discuss it with the client. Use your system dynamics knowledge to develop the simulation model.

Please provide appropriate documentation for the simulation model developed.

Discuss and analyse your results in the context of the questions provided by the client. Show the output on a chart representation if necessary.

Appendix C4: The RSMP pre evaluation questionnaire.

You have been just given an overview of the RSMP. In this questionnaire, you will be asked to evaluate RSMP. The data collected during the experiment is confidential and you will not be personally identified in any analysis or reports.

Some questions require a written answer and you should write in the box provided. Otherwise, tick the box that most matches your opinion.

Questions

1. It was easy to understand the RSMP

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

2. Learning the RSMP was easy for me

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

3. The instructions provided in the RSMP are clear

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

4. Using the RSMP for simulation modelling will improve the quality of the models I develop

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

5. Using RSMP for simulation modelling is likely bring discipline in my simulation modelling practices without compromising speed

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

6. The documentation guidelines of the RSMP are helpful

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

7. It would be useful to follow the RSMP

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

8. I am confident to use the RSMP

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

(Continue to the next page...)

9. Please answer each of the following questions.

a) Are there any features in the RSMP that you particularly like? If so, describe them please and tell us why you like them?

b) Are there any features the RSMP that you dislike? If so, please describe please and tell us why you dislike them?

c) Any other comments.

Appendix C5: Experiment evaluation questionnaire

In this questionnaire, you will be asked a number of questions to evaluate the experiment. The data collected during the experiment is confidential and you will not be personally identified in any analysis or reports.

Some questions require a written answer and you should write in the box provided. Otherwise, tick the box that most matches your opinion.

<u>**Questions**</u>

1. The problem I was asked to model was clear to me

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

2. Given time was enough to solve the problem

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

3. It was easy to access the client during the experiment

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

4. I wanted to spend more time with the client

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

5. I am happy with the SD model I have produced

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

6. I am happy with the documentation I have produced

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

7. Please describe what steps you took to develop this simulation model. Provide as much detail as you can.

8. Please answer each of the following questions.
   a) Were there any features in the EXPERIMENT that you particularly liked? If so, describe them please.

   b) Were there any features in the EXPERIMENT that you particularly disliked? If so, please describe them.

   c) Any other comments about the EXPERIMENT.

Appendix C6: The RSMP post evaluation questionnaire

In this questionnaire, you will be asked a number of questions to evaluate your experience of using the RSMP. The data collected during the experiment is confidential and you will not be personally identified in any analysis or reports.

Some questions require a written answer and you should write in the box provided. Otherwise, please tick the box that most matches your opinion.

Questions

9. I found it easy to follow the RSMP guidelines

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

10. The RSMP helped me to produce a better model than I otherwise would have

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

11. Using the RSMP brought discipline in my simulation practice

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

12. I found the documentation guidelines of the RSMP helpful

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

13. I found it useful to follow the RSMP

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

14. I would like to use RSMP in future

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

15. Please answer each of the following questions.

d) Were there any features in the RSMP that you found particularly useful? If so, describe them please.

e) Were there any features of the RSMP that you found not very useful? If so, please describe them.

f) Any other comments.

Appendix C7: Peer assessment questionnaire

You have been provided with the model and documentation of one of a fellow participant. In this final questionnaire, you will be asked a number of questions about the provided model. The data collected during the experiment is confidential and you will not be personally identified in any analysis or reports.

Some questions require a written answer and you should write in the box provided. Otherwise, please tick the box that most matches your opinion.

Questions

1. The model documentation is well structured

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

2. The model documentation is helpful to understand the model

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

3. The model structure is easy to understand

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

4. The model has meaningful variable names

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

5. Comments in the model help me to understand the model

   Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

6. Please answer each of the following questions.

   d) What features of the MODEL has been done particularly well?

e) What features of the MODEL could have been done better?

f) Any other comments about the MODEL.

Appendix C8: Client assessment questionnaire

You have been provided with the model and documentation of the participants of the experiments. In this questionnaire, you will be asked a number of questions about the provided model to assess it.

<u>**Questions**</u>

The Model

7. The model is valid on face value

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

8. Model feasibly covers the scope

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

9. The model is feasibly modular

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

10. It would be easy to couple this model with another model

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

11. Model layout is clear enough

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

Model Documentation

12. Simulation objectives have been defined well

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

13. Simulation questions have been defined well

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

14. Model scope has been defined well

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

15. Model inputs have been defined well

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

16. Model outputs have been defined well

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

17. Overall documentation is good

Strongly disagree ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 **Strongly agree**

18. Please provide us with any other comment that you feel would be helpful

Appendix C9: Model assessment criteria

The models produced by the participants in the experiments to evaluate the RSMP were assessed on the evaluation criteria as described in this document. These evaluation criteria were established from the literature prior to developing the RSMP. The purpose for devising assessment criteria prior to developing a simulation modelling process and conducting experiments is to minimise my own bias. If the assessment criteria are established after proposing simulation modelling process, there is a fair chance that it may get influenced so as to prove the effectiveness of modelling process. Therefore, I establish the assessment criteria in advance. The criteria have been established by the recommendations from simulation modelling literature.

The assessment criteria have some elements which can be measured objectively while others need subjective judgement. The models produced during the experiments are assessed by three different assessors. Criteria that can be measured objectively will be assessed by me. To minimise self bias, subjective criteria will be performed by the client and peers. To increase reliability of subjective judgements, the client is invited to assess models on the established criteria. These are to be assessed by peer review i.e. models will be swapped across groups, and the participants will be given a questionnaire asking questions to assess those items.

Table C9 summarises the assessment criteria derived from simulation modelling literature. The table shows the type of assessment (subjective or objective) needed for the particular criteria, and the type of assessor. Moreover, it gives a definition of each criterion.

Gass [1983] says that model assessment not only includes validation and verification but also usability, utility. Gass and Joel [1981] suggest that typically model assessment criteria should consist of model definition, model structure, model data, computer model verification, model validation, usability, performance, and model pedigree. Kitchenham et al. [2002c] report use of a framework for evaluating simulation models for software bidding. These assessment criteria have been derived from simulation modelling literature. Table 2 summarises the assessment criteria, the assessors and the type of judgement. Each of the criterions is described as following.

1. Syntactic quality

Kitchenham et al. [2002c] propose syntactic quality as a measure to assess simulation model's quality. To assess syntactic quality, model would be manually checked for correctness of model diagrams and any equations. Checking the consistency of the inputs and outputs with the direction of the links in the model and testing the algebraic equations with selected predefined values. This criterion is solely academic, as the modelling tool will automatically ensure syntactic correctness.

2. Semantic quality

Semantic quality examines how well the model conforms to the reality being modelled. Kitchenham et al. [2002c] proposed a framework for evaluating simulation models for software bidding. Validation and verification are two parts of ensuring semantic quality of simulation models.

Table C9: The assessment criteria

Criterion	Measure	Assessor	Description
1. Syntactic quality	Objective	Self	To asses syntactic quality model would be manually checked for correctness of model diagrams and any equations. Checking the consistency of the inputs and outputs with the direction of the links in the model and testing the algebraic equations with selected predefined values.
2. Semantic quality			Checking how well the model conforms to the reality being modelled.
2.1 Validity			Checking if this is the right model.
2.1.1 Face validity	Subjective	Client	Examining that the model accurately represents the given problem.
2.1.2. Replication of reference mood	Objective	Self	Checking if the model accurately represents various reference modes of behaviour
2.1.3. Scope	Subjective	Client	Checking if the model feasibly covers the scope of the given problem.
2.2. Design/Structure			Checking the model for the quality of its design.
2.2.1 Modularity	Subjective	Client	How well the model has been modularised which makes it easier to modify or add further details in the model.
2.2.2. Interoperability	Subjective	Client	Examining if the model can be coupled with another model easily.
2.3. Verification	Subjective	Modeller	Checking if the built model is right
3. Quality of documentation			How well the model is documented?
3.1. Objectives and questions definition	Subjective	Client	
3.2. Scope definition	Subjective	Client	
3.3. Input and output definition	Subjective	Client	
3.4. Overall documentation	Subjective	Client	
4. Maintainability			How maintainable the model is?
4.1. Understandability	Subjective	Peer	Is the model easily understandable by the peers?
4.2. Documentation	Subjective	Peer	How well the documentation helps the peer to understand the models?
4.3. Model structure	Subjective	Peer	Is the model structure documented?
4.4. Meaningful variable names	Subjective	Peer	Names of variables in the model, are they meaningful to the peers?
4.5. Amount of comments	Subjective	Peer	Is the model well commented and help understanding the model?
5. Efficiency/ Performance	Objective	Self	The amount of computing resources and time it takes to execute the model.

2.1. Validation

Boehm [1981] defines product validation as, *"are we building the right product"*. Carson [1986] defines model validation as, *"the process of ensuring that the model is sufficiently accurate for the purpose at hand"*, or building the right model [Robinson 1997]. Model validation examines the correspondence of the model and its outputs to perceived reality [Gass 1983]. There are two dimensions of model's validity; one from modeller's perspective and other from client's perspective often called credibility. The client will actually assess the model's credibility.

2.1.1. Face validity

Face validity is the most common method of validating a simulation model. Sargent [1998] defines face validity as, "asking people who are knowledgeable about the system whether the model and/or its behaviour are reasonable".

2.1.2. Scope

Assessment of scope examines whether the simulation model has feasibly covered the problem scope. This is a subjective judgement and depends on the assessor's knowledge of the problem. It entails subjectively judging the appropriateness of amount of detail provided in the model [Brooks and Tobias 1996]. A model may get very complex if unnecessary detail is given or it may get uselessly simple if too much detail is suppressed.

2.1.3. Replication of reference modes

Abdel-Hamid and Madnick [1989] and Kitchenham et al. [2002c] use this criterion to validate a simulation model. Raffo and Kellner [2000] suggest similar criterion for model validation. Replication of reference modes reproduces various reference models of behaviour (e.g. 90% complete syndrome).

2.2. Design/Structure

Simulation model design affects model future usage in various aspects. A well designed model has potential to be used for a longer term compared to a badly designed model [Gass 1981]. Following sub criterion will be used to assess the model design.

2.2.1. Modularity

Modularity is defined as use of common units to create product variants [Huang and Kusiak 1998]. A module may implement a common function that can be used throughout the application. Modularity enhances reuse and understanding of the product [Huang and Kusiak 1998]. This would again be a subjective measure and will be assessed by the client.

2.2.2. Interoperability

Interoperability is the measure used by Scholten and Udink [1999] for quality assessment of simulation models. It examines how easy it is to couple this model with another model.

2.3. Verification

Boehm's [1981] definition of product verification is, *"are we building the product right"*. Davis [1992] states, *"verification is the process of ensuring that the model design (conceptual model) has been transformed into a computer model with sufficient accuracy"*. Verification is a micro check on the model behaviour. The purpose of verification is to ensure that model elements exhibit the correct behaviour as intended. It is similar to software code debugging. Verification checks that the correct logic has been employed in the model and the outputs obtained through computation are correct. Verification of the simulation model is done by the modeller himself; therefore it will not be possible to verify the simulation by the assessors.

3. Quality of documentation

Documentation is perhaps one of the most important things to enhance model's understanbility, maintainability and reusability. Law and McComas [2001], Gass [1981, 1984] have proposed various guidelines to document simulation models. Assessing the quality of documentation is a subjective judgement and will be done by the client.

4. Maintainability

Gass (1981) proposes that maintainability be considered as a measure to assess quality of simulation models. Very little debate can be found in simulation modelling literature about the maintainability of simulation models and no established measures can be found. Maintainability of the models will be judged by peer observation and will be subjective. Clarity in definition of objectives and questions, definition of inputs and outputs, comments in model code, meaningfulness of variable names, and mode structure are considered to be very helpful for understanding and hence maintaining the model [Brooks and Tobias 1996, Robinson 2003].

Understandability of model indicates how easy is it to understand a model. Kitchenham et al. [2002c] propose it as a quality measure for simulation models. This is a subjective judgement and also depends on the individual's experience and background. Understandability assessment will be conducted by peer observation because all the participants in the experiment are expected to have similar level of expertise in simulation model. A 3rd party assessment of this feature may not produce reliable results because looking at similar models again and again will increase his/her understanding of the model. For example, where there are 10 models to be assessed, model no. 10 may seem to him/her more understandable than model no. 1.

5. Efficiency/Performance

Scholten and Udink [1999], and Brooks and Tobias [1996] consider efficiency of a model as a quality measure. They define it as the amount of computing resources required by a model to perform its functions. This is a feature which can be assessed objectively on a working model.

Appendix C10: SPSS output for statistical significance

This appendix show the results of applying statistical significance test to compare means of time spent on client contact, tool use, and documentation by the RSMP and the Non-RSMP groups in the SE experiments.

Client contact

Null hypothesis: The difference between the Non-RSMP and the RSMP group in amount of time spent in "Client Contact" is by chance

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Client Contact	Non-$RSMP^{SE}$	4	11.2500	5.90903	2.95452
	$RSMP^{SE}$	4	22.0000	8.24621	4.12311

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Client Contact	Equal variances assumed	2.220	.187	-2.119	6	.078	-10.75000	5.07239	-23.16170	1.66170
	Equal variances not assumed			-2.119	5.438	.083	-10.75000	5.07239	-23.47932	1.97932

Significance value for 2-tailed test = 0.078
Significance value for 1-tailed test = 0.078 / 2 = 0.039

Interpretation: The statistical significance value (0.039 or 3.9%) shows that there is a probability of only 3.9% that the difference in time spent on client contact is by chance on a 95% confidence interval. This does not provide enough evidence to accept the null hypothesis that the difference between the two groups in the amount of time spent with the client is by chance.

Tool use

Null hypothesis: The difference between the Non-RSMP and the RSMP group in amount of time spent "using the tool" is by chance

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Tool Use	Non-RSMP^{SE}	4	74.2500	11.87083	5.93542
	RSMP^{SE}	3	36.3333	12.66228	7.31057

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Tool Use	Equal variances assumed	.006	.942	4.071	5	.010	37.91667	9.31300	13.97684	61.85649
	Equal variances not assumed			4.027	4.269	.014	37.91667	9.41667	12.40906	63.42428

Significance value for 2-tailed test = 0.01
Significance value for 1-tailed test = 0.01 / 2 = 0.005

Interpretation: The statistical significance value (0.005 or 0.5%) shows that there is a probability of only 0.5% that the difference in time spent on using the tool is by chance on a 95% confidence interval. This does not provide enough evidence to accept the null hypothesis that the difference between the two groups in the amount of time spent using the tool is by chance.

Documentation
Null hypothesis: The difference between the Non-RSMP and the RSMP group in amount of time spent on "documentation" is by chance

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Documentation	Non-RSMP^{SE}	4	1.2500	2.50000	1.25000
	RSMP^{SE}	4	28.0000	18.03700	9.01850

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Documentation	Equal variances assumed	3.040	.132	-2.938	6	.026	-26.75000	9.10471	-49.02843	-4.47157
	Equal variances not assumed			-2.938	3.115	.058	-26.75000	9.10471	-55.12831	1.62831

Significance value for 2-tailed test = 0.026
Significance value for 1-tailed test = 0.026 / 2 = 0.013

Interpretation: The statistical significance value (0.026 or 0.013%) shows that there is a probability of only 0.5% that the difference in time spent on documentation is by chance on a 95% confidence interval. This does not provide enough evidence to accept the null hypothesis that the difference between the two groups in the amount of time spent on documentation is by chance.

Appendix D1: Expert panel questionnaire

Thank you very much for agreeing to participate in this evaluation. In this questionnaire, you will be asked to evaluate RSMP. The data collected during the experiment is confidential and you will not be personally identified in any analysis or reports without your explicit consent. The work has been approved by the Faculty's ethics procedures (under protocol 03/87).

Instructions

i. Please first read the accompanying documentation in order to fill the questionnaire.

ii. This questionnaire and reading the accompanying documentation should take less than 40 minutes to complete.

iii. The questionnaire has three sections. Some questions require a written answer and you should write in the box provided. Otherwise, make your selection bold-faced.

iv. The target date for return of this questionnaire is April 22, 2005.

v. Questionnaire should preferably be returned by email, alternatively post on the address given below.

vi. If you recommend any changes in the accompanying documentation, please return us a copy indicating the recommended changes.

vii. Please read the consent statement below and sign and date in the appropriate boxes.

Consent

I have agreed to participate in the questionnaire described above. I understand that I am free to ask questions or to withdraw from participation at any time.

Name & Signature	Date

Rizwan Ahmed

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About you

Name: ______________________

Address: ____

____

Phone No.: ______________________

Email Address: ______________________

Experience in simulation modelling (years): ______________________

Position held (Academic/Industry): ______________________

Job Title: ______________________

Modelling techniques used (make your choices bold-faced):

1. System dynamics
2. Discrete event simulation
3. Other (please specify)

____

Types of problems worked on (make your choices bold-faced):

1. Software process improvement
2. Software project management
3. Control and operations management
4. Project planning
5. Software evolution/maintenance
6. Training and education
7. Other (please specify)

____

Part-I: Scope of the RSMP

(Part-I of the questionnaire aims to evaluate the scope of the RSMP. Please make your selection bold-faced)

1. The activities recommended by the RSMP are general and likely to apply in most contexts

   Less likely 1 2 3 4 5 Very likely

2. The RSMP framework is ***applicable*** to

   a. System dynamics modelling

   Strongly disagree 1 2 3 4 5 Strongly agree

   b. Discrete event simulation

   Strongly disagree 1 2 3 4 5 Strongly agree

3. RSMP would be useful for ***what type*** of simulation models (you may choose multiple)

   a. 1. Small 2. Medium 3. Large
   b. 1. Simple 2. Medium 3. Complex
   c. All of above
   d. None of above

Part-II: Understandability of the RSMP

(Part-II of the questionnaire aims to evaluate the understandability of the RSMP. Please make your selection bold-faced)

1. The accompanying documentation ***clearly*** defines the RSMP for novice simulation modellers

   Not very clear 1 2 3 4 5 Very clear

2. The level of detail in the accompanying documentation of the RSMP is ***appropriate*** for novice simulation modellers

   Not very appropriate 1 2 3 4 5 Very appropriate

3. The RSMP is ***easy to understand*** by novice simulation modellers

   Not very easy 1 2 3 4 5 Very easy

4. What ***improvements*** do you suggest in the ***RSMP and its documents***? Please comment to improve the RSMP description document, graphical figures and documentation guidelines (you may specify improvements by editing the RSMP documents in a different font colour)

Part-III: Usability of the RSMP

(Part-III of the questionnaire aims to evaluate usability of the RSMP from your perspective. Please make your selection bold-faced)

1. The RSMP provides a ***usable process*** for novice simulation modellers

   Not very usable 1 2 3 4 5 Very usable

2. The RSMP provides a ***logical set of steps*** for novice simulation modellers for simulation model development

   Not very logical 1 2 3 4 5 Very logical

3. The RSMP includes a ***realistic*** level of client contact

   Not very realistic 1 2 3 4 5 Very realistic

4. The documentation required in the RSMP is ***appropriate***

   Not very appropriate 1 2 3 4 5 Very appropriate

5. It would be ***easy*** for novice simulation modellers ***to follow*** the RSMP

   Not very easy 1 2 3 4 5 Very easy

6. It would be ***easy*** for novice simulation modellers ***to use*** the RSMP documentation guidelines

   Not very easy 1 2 3 4 5 Very easy

7. What difficulties do you think novice simulation modellers may face following the RSMP and how it can be improved to overcome such difficulties?

Part-IV: Usefulness of the RSMP

(Part-IV of the questionnaire aims to evaluate usefulness of the RSMP with your perceptions. Please make selection choice bold-faced)

1. It would be ***useful*** for a novice simulation modeller to take a ***process view*** of simulation modelling practice

   Not very useful 1 2 3 4 5 Very useful

2. Using the RSMP is likely to ***bring discipline*** into the novice simulation modellers' practice

   Not very likely 1 2 3 4 5 Very likely

3. RSMP's emphasis on client contact will help the novice simulation modellers ***effectively define the problem***

   Strongly disagree 1 2 3 4 5 Strongly agree

4. Following the RSMP *Foundation* step guidelines, novice simulation modellers would be able to capture the ***scope of problem better***

   Strongly disagree 1 2 3 4 5 Strongly agree

5. Identifying and defining inputs, outputs and their interaction (*Foundation* step) in advance will help novice simulation modellers in producing ***better model design***

   Strongly disagree 1 2 3 4 5 Strongly agree

6. Identification of scenarios (*Foundation* step) in advance will help novice simulation modellers in ***designing the experiments better***

   Strongly disagree 1 2 3 4 5 Strongly agree

7. Planning the model structure in advance (*Construction* step), a novice simulation modeller would be able to produce a better model design in terms of

   a. Reusability

   Strongly disagree 1 2 3 4 5 Strongly agree

   b. Modularity

   Strongly disagree 1 2 3 4 5 Strongly agree

   c. Interoperability

   Strongly disagree 1 2 3 4 5 Strongly agree

8. Using the RSMP is likely to ***improve the validity*** of the simulation models produced by novice simulation modellers

   Not very likely 1 2 3 4 5 Very likely

9. Designing the experiments prior to conducting them is more likely to produce ***valid results***

   Strongly disagree 1 2 3 4 5 Strongly agree

10. Using the RSMP documentation guidelines, the novice simulation modellers would be able to produce ***better documentation***

    Strongly disagree 1 2 3 4 5 Strongly agree

11. Documentation produced following the RSMP guidelines will ***make it easier*** to understand the model

    Strongly disagree 1 2 3 4 5 Strongly agree

12. Documentation produced following the RSMP guidelines will ***help model maintenance***

    Strongly disagree 1 2 3 4 5 Strongly agree

13. Producing the documentation, as specified by RSMP, would need further cost/effort to simulation model development

    Strongly disagree 1 2 3 4 5 Strongly agree

14. If you "agree" to above question, having the appropriate documentation would ***outweigh*** the additional cost/effort

    a. Yes

    b. No

    c. Other (please elaborate)

15. In your opinion, what are the advantages or disadvantages of using the RSMP. Please suggest improvement if any disadvantage identified.

Part-V: Tailorability of the RSMP

(Part-V of the questionnaire aims to evaluate tailorability of the RSMP with your perceptions. Please make selection choice bold-faced)

1. The RSMP can be ***tailored*** to suit an individual simulation modeller's needs

   Not very tailorable 1 2 3 4 5 Very tailorable

2. It would be easy to ***adapt*** the RSMP (e.g. add/remove/amend process activities)

   Not very adaptable 1 2 3 4 5 Very adaptable

3. It would be possible to ***extend*** each process activity to create specific guidelines and prescription in specific situations

   Not very extensible 1 2 3 4 5 Very extensible

May we contact you be e-mail/telephone if we need to follow up any of your responses to this questionnaire?

Yes /No

Thank you for participating in this expert panel. We would like to be able to list the members of this expert panel in any subsequent publications on this validation process. Please indicate whether you are happy to be named as a member of our expert panel.

Yes /No

The first four sections of the questionnaire largely replicate the questionnaire survey conducted by Willemain [1994] with expert modellers in the field of operational research. I have added a fifth section to discover what process simulation modellers use for developing models of software processes and a sixth section to identify the most critical issues. Appendix A2 shows the questionnaire used in the preliminary survey.

5.2.1. The respondents

The target sample for this survey is the delegates of the ProSim03 workshop. Questionnaires were distributed to all delegates 30 of the workshop and 17 responses were collected. To ensure a higher response rate the questionnaire was distributed and collected by hand. This also helped avoiding the time and money costs of sending the questionnaire by post. A normal response rate is considered between 30-40% [Oppenheim 1992]. I obtained a better than average response rate of 57%. This increases confidence in the study results.

Figure 5.1 shows the divide between respondents; 9 of the 17 respondents are academics (including 1 research student), 8 respondents are from industry. Hence, the sample is a good mix of academics and practitioners. Figure 5.2 shows the experience profile of the respondents in simulation modelling. The average simulation modelling experience of the sample is 6.5 years.

Figure 5.1: Survey respondents

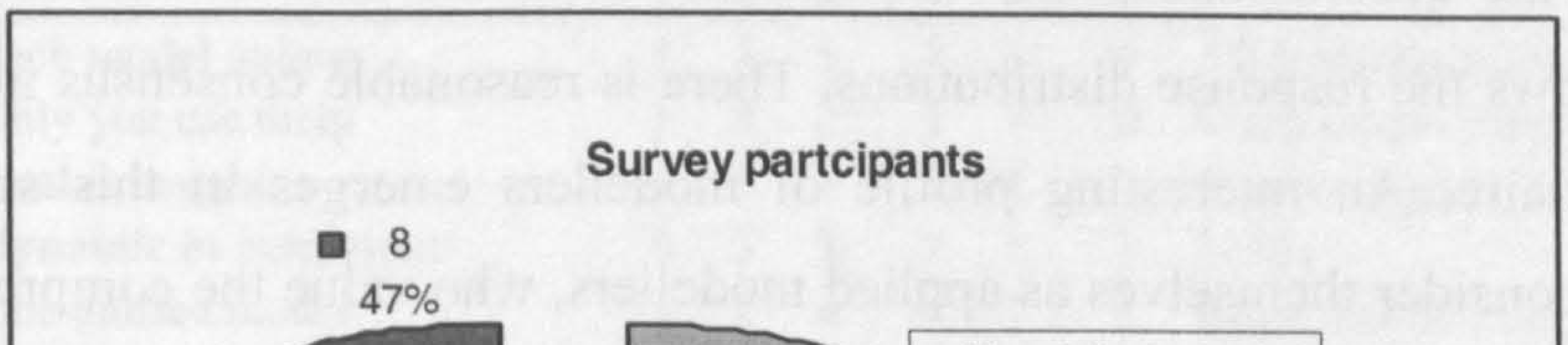
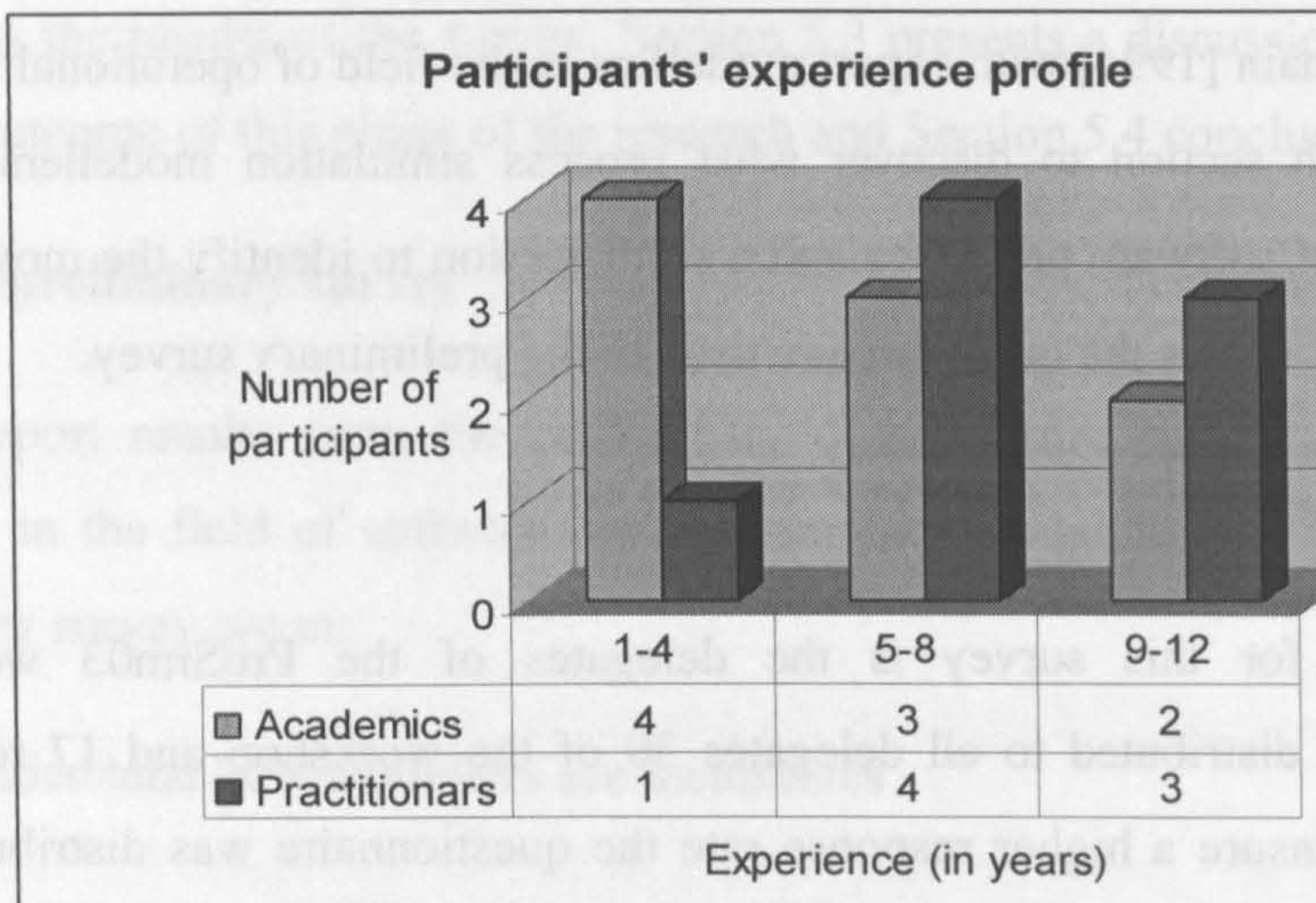


Figure 5.2: Respondents' experience profile in simulation modelling



5.2.2. Questionnaire results

Here I discuss the results of the questionnaire. The discussion has been divided into 6 subsections corresponding to the 6 sections of the questionnaire. The response distributions have been shown in the tables for each part separately. Following Willemain [1994], I consider a consensus in response if 75% of the responses lie on one side of the Likert scale. I do not attempt to generalise the results to a population by showing a consensus, rather highlight general trends in response of the respondents. The items with consensus have been marked in bold face.

I. Describe yourself as a modeller

This part of the questionnaire asks respondents about the kind of modeller they are? Table 5.1 shows the response distributions. There is reasonable consensus in this part of the questionnaire. An interesting profile of modellers emerges in this section; most respondents consider themselves as applied modellers, who value the comprehensiveness of their models; and who are methodical rather than intuitive and who value practicality rather than creativity. This implies that most of the respondents work on real-world problems, where the emphasis is to provide a comprehensive solution to the customer following a methodical way.