Proceedings of the 2006 Winter Simulation Conference
L. F. Perrone, F. P. Wieland, J. Liu, B. G. Lawson, D. M. Nicol, and R. M. Fujimoto, eds.

CONCEPTUAL MODELING FOR SIMULATION: ISSUES AND RESEARCH REQUIREMENTS

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ABSTRACT

It is generally recognized that conceptual modeling is one of the most vital parts of a simulation study. At the same time, it also seems to be one of the least understood. A review of the extant literature on conceptual modeling reveals a range of issues that need to be addressed: the definition of conceptual model(ling), conceptual model requirements, how to develop a conceptual model, conceptual model representation and communication, conceptual model validation, and teaching conceptual modeling. It is clear that this is an area ripe for further research, for the clarification of ideas and the development of new approaches. Some areas in which further research could be carried out are identified.

1 INTRODUCTION

Conceptual modeling is the abstraction of a model from a real or proposed system. This process of abstraction involves some level of simplification of reality (Zeigler 1976). Effective conceptual modeling requires that the abstraction is an appropriate simplification (Pidd 2003).

Put in these terms, conceptual modeling is probably the most important aspect in the process of developing and using simulation models. The design of the model impacts all aspects of a simulation study, in particular the data requirements, the speed with which the model can be developed, the validity of the model, the speed of experimentation and the confidence that is placed in the model results. A well designed model significantly enhances the likelihood of a successful outcome to a simulation study.

Although effective conceptual modeling is vital, it is also the most difficult and least understood stage in the modeling process (Law 1991). There is surprisingly little written on the subject. It is difficult to find a book that devotes more than a handful of pages to the design of the conceptual model. Neither are there a plethora of research papers, with only a handful of well regarded papers over the last four decades. A search through the academic tracks at major simulation conferences on discrete-event simulation reveals a host of papers on other aspects of simulation modeling. There are, however, very few papers that give any space to the subject of conceptual modeling.

This paper aims to outline the key issues in conceptual modeling for simulation. Based on a review of the current literature in the field a series of issues are identified. The aim is not to address these issues here. The hope is that in identifying the issues and the extent to which they have (and in most cases have not) been addressed, a research agenda for conceptual modeling might emerge. The issues are discussed under the following headings:

- Definition of conceptual model(ling)
- Conceptual model requirements
- How to develop a conceptual model
- Conceptual model representation and communication
- Conceptual model validation
- Teaching conceptual modeling
- Other issues in conceptual modeling

It should be noted that the prime interest of the author is in discrete-event simulation and its application to aiding organisational change. This generally involves medium sized simulation studies (weeks or months), with models developed in commercial-off-the-shelf packages. These models are often developed by a lone modeler and thrown away at the end of the simulation study (Robinson 2002).

2 THE DEFINITION OF CONCEPTUAL MODEL(LING)

The notion of conceptual modeling is vague and ill-defined, with varying interpretations as to its meaning. What seems to be agreed is that it refers to the early stages of a simulation study. This implies a sense of moving from the recognition of a problem situation to be addressed with a simulation model to a determination of what is going to be modeled and how. Balci (1994) breaks the early parts of a simulation study down into a number of processes: problem formulation, investigation of solution techniques,

1-4244-0501-7/06/$20.00 ©2006 IEEE

system investigation, model formulation, model representation and programming. Which of these is specifically included in conceptual modeling is not identified. What is clear from Balci and other authors is that these early stages of a simulation study are not just visited once, but that they are continually returned to through a series of iterations in the life-cycle of a project. As such, conceptual modeling is not a one-off process, but one that is repeated and refined a number of times during a simulation study.

Zeigler (1976) sheds some light on the subject by identifying five elements in modeling and simulation from the "real system" through to the "computer" (the computer based simulation model). In between is the "experimental frame", "base model" and "lumped model". The experimental frame is the limited set of circumstances under which the real system is observed, that is, specific input-output behaviors. The base model is a hypothetical complete explanation of the real system, which is capable of producing all possible input-output behaviors (experimental frames). The base model cannot be fully known since full knowledge of the real system cannot be attained. For instance, almost all systems involve some level of human interaction that will affect their performance. This interaction cannot be fully understood since it will vary from person-to-person and time-to-time.

In the lumped model the components of a model are lumped together and simplified. The aim is to generate a model that is valid within the experimental frame, that is, reproduces the input-output behaviors with sufficient fidelity. The structure of the lumped model is fully known. Returning to the example of human interaction with a system, in a lumped model specific rules for interaction are devised, e.g., a customer will not join a queue of more than 10 people.

Nance (1994) separates the ideas of conceptual model and communicative model. The conceptual model exists in the mind of a modeler, the communicative model is an explicit representation of the conceptual model. He also specifies that the conceptual model is separate from model execution. In other words, the conceptual model is not concerned with how the computer-based model is coded. Fishwick (1995) takes a similar view, stating that a conceptual model is vague and ambiguous. It is then refined into a more concrete executable model. The process of model design is about developing and refining this vague and ambiguous model and creating the model code. In these terms, conceptual modeling is a sub-set of model design, which also includes the design of the model code.

Robinson (2004) offers the following definition for a conceptual model: "The conceptual model is 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." This definition highlights the non-software specificity of the conceptual model and the components of such a model.

The main debate about conceptual modeling and its definition has been held among military simulation modelers. Pace has lead the way in this debate and defines a conceptual model as "a simulation developer's way of translating modeling requirements … into a detailed design framework …, from which the software that will make up the simulation can be built" (Pace 1999a). In short, the conceptual model defines what is to be represented and how it is to be represented in the simulation. Pace sees conceptual modeling as being quite narrow in scope viewing objectives and requirements definition as precursors to the process of conceptual modeling. The conceptual model is largely independent of software design and implementation decisions. Pace (2000) identifies the information provided by a conceptual model as consisting of assumptions, algorithms, characteristics, relationships and data.

Lacy et al. (2001) further this discussion reporting on a meeting of the Defense Modeling and Simulation Office (DMSO) to try and reach a consensus on the definition of a conceptual model. The paper describes a plethora of views, but concludes by identifying two types of conceptual model. A *domain-oriented* model that provides a detailed representation of the problem domain and a *design-oriented* model that describes in detail the requirements of the model and is used to design the model code. Meanwhile, Haddix (2001) points out that there is some confusion over whether the conceptual model is an artifact of the user or the designer. This may, to some extent, be clarified by adopting the two definitions above.

The approach of military simulation modelers can be quite different to that of those working in business oriented simulation (Robinson 2002). Military simulations often entail large scale models developed by teams of software developers. There is much interest in model reuse and distributed simulation, typified by the High Level Architecture. Business oriented simulations tend to be smaller in scale, involve lone modelers normally using a visual interactive modeling tool (Pidd 2004), and the models are often thrown-away on completion of a project. Interest in distributed simulation is moderate, mostly because the scale and life-time of the models does not warrant it (Robinson 2005). As a result, although the definition and requirements for conceptual modeling may be similar in both these domains, some account must be made of the differences that exist.

In summary, the discussion above identifies some key facets of conceptual modeling and the definition of a conceptual model:

- Conceptual modeling is about moving from a problem situation, through model requirements to a definition of what is going to be modeled and how.

- Conceptual modeling is iterative and repetitive, with the model being continually revised throughout a modeling study.
- The conceptual model is a simplified representation of the real system.
- The conceptual model is independent of the model code or software, while model design includes both the conceptual model and the design of the code (Fishwick 1995).
- The perspective of the client and the modeler are both important in conceptual modeling.

It is clear, however, that complete agreement does not exist over these facets.

3 CONCEPTUAL MODEL REQUIREMENTS

"Perfection is achieved, not when there is nothing more to add, but when there is nothing left to take away." Antoine de Saint-Exupery.

The overarching requirement for effective (conceptual) models is generally agreed to be the need to develop the simplest model possible (Robinson 1994). Simple models have a number of advantages. They can be developed faster, are more flexible, require less data, run faster, and it is easier to interpret the results since the structure of the model is better understood (Innis and Rexstad 1983; Ward 1989; Salt 1993; Chwif et al. 2000). As the complexity increases these advantages are lost.

There are those, however, that warn against taking simplicity to an extreme. Pritsker (1986) reflects on his experience of developing models of differing complexity of the same system. He concludes that the simplest model is not always best because models need to be able to evolve as the requirements change. The simplest model is not always the easiest to embellish. Schruben and Yücesan (1993) make a similar point, stating that simpler models are not always as easy to understand, code and debug. Davies et al. (2003) point out that simpler models require more extensive assumptions about how a system works and that there is a danger in setting the system boundary too narrow in case an important facet is missed.

Beyond the need for simplicity, assessment criteria (requirements) for models have been discussed by a number of authors, for instance, Gass and Joel (1981), Robinson and Pidd (1998) and Balci (2001). The majority of this work is in the domain of large scale military and public policy models; Robinson and Pidd is an exception. Furthermore, the criteria focus on assessing models that have been developed rather than on the assessment of conceptual models.

In terms of criteria for conceptual models there has been little reported in the operational research literature. Willemain (1994), who investigates the preliminary stages of operational research interventions, briefly lists five qualities of an effective model: validity, usability, value to the clients, feasibility, and aptness for the clients' problem. Meanwhile, Brooks and Tobias (1996a) identify eleven performance criteria for a good model. Robinson (2004) identifies four requirements of a conceptual model: validity, credibility, utility and feasibility. Requirements are also briefly discussed by Pritsker (1986), Henriksen (1988), Nance (1994), and van der Zee and van der Vorst (2005).

Outside of operational research there are some discussions, for instance, Teeuw and van den Berg (1997) who discuss the quality of conceptual models for business process reengineering.

4 HOW TO DEVELOP CONCEPTUAL MODELS

The overarching requirement to develop simple models highlights an important consideration in designing a conceptual model. Modeling requirements provide a guide as to whether a conceptual model is appropriate. Neither, however, describes how a modeler might go about determining what the conceptual model should be in a simulation study. So what help is offered in the simulation and modeling literature to guide modelers in designing the conceptual model?

First, it is worth recognizing that conceptual modeling requires creativity (Henriksen 1989). Simulation modeling is both art and science (Shannon 1975) with conceptual modeling lying more at the artistic end! As Schmeiser (2001) points out: "While abstracting a model from the real world is very much an art, with many ways to err as well as to be correct, analysis of the model is more of a science, and therefore easier, both to teach and to do." The need for creativity does not, however, excuse the need for guidelines on how to model (Evans 1992). Ferguson et al. (1997), writing about software development, point out that 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 creativity can happen."

In searching for advice from simulation modelers and operational researchers on how to develop models, three basic approaches can be found: principles of modeling, methods of simplification and modeling frameworks.

4.1 Principles of Modeling

Providing a set of guiding principles for modeling is one approach to advising simulation modelers on how to develop (conceptual) models. For instance, Pidd (1999) describes six principles of modeling:

- Model simple; think complicated
- Be parsimonious; start small and add

- Divide and conquer; avoid megamodels
- Use metaphors, analogies, and similarities
- Do not fall in love with data
- Modeling may feel like muddling through

The central theme is one of aiming for simple models through evolutionary development. Others have produced similar sets of principles (or guidelines), for instance, Morris (1967), Powell (1995), Pritsker (1998) and Law and Kelton (2000). The specific idea of evolutionary model development is further explored by Nydick et al. (2002).

These principles provide some useful guidelines for those developing conceptual models. It is useful to encourage modelers to start with small models and to gradually add scope and detail. What such principles do not do, however, is guide a modeler through the conceptual modeling process. When should more detail be added? When should elaboration stop? There is a difference between giving some general guidelines and guiding someone through a process.

4.2 Methods of Simplification

Simplification entails removing scope and detail from a model or representing components more simply while maintaining a sufficient level of accuracy. In Zeigler's (1976) terms this could be described as further lumping of the lumped model. This is the opposite of the start small and add principle.

There are quite a number of discussions on simplification, both in the simulation and the wider modeling context. Morris (1967) identifies some methods for simplifying models: making variables into constants, eliminating variables, using linear relations, strengthening the assumptions and restrictions, and reducing randomness. Ward (1989) provides a similar list of ideas for simplification. Meanwhile, Courtois (1985) identifies criteria for the successful decomposition of models in engineering and science.

For simulation modeling, Zeigler (1976) suggests four methods of simplification: dropping unimportant components of the model, using random variables to depict parts of the model, coarsening the range of variables in the model, and grouping components of the model. Yin and Zhou (1989) build upon these ideas, discussing six simplification techniques and presenting a case study. Sevinc (1990) provides a semiautomatic procedure based on Zeigler's ideas. Innis and Rexstad (1983) enter into a detailed discussion about how an existing model might be simplified. They provide a list of seventeen such methods, although they do not claim that these are exhaustive. They conclude by suggesting that managers should be provided with both a full and a simplified simulation model. Robinson (1994) also lists some methods for simplifying simulation models.

Such ideas are useful for simplifying an existing (conceptual) model, but they do not guide the modeler over how to bring a model into existence. Model simplification acts primarily as a redesign tool and not a design tool.

4.3 Modeling Frameworks

A modeling framework goes beyond the idea of guiding principles and methods of model simplification by providing a specific set of steps that guide a modeler through the development of a conceptual model. There have been some attempts to provide such frameworks going back to Shannon (1975) who describes four steps: specification of the model's purpose; specification of the model's components; specification of the parameters and variables associated with the components; and specification of the relationships between the components, parameters and variables.

Both Nance and Pace have devised frameworks which relate primarily to the development of large scale models in the military domain. Nance (1994) outlines the conical methodology. This is an object oriented, hierarchical specification language which develops the model definition (scope) top-down and the model specification (level of detail) bottom-up. A series of modeling steps are outlined. Balci and Nance (1985) focus specifically on a procedure for problem formulation. Meanwhile, Nance and Arthur (2006) identify the potential to adopt software requirements engineering (SRE) approaches for simulation model development. They also note that there is little evidence of SRE actually being adopted by simulation modelers.

Pace (1999a 2000) explores a four stage approach to conceptual model development, similar to that of Shannon: collect authoritative information on the problem domain; identify entities and processes that need to be represented; identify simulation elements; and identify relationships between the simulation elements. He also identifies six criteria for determining which elements to include in the conceptual model.

Outside the domain of military models there is quite limited work on conceptual modeling frameworks. Brooks and Tobias (1996b) briefly propose a framework for conceptual modeling, but go no further in expanding upon the idea. Recent papers by Guru and Savory (2004) and van der Zee and van der Vorst (2005) propose conceptual modeling frameworks in some more detail. Guru and Savory propose a set of modeling templates (tables) useful for modeling physical security systems. Meanwhile, van der Zee and van der Vorst propose a framework for supply chain simulation. Both are aimed at an object oriented implementation of the computer based simulation model. Robinson (2004) describes a framework based around a set of tables that guides a modeler through setting objectives, identifying model inputs and outputs, and determining the scope and level of detail of a model. Meanwhile, Kotiadis (2006) looks to the ideas of Soft Operational Research, and specifically Soft Systems Methodology (Checkland 1981), for aiding the conceptual modeling process.

These frameworks provide some guidance to the modeler. Although there have been developments in the domain of military simulation modeling, especially with the recent work of Pace and others, outside of this area there has been only limited work. It would seem that there is much scope for developing more discipline in the field, and so to release a greater level of creativity.

5 CONCEPTUAL MODEL REPRESENTATION AND COMMUNICATION

Conceptual modeling not only requires that the modeler devises an appropriate model, but that all parties involved in a simulation study understand and buy-in to that model. Without this, the credibility of the model would be significantly compromised and with it the chances of a successful outcome to the simulation study. As such, it is important that the conceptual model is represented and communicated in a manner that is understandable to all. In the terms of Nance (1994), this requires the expression of the modeler's mental conceptual model as a communicative model.

A range of methods have been proposed for representing and communicating simulation conceptual models, for instance: process flow diagrams (Robinson 2004), activity cycle diagrams (Hills 1971), petri nets, event graphs, UML,object models (van der Zee 2006), simulation activity diagrams (Ryan and Heavey 2006), and tables describing the model rationale and content (Robinson 2004). Pooley (1991) provides a useful, but now slightly out-of-date, review of diagramming techniques that might support simulation modeling.

An alternative to these methods is to use the visual display facilities of a simulation software package. This would not require detailed coding of the model, but a basic outline of the components of the model and some of the detail associated with them.

Within the field of discrete-event simulation it is apparent that there is no agreed way of describing simulation models. This is somewhat different to the case in system dynamics modeling where models are either represented using causal loop diagrams, or stock and flow diagrams (Sterman 2000). This has the advantage of providing a common and well understood framework for describing and discussing models.

6 CONCEPTUAL MODEL VALIDATION

The need for conceptual model validation is well documented (e.g., Sargent 2004; Robinson 2004). This entails checking that the conceptual model is sufficiently accurate for its intended purpose. The difficulty lies in defining methods for performing this validation. Because the conceptual model merely describes a proposed model structure, methods that compare outputs to the real world or expectations cannot be utilized.

Robinson (2004) discusses the use of a conceptual model description (project specification) as a means for debating the probable validity of a model. Sargent (2004) suggests that the statistical assumptions underlying the proposed model are tested and that face validation techniques are used. Balci and Nance (1985) provide a detailed questionnaire for evaluating the formulated problem; a subset of the conceptual model.

Pace (1999a) discusses the conceptual validation process for military simulation models. He sees the purpose of such validation as twofold: to increase the correctness of the simulation and to increase the model's credibility. He goes on to describe a six stage review process and the reports that need to be provided to support the review. Pace (1999b) also discusses the involvement of subject matter experts in the review process.

It seems that the base requirement for conceptual model validation is a well documented model (section 5). It is also useful to have a set of evaluation criteria, such as those discussed in section 3. Both of these also provide a basis for independent validation of the conceptual model and for continuing model reviews, such as those required to determine if a model could be reused.

7 TEACHING CONCEPTUAL MODELING

Wang and Brooks (2006) provide some empirical evidence to show how novice modelers, in this case students, put little effort into conceptual modeling at the expense of the time spent on model realization. Experts, meanwhile, place a lot more emphasis on getting the right model structure. As would be suspected, there is a gap between the conceptual modeling skills of a novice modeler and those of an expert. This leads to the question of how these skills can be taught. It is not only important that conceptual modeling is better understood, but that the effectiveness of new modelers can be improved. It is difficult, however, to teach modeling skills.

In one of the few papers on teaching modeling, Morris (1967) discusses the art of modeling and some specific hypotheses and steps for helping individuals acquire modeling skills. Powell (1995) discusses six modeling heuristics (rules of thumb used by expert modelers) and how they might be used to teach modeling skills.

Outside of these works there seems to be very little discussion on how modeling skills might be taught. This is probably more a result of the lack of understanding of conceptual modeling than a lack of need for teaching methods.

8 OTHER ISSUES IN CONCEPTUAL MODELING

Apart from the issues discussed above, a range of other issues in conceptual modeling may be seen as important.

These cover areas such as: enhancing creativity in modeling, rapid prototyping for model development, group model building and facilitation, iterative development of the conceptual model throughout the lifecycle of a simulation project, and the role of data in conceptual modeling. All of these present challenges for research.

9 SUMMARY OF RESEARCH REQUIREMENTS

The discussion above identifies a set of issues that need to be addressed in order to develop the field of conceptual modeling for simulation (and modeling more generally). These issues include:

- Developing consensus over the definition of a conceptual model/conceptual modeling.
- Identifying the requirements for a conceptual model.
- Development of methods for designing conceptual models including modeling principles, methods of simplification and modeling frameworks.
- Moving towards standard methods for representing and communicating a conceptual model.
- Developing procedures for validation of a conceptual model.
- Investigating effective means for teaching the art of conceptual modeling.

It is believed that these issues should form the basis for a research agenda in conceptual modeling for simulation.

10 MOVING THE FIELD FORWARD

In order to move the field forward it would seem useful to have a concerted effort with a research community working on these issues in a coordinated fashion. This has been lacking in the past four decades, with the possible exception of the more recent work in the military domain through the Summer and Fall Simulation Interoperability Workshops. Such a research community needs to identify and work on specific projects, meet to discuss ideas and findings, and report these to the wider simulation and modeling community.

Following a successful stream at the United Kingdom Operational Research Society Simulation Workshop (SW06) in March 2006, a group of researchers interested in the field of conceptual modeling met to discuss the state of the field and future directions. Those present were (in alphabetic order): Sean Arthur (Virginia Tech), Roger Brooks (University of Lancaster), Kathy Kotiadis (University of Kent), Cathal Heavey (University of Limerick), Richard Nance (Orca Computer), Stewart Robinson (University of Warwick), John Ryan (University Dublin Institute), Durk-Jouke van der Zee (University of Groningen) and Wang Wang (University of Lancaster). Papers from the conference stream can be found at <www.conceptualmodeling.info>.

The discussions that followed identified two key domains in conceptual modeling (which might also be termed the "pre-coding phase"): the problem/objective domain and the model domain. In the domain of the problem/objective the aims of conceptual modeling are to specify the problem, identify important issues, understand the boundaries of the system under study, develop a consensus (or accommodation) over the problem, acquire knowledge and agree the objectives for modeling. In the model domain the aims are to agree on the model, determine an appropriate level of simplification/abstraction, communicate the model, validate the model and identify data requirements.

Having identified these underlying aims, the group went on to discuss specific areas and ideas for research. Among the areas of study identified, were:

- Use of subject matter experts
- Organizing and structuring knowledge
- Adoption of "soft" OR approaches (Rosenhead and Mingers 2001)
- Dimensions for determining the performance of a conceptual model
- Studying experts to understand what they do
- Identifying, adapting and developing modeling frameworks
- Model simplification methods
- Model representation methods
- Use of software engineering techniques
- Including conceptual modeling in educational and industrial simulation courses

Following this preliminary scoping discussion, the group aims to continue collaboration, meeting and publishing. The hope is to be able to work on specific projects in some of the areas outlined above and to report on progress. In so doing, a community of researchers in conceptual modeling should emerge. Obviously, any others with a specific interest in conceptual modeling are welcome to join this group. This can be done by contacting the author or any other of the members.

Overall it is believed that research in conceptual modeling can provide benefits both to novice and expert simulation modelers. Novice modelers could obtain substantial benefits from obtaining modeling skills more rapidly, thus averting some modeling failures. Experts would gain from having a more formal process for guiding their modeling, relying less on hopeful intuition and more on guided practice.

ACKNOWLEDGMENTS

This paper is based on Robinson, S. 2006. Issues in Conceptual Modelling: Setting a Research Agenda. *Proceedings of the Third Operational Research Society Simulation Workshop (SW06).* The Operational Research Society, Birmingham, UK, 165-174.

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