

## ISSUES IN CONCEPTUAL MODELLING FOR SIMULATION: SETTING A RESEARCH AGENDA

*Professor Stewart Robinson*  
Warwick Business School  
University of Warwick  
Coventry, CV4 7AL  
UNITED KINGDOM  
stewart.robinson@warwick.ac.uk

### ABSTRACT:

*Conceptual modelling is one of the most vital aspects of a simulation study, but at the same time it is probably the least understood. Based on a review of the literature a range of issues in conceptual modelling are discussed. These issues include: 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 modelling. It is apparent that there is a need for further developments in all of these areas. As such, the issues provide a basis for a research agenda in conceptual modelling for simulation.*

Keywords: Conceptual Modelling, Simulation

### 1. INTRODUCTION

Conceptual modelling is the abstraction of a model from a real or proposed system. This process of abstraction involves some level of simplification of reality [1]. Effective conceptual modelling requires that the abstraction is an appropriate simplification [2].

Put in these terms, conceptual modelling 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 modelling is vital, it is also the most difficult and least understood stage in the modelling process [3]. 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 modelling. There are, however, very few papers that give any space to the subject of conceptual modelling.

This paper aims to outline the key issues in conceptual modelling 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 modelling 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 modelling
- Other issues in conceptual modelling

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 modeller and thrown away at the end of the simulation study [4].

### 2. DEFINITION OF CONCEPTUAL MODEL(LING)

The notion of conceptual modelling 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 modelled and how. Balci [5] breaks the early parts of a simulation study down into a number of processes: problem formulation, investigation of solution techniques, system investigation, model formulation, model representation and programming. Which of these is specifically included in conceptual modelling 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 modelling is not a one-off process, but one that is repeated and refined a number of times during a simulation study.

Zeigler [1] sheds some light on the subject by identifying five elements in modelling 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 behaviours. The base model is a hypothetical complete explanation of the real system, which is capable of producing all possible input-output behaviours (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 behaviours 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 [6] separates the ideas of conceptual model and communicative model. The conceptual model exists in the mind of a modeller, 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 [7]

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 modelling is a sub-set of model design, which also includes the design of the model code.

Robinson [8] 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 modelling and its definition has been held among military simulation modellers. Pace has led the way in this debate and defines a conceptual model as 'a simulation developer's way of translating modelling requirements ... into a detailed design framework ..., from which the software that will make up the simulation can be built' [9]. In short, the conceptual model defines what is to be represented and how it is to be represented in the simulation. Pace sees conceptual modelling as being quite narrow in scope viewing objectives and requirements definition as precursors to the process of conceptual modelling. The conceptual model is largely independent of software design and implementation decisions. Pace [10] identifies the information provided by a conceptual model as consisting of assumptions, algorithms, characteristics, relationships and data.

Lacy et al [11] 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 [12] points out that there is some confusion over whether the conceptual model is an artefact of the user or the designer. This may, to some extent, be clarified by adopting the two definitions above.

The approach of military simulation modellers can be quite different to that of those working in

business oriented simulation [4]. 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 [13]. Business oriented simulations tend to be smaller in scale, involve lone modellers normally using a visual interactive modelling tool [14], 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 [15]. As a result, although the definition and requirements for conceptual modelling 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 modelling and the definition of a conceptual model:

- Conceptual modelling is about moving from a problem situation, through model requirements to a definition of what is going to be modelled and how.
- Conceptual modelling is iterative and repetitive, with the model being continually revised throughout a modelling 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 [7].
- The perspective of the client and the modeller are both important in conceptual modelling.

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

### **3. CONCEPTUAL MODEL REQUIREMENTS**

The overarching requirement for effective (conceptual) models is generally agreed to be the need to develop the simplest model possible [16]. 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 [17-21]. As the complexity increases these advantages are lost.

There are those, however, that warn against taking simplicity to an extreme. Pritsker [22] 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 [23] make a similar point, stating that simpler models are not always as easy to understand, code and debug. Davies et al [24] 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 [25], Ören [26, 27], Robinson and Pidd [28] and Balci [29]. 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 [30], 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 [31] identify eleven performance criteria for a good model. Robinson [8] identifies four requirements of a conceptual model: validity, credibility, utility and feasibility. Requirements are also briefly discussed by Pritsker [22], Henriksen [32], Nance [6], and van der Zee and van der Vorst [33].

Outside of operational research there are some discussions, for instance, Teeuw and van den Berg [34] who discuss the quality of conceptual models for business process reengineering.

Table 1 summarises these lists of requirements. It is clear that there is some level of agreement over the requirements, for instance, validity and ease of modification. But it is also clear that there are differences, for example, completeness, transparency and maintainability.

### **4. HOW TO DEVELOP CONCEPTUAL MODELS**

The overarching requirement to develop simple models highlights an important consideration in designing a conceptual model. Modelling requirements provide a guide as to whether a conceptual model is appropriate.

**Table 1** Documented Requirements for Conceptual Models

Pritsker [22]	Henriksen [32]	Nance [6]	Willemain [30]	Brooks and Tobias [31]	Robinson [8]	van der Zee and van der Vorst [33]
Valid Understandable Extendible Timely	Fidelity Execution speed Ease of modification Elegance	Model correctness Testability Adaptability Reusability Maintainability	Validity Aptness for problem Value to client Usability Feasibility	Model describes behaviour of interest Accuracy of the model's results Ease of understanding Portability and ease with which model can be combined with others Probability of containing errors Validity Strength of theoretical basis of model Time and cost to build model Time and cost to run model Time and cost to analyse results Hardware requirements	Validity Credibility Utility Feasibility	Completeness Transparency

Neither, however, describes how a modeller might go about determining what the conceptual model should be in a simulation study. So what help is offered in the simulation and modelling literature to guide modellers in designing the conceptual model?

First, it is worth recognising that conceptual modelling requires creativity [35]. Simulation modelling is both art and science [36] with conceptual modelling lying more at the artistic end! As Schmeiser [37] 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 [38]. Ferguson et al [39], 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 modellers and operational researchers on how to develop models, three basic approaches can be found: principles of modelling, methods of simplification and modelling frameworks.

#### 4.1 PRINCIPLES OF MODELLING

Providing a set of guiding principles for modelling is one approach to advising simulation modellers on how to develop (conceptual) models. For instance, Pidd [40] describes six principles of modelling:

- 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
- Modelling 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 [41], Musselman [42], Powell [43], Pritsker [44] and Law and Kelton [45]. The specific idea of evolutionary model development is further explored by Nydick et al [46].

These principles provide some useful guidelines for those developing conceptual models. It is useful to encourage modellers to start with small models and to gradually add scope and detail. What such principles do not do, however, is guide a modeller through the conceptual modelling 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 [1] 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 modelling context. Morris [41] identifies some methods for simplifying models: making variables into constants, eliminating variables, using linear relations, strengthening the assumptions and restrictions, and reducing randomness. Ward [18] provides a similar list of ideas for simplification. Meanwhile, Courtois [47] identifies criteria for the successful decomposition of models in engineering and science.

For simulation modelling, Zeigler [1] 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 [48] build upon these ideas, discussing six simplification techniques and presenting a case study. Sevinc [49] provides a semiautomatic procedure based on Zeigler's ideas. Innis and Rextad [17] 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 [16] also lists some methods for simplifying simulation models. Finally, Webster et al [50] describe how they selected an appropriate level of detail for generating samples in a timber harvesting simulation model.

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

### **4.3 MODELLING FRAMEWORKS**

A modelling framework goes beyond the idea of guiding principles and methods of model simplification by providing a specific set of steps that guide a modeller through the development of a conceptual model. There have been some attempts to provide such frameworks going back to Shannon [36] 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 [6] 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 modelling steps are outlined. Balci and Nance [51] focus specifically on a procedure for problem formulation. Meanwhile, Pace [9, 10] 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 modelling frameworks. Brooks and Tobias [52] briefly propose a framework for conceptual modelling, but go no further in expanding upon the idea. Recent papers by Guru and Savory [53] and van der Zee and van der Vorst [33] propose conceptual modelling frameworks in some more detail. Guru and Savory propose a set of modelling templates (tables) useful for modelling 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 [8] describes a framework based around a set of tables that guides a modeller through setting objectives, identifying model inputs and outputs, and determining the scope and level of detail of a model.

These frameworks provide some guidance to the modeller. Although there have been developments in the domain of military simulation modelling, 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 modelling not only requires that the modeller 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 [6], this requires the expression of the modeller's mental conceptual model as a communicative model.

A range of methods have been used for representing and communicating simulation conceptual models, for instance:

- Process flow diagrams [8]
- Activity cycle diagrams [54]
- Petri nets [55]
- Event graphs [56, 57]
- UML (the unified modelling language) [58]
- Tables describing the model rationale and content [8]

Pooley [59] provides a useful, but now slightly out-of-date, review of diagramming techniques that might support simulation modelling.

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 modelling where models are either represented using causal loop diagrams, or stock and flow diagrams [60]. 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. 61, 8]. 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 utilised.

Robinson [8] discusses the use of a conceptual model description (project specification) as a means for debating the probable validity of a

model. Sargent [61] suggests that the statistical assumptions underlying the proposed model are tested and that face validation techniques are used. Balci and Nance [51] provide a detailed questionnaire for evaluating the formulated problem; a subset of the conceptual model.

Pace [9] 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
- 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 [62] 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 MODELLING

How can (conceptual) modelling skills be taught? It is not only important that conceptual modelling is better understood, but that the effectiveness of new modellers can be improved. It is difficult, however, to teach modelling skills.

In one of the few papers on teaching modelling, Morris [41] discusses the art of modelling and some specific hypotheses and steps for helping individuals acquire modelling skills. Powell [43] discusses six modelling heuristics (rules of thumb used by expert modellers) and how they might be used to teach modelling skills.

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

## 8. OTHER ISSUES IN CONCEPTUAL MODELLING

Apart from the issues discussed above, a range of other issues in conceptual modelling may be seen as important. These cover areas such as:

- Enhancing creativity in modelling
- Rapid prototyping for model development
- Group model building and facilitation
- Iterative development of the conceptual model throughout the lifecycle of a simulation project
- The role of data in conceptual modelling

All of these present challenges for research.

## 9. CONCLUSION: A RESEARCH AGENDA?

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

- Developing consensus over the definition of a conceptual model/conceptual modelling.
- Identifying the requirements for a conceptual model.
- Development of methods for designing conceptual models including modelling principles, methods of simplification and modelling 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 modelling.

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

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 modelling community.

Such work could provide benefits both to novice and expert simulation modellers. Novice modellers could obtain substantial benefits from obtaining modelling skills more rapidly, thus averting some modelling failures. Experts will gain from having a more formal process for

guiding their modelling, relying less on hopeful intuition and more on guided practice.

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## AUTHOR BIOGRAPHY

**STEWART ROBINSON** is Professor of Operational Research at Warwick Business School. He holds a BSc and PhD in Management Science from Lancaster University. Previously employed in simulation consultancy, he supported the use of simulation in companies throughout Europe and the rest of the world. He is author/co-author of three books on simulation. His research focuses on the practice of simulation model development and use. Key areas of interest are conceptual modelling, model validation and output analysis. Stewart is also managing a project to investigate the use of artificial intelligence for representing human decision-making in simulation models. Home page [www.btinternet.com/~stewart.robinson1/SR.HTM](http://www.btinternet.com/~stewart.robinson1/SR.HTM)