

## ON SIMULATION MODEL COMPLEXITY

Leonardo Chwif  
Marcos Ribeiro Pereira Barretto

Mechatronics Lab  
University of São Paulo  
Av. Prof. Mello Moraes 2231  
Sao Paulo, 05508-900, Brazil

Ray J. Paul

Centre for Applied Simulation Modelling  
Department of Information Systems and Computing  
Brunel University  
Uxbridge, Middlesex, UB8 3PH, U.K.

### ABSTRACT

Nowadays the size and complexity of models is growing more and more, forcing modelers to face some problems that they were not accustomed to. Before trying to study ways to deal with complex models, a more important and primary question to explore is, is there any means to avoid the generation of complex models? The primary purpose of this paper is to discuss several issues regarding the complexity of simulation models, summarizing the findings in this area so far, and calling attention to this area that, despite its importance, appears to remain at the bottom of simulation research agendas.

### 1 INTRODUCTION

There is a consensus amongst the simulation community that a simple model is mostly preferable to a complex one. In fact, “Model Simple - Think Complicated”, is one of Pidd’s (Pidd 1996) “Five Principles of Simulation Modelling”. Several other authors have reinforced this point of view through time (Ward (1989); Yin and Zhou (1989); Innis and Rexstad (1983); Law et. al (1993); Musselman (1993); Robinson (1994); Pedgren, Shannon and Sadowski (1995)). Salt (1993) asserts that “simplification is the essence of simulation” and Pidd (1996) is conclusive in his declaration: “complicated models have no divine right of acceptance”.

Despite this, for several reasons that we are going to discuss further, a proliferation of complex and large models has taken place, forcing modelers to face problems that they were not accustomed to (e.g. how to express, validate, solve and understand the results of complex models). These problems were called by Nicol (Page et al. 1999) “Problems of Scale”, and he indicated that they should be part of the roadmap of simulation research.

This paper’s primary intention is to contribute to a necessary discussion about complex simulation models. According to Brooks and Tobias (1999) the scarcity of

research into simplification in simulation is surprising, despite the importance of the subject. This still is a “green field” of simulation research and much has to be done.

This concern could be seen by some people as a historical worry since “nowadays we have computational power to deal with huge and complex simulation models”. This may be true, but complex models not only have an impact on computer performance, but also on all aspects of simulation modeling, such as managing a simulation project, communication time and resource constraints, etc.

The discussion in this paper is organized as follows. In section 2 we examine definitions of a complex model and measures of complexity. Section 3 tries to pinpoint some possible reasons for the increasing number of complex simulation models. In Section 4, we show several relationships between some properties of the model, simulation software and modelers (such as validity, computational performance, animation capabilities, modeler expertise, etc) to model complexity. Based on this, in section 5 we present the advantages and disadvantages of a simple model. In section 6 we show how we can try to better deal with complexity. Finally, section 7 makes a brief summary and draws conclusions.

### 2 COMPLEXITY OF SIMULATION MODELS

Although complexity is in some sense an intuitive concept, there is no general definition or single accepted definition of complexity when applied to a model (Brook and Tobias 1996). Some definitions (Golay, Seong and Manno 1989) relate model complexity with the cognitive aspect, i.e. the difficulty of understanding the system being modeled. Others (Simon 1964) associates the complexity of a system with the number of parts and elements that it contains. Using the same line of thinking Ward (1989) defines model simplicity with regard to the concepts of “transparency” (related to understanding) and “constructive simplicity” (related to the model itself). Here we focus on the

constructive complexity aspect of the model, although some aspects of “transparency” will also be discussed.

Very often the complexity of a simulation model is confounded with “level of detail” (Webster et al. 1984). In fact “level of detail” is one of complexity’s components whereas “scope” is another. As an example, consider when simulating manufacturing systems, then either the entire facility or just one work-center can be modeled. “Scope” is reduced in the latter case when compared to the former. On the other hand, the work-center could be modeled with an associated processing time or processing times, breakdowns, shift patterns, material handling equipment, etc. In this case the “level of detail” is much higher although the scope remains the same (the same work-center). The reader should refer to Robinson (1994) for a detailed discussion on “Scope” and “Level”.

Complexity measures were defined in order to objectively quantify the complexity of a simulation model. Wallace (1987) defined a metric called CAT, which measures the complexity of a simulation model represented using Condition Specification [see Overstreet and Nance (1985) for details]. Yucesan and Schruben (1998) proposed metrics based on Event Graphs representations; one of them following McCabe’s (1976) work on the complexity within software engineering.

All these measures share common issues. First, they are associated with a specific model representation technique i.e. the simulation model should be described in the given technique in order to be able to measure the complexity. Second, none of them covers all aspects of complexity in a model. Finally, there are no standard measures widely accepted.

This clearly leaves room for discussion and research to better define model complexity and the components of complexity.

### 3 REASONS FOR INCREASING COMPLEXITY

Complex and large models are growing at a significant rate (Arthur et al. 1999). This goes against what the general simulation community preaches. In the following, we enumerate some reasons for this fact, dividing them into technical and non-technical. Non-technical reasons are related to human nature and we can cite:

1. **“Show off” factor:** A complex model when shown to managers has more impact than a simpler one, even if they both could perform the same job. Furthermore since it is more complex it has a connotation that it was more difficult to build, valorizing in some sense the modeler’s job. Besides this, the great focus on animation features could lead to a complex model due to the

incorporation of more objects and elements (we will discuss this matter in the next section).

2. **“Include all” Syndrome:** it attacks more inexperienced modelers. Since they feel “insecure” about what to include in the simulation model, they follow the maxim “It is better the excess than the lack” having the tendency to include everything that is possible in the model.
3. **“Possibility” factor:** Because of increasing computation power (approximately the speed of CPU and memory size doubles its capacity every 18 months, according to the old but still in effect Moore’s law), complexity and size is not a constraint on building a simulation model anymore. So some people, as amazing as it may seem, can create complex models, just because computer power allows it. The increase of computational power allows better model performances during the runs. It also gives birth to better software tools. Paradoxically it is also one factor that is affecting the growing of complex models.

Among technical factors we outline:

1. **Lack of understanding of the real system:** The system being modeled must be very well understood by the modeller in order for him to formulate correctly the hypothesis and to consider proper levels of detail. If the system is poorly understood, the model will be a result of modeler’s misunderstandings, possibly adding complications that could be unnecessary.
2. **Inability to model correctly the problem (conceptual model):** The lack of ability to model (or abstract) correctly the problem is common. Modelers who tend to build the model “as close to reality as possible”, including practically everything seen in real world. Since modeling is an abstraction of reality, model results (not the model itself) should be close to reality, not exactly the same. Who needs the complexity of reality in the model when that complexity was what started the project?
3. **Inability to translate or code correctly the conceptual model into a computerized model or lack of the simulation software knowledge:** If the modeler is not totally acquainted with the functionality of the simulation software or he has a lack of good programming skills, he can generate the code in a very complex way. This can lead to a more complex computerized simulation model.
4. **Unclear simulation objectives:** There is unanimity among several authors [Innis and

Rexstad (1983); Yin and Zhou (1989); Salt (1993)] that this is one factor that contributes the most to the growth of complex models. Unclear or poorly defined objectives directly affects complexity “scope” component of a given model. As Salt (1993) points out: “Where the overall aim (of the simulation model) is poorly defined, the anxious simulationist may draw the bounds of the model too wide, in the hope of including whatever it is that the user is really interested in”.

Another point related to the last item is the fact that we are usually tempted to focus on the system itself instead of having always in mind the objectives of the system. In order to try to reinforce this fact, we conducted an experiment involving 17 people with various knowledge of simulation modeling, from very little knowledge (less than 1 year) to experienced (more than 5 years). We distributed questionnaires containing a written description of a problem. Then the respondent was asked to draw a communicative model in an ACD (Activity Cycle Diagram) from the description. The problem consists basically of three machines in serial with infinite buffers between them. The objective of this model is to determine the utilization of machine two (the machine in the middle). All the people involved in this test (including beginners, intermediate and expert modelers) included all the three machines. Since this model has no constraint on buffer size, it could be modeled with only the first two machines, because the behavior of machine three does not affect machine two. Although this example is very simple and the number of persons involved did not allow us to reach a conclusive response in statistical terms, it reinforces our hypothesis that modelers have a tendency to focus on the “system structure” instead of on the “simulation objectives”.

#### 4 RELATIONSHIPS OF COMPLEXITY

In this section we discuss briefly some of the relationships of complex models with regard to several aspects within the M&S area (Modeling and Simulation). These will help us to draw conclusions about the advantages and disadvantages of a simple model (section 5) and raise some discussions about model complexity.

##### 4.1 Complex Models and Expert Modelers

As we saw in section 3, inexperienced modelers have a tendency to develop more complex models than expert modelers mostly due to the “Include all Syndrome”. It has been shown (Willemain 1994, Willemain 1995) that expert modelers tend to concentrate their modeling efforts mostly at the conceptual phase of modeling, and this should be a

plausible reason that their models are better “polished” and thus simpler.

##### 4.2 Complex Models and Model Validity

It seems there is no conclusive answer about this relationship reported in literature. According to Zeigler (1984), a more complex model can apparently represent reality better, although we have to agree with Salt’s (1993) point of view that it is possible to create a complex and fully detailed model that is completely imprecise. According to Lobão and Porto (1997) the relationship between “level of detail” (which is a component of complexity) and model confidence (which is directly related to validity) follows a tendency shown in figure 1. Nevertheless, all of these statements are hypothesis based on “experience” and “good sense” on how validity is related to complexity, because no extensive experiments have been reported. There is a possibility to explore this relationship further, since it receives so little attention in the literature.

##### 4.3 Complex Models and Computer Performance

Even though there are no conclusive studies, this relationship is quite obvious: computer performance decreases as model complexity increases. However, the shape of this relationship (linear, polynomial, exponential, etc) is unknown, as are those components of complexity that mostly affect computer performance (Brooks and Tobias 1996). We did some experiments (reported in Chwif, Barretto and Santoro 1998) in which a simplified version of a given model (yielding the statistically equivalent results) ran 8 times faster.

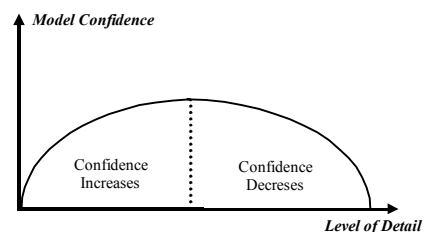


Figure 1: Relationship Between “Level of Details” and “Model Confidence” (Lobão and Porto 1997).

##### 4.4 Complex Models and Simulation Study Total Time

It is intuitive that a simple model is easier to code, validate and analyze. Thus in general complexity will increase the time to perform a simulation study (including conceptualization, implementation and analysis). In another experience reported in Chwif, Barretto and Santoro (1998), we created two models: a complex and a simple model of the same system. A reduction of more than 50%

of the total simulation study time was found (39 hours to 17 hours). This kind of reduction could be achieved when the model is “born” simple, but if we think about a model that we attempt to simplify later, since a great effort could be spent on this process (Rextad and Innis 1985), this result would not hold.

#### 4.5 Complex Models and Graphical Animation

Despite the importance of animation and visualization on model understanding, a model could have its complexity increased if it is “driven” for animation. Hence a series of elements and building blocks have to be put in the model for “easing understanding” and “closing the model to reality”. For instance, one transport process could be modeled simply by assigning a timed distribution to it with practically no animation, or a complete path of a forklift truck has to be built in order to show the forklift truck movement.

### 5 ADVANTAGES/DISADVANTAGES OF SIMPLER MODELS

Robinson (1994) reported two real cases of simulation modeling which made him conclude that “small is beautiful”. In fact, based on our previous discussions, we can enumerate some of the advantages of a simpler model:

1. It is easier to implement, validate and analyze. Salt (1993) also pointed out that it is much easier to “throw away” a simpler model if it is wrong or not reliable, because “it is much harder to admit the failure of a million dollar systems than a thousand dollar one”.
2. It is easier to “change” a simpler model than a complex one if the conditions and hypothesis of the systems change (as they usually do!).
3. The time to complete a simulation study could be reduced with a simpler model. In fact according to Pedgren, Shannon and Sadowski (1995), it is infinitely better to have results (even approximate) of a simpler model before the deadline of the simulation study than to have the results of a highly complex model after the deadline.

Simple models, however, are not always the best choice. Below we summarize a list of problems of simple models:

1. **Problems of Validity:** Paraphrasing Einstein: A model must be as simple as possible, but not simpler. It must be complicated if necessary, but not so much. So an over simplified model could lead to a validity loss. Unfortunately there is no

method for determining the best complexity level of a given model that still maintains its validity.

2. **Problems of Scope Reduction:** In some cases a simpler model could be achieved by reducing its scope. For example in an AGV system, a model that can deal with up to five AGVs could be simplified to deal with only two. In Zeigler’s Terminology this means to reduce the “Experimental Frame” of a model (Zeigler 1976). This could be translated also into less flexibility of the simpler model.
3. **Difficulties in understanding:** In some case a very simple model could be achieved by applying one great human ability: abstraction. This is great for the modeler because he understands his model by knowing exactly what kind of abstractions he made. Then when he shows it to another person, the model could be considered totally “unintelligible” and it then becomes necessary to decrease the level of abstraction of the model (to ease the peoples’ part understanding). So a simpler model is not always easy to understand.

The complexity of a simulation model has two sides. In the next section we present some “rules” of thumb to try to cope with complexity.

### 6 HOW TO TACKLE COMPLEXITY

This section provides some rules of thumb based on the literature and our own experience.

1. **Keep it Simple:** Always try to pursue the simpler model for your purposes (having also in mind the problems described in the previous section). Remember: if the model is born simple, there will be gains throughout all the simulation study. In the literature we found some possible guidelines to make a model simpler (Yi and Zhou 1989, Innis and Rextad 1983, Robinson 1994, Pedgren, Shannon e Sadowski 1995, Frantz 1995).
2. **Add complexity later:** If you are in doubt of including some element or factor in a model, do the following: do not include it; assume the hypothesis it will not affect model results. Then only after you validate, analyze and have the results, include this if you feel it is really necessary. Always ask the question: Is this strictly necessary? Instead of using “It is better the excess than the lack” try this “It is worthier the necessary minimum than the possible maximum”. This complies with Pidd’s (Pidd 1996) second principle of modeling which is “be parsimonious, start small and add”.

3. **The complex model was already built. Is there any means to simplify it?** Unfortunately, once a complex model is created, the efforts to simplify it could be unworthy. Moreover there is a lack of simplification procedures related to simulation models reported in the literature. Chwif, 1999 developed an automated method that tries to simplify an existing model based on its objectives. Although his algorithm reached in some case reductions in complexity of almost 50%, the simulation model has to be described using a specific simulation model representation technique.
4. **“Reduce” the Level of Detail using Hierarchy:** Hierarchy is considered one method of model abstraction (Luna 1993) and thus can “simplify” the simulation model. The use of hierarchical modeling can be crucial for the manageability of complex models (Daum and Sargent 1999). Since hierarchy sometimes could not simplify a model in terms of “constructive simplicity”, we use the words “Reduce” and “Simplify” in quotation marks. That is because the number of elements in a model that is hierarchically constructed could be the same as in a “flat” model, with the difference that some of them are “hidden” by the hierarchy. A simplification could be achieved if it is possible to aggregate some portions of the model (e.g. a set of machines becomes one “big” machine).
5. **Reduce the Scope of the Model:** Another possibility to try to obtain a simpler model (or many, various simpler models) is to attack the scope component of complexity. In this case, divide your system into parts and model each part separately creating a series of simpler models instead of one “huge” model. Once these parts pass through all phases of the simulation study and if and only if there is a need, integrate these models into a bigger one. Another possibility is to reduce the scope of a model for analyzing a more specific and urgent question. But remember this coarsening in scope can lead to less flexibility of the model.

## 7 SUMMARY AND CONCLUSIONS

Based on our discussions the most important issues on simulation model complexity are the following:

1. The simulation community is pro to the simplicity of simulation models.
2. There is no widely accepted definition of what a complex model is. There is also no general complexity measure of a given simulation model.

3. There is a substantial increase in the complexity in our current simulation models. One factor that surely contributes to this is the development of powerful computer hardware.
4. Several relationships that involve complexity are not explored in detail in the literature.
5. Despite some very good “guidelines” there is a lack of methodologies to lead a modeler to obtain a simpler model.

Since complexity will be a constant in our simulation models, Nicol (Page et al. 1999) mentions one possible future line of research which would try to answer the question “How can we deal with complex and huge simulation models?” On the other hand we have to keep in mind that there are a number of advantages if we were able to obtain a simpler model. Therefore the real question might be “How can we avoid the generation of complex models?”

## ACKNOWLEDGMENTS

The authors would like to thank the Department of Information Systems and Computing, Brunel University, who provided the resources necessary for part of this research, whilst Leonardo Chwif was a Research Visitor. Thanks also to the Brazilian’s Research Funding Agencies CAPES who supported partially this research (under reference no. 0439/98-8) and FAPESP.

## REFERENCES

- Arthur J. D. et al. 1999. Verification and validation: what impact should project size and complexity have on attendant V&V activities and supporting infrastructure? In *Proceedings of the 1999 Winter Simulation Conference*, ed., P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 148 - 155. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Brooks, R. J. and Tobias, A. M. 1996. Choosing the best model: level of detail, complexity and model performance, *Mathl. Comput. Modelling*, 24(4):1-14.
- Brooks, R. J. and Tobias, A. M. 1999. Methods and benefits of simplification in simulation, In: *Proceedings of UKSIM*, United Kingdom Simulation Society, 88-92.
- Chwif, L. 1999. Discrete event simulation model reduction in its conceptualization: a causal approach. Ph.D. Thesis (Portuguese), Department of Mechatronics Engineering, University of São Paulo.
- Chwif, L., Barretto M.R. and Santoro, M. C. 1998. Model Reduction Some Results, In: *Proceedings of the 31<sup>st</sup> Annual Simulation Symposium*, 120-125. IEEE Comput. Society, Los Alamitos, CA, USA.

- Daum, T and Sargent, R.G. 1999. Scaling, hierarchical modeling, and reuse in an object-oriented modeling and simulation system, In *Proceedings of the 1999 Winter Simulation Conference*, ed., P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 1509-1520. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Frantz, F. K. 1995. A taxonomy of model abstraction techniques, In: *Proceedings of the 1995 Winter Simulation Conference*, ed. C. Alexopoulos, K. Kang, W. R. Lilegdon, and D. Goldsman, 1413-1420. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Golay, M. P., Seong, P.H. and Manno, V.P. 1989. A measure of the difficulty of systems diagnosis and its relationship to complexity, *International Journal of General Systems*, 16(1): 1-23.
- Innis, G. and Rextad, E. 1983. Simulation model simplification, *Simulation*, 41(1): 7-15, July.
- Law, A.M., et al. 1993 A forum on crucial issues in the simulation of manufacturing systems, In *Proceedings of the 1993 Winter Simulation Conference* ed. G. W. Evans, M. Mollaghasemi, E. C. Russell, and W. E. Biles, 916-922. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Lobão, E.C. and Porto, A.J.V. 1997. A simulation study systematization. (Portuguese) In: *Proceedings of the XVII ENEGEP – NATIONAL CONGRESS OF INDUSTRIAL ENGINEERING*, Gramado, Rio Grande do Sul, Brazil.
- Luna, J. J. 1993. Hierarchical Relations in simulation models. In: *Proceedings of the 1993 Winter Simulation Conference*, ed. G. W. Evans, M. Mollaghasemi, E. C. Russell, and W. E. Biles, 132-137. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Mc Cabe, T.J. 1976. A Complexity Measure, *IEEE Transactions on Software Engineering*, 2(4): 308-320.
- Musselman, K.J. 1993. Guidelines for simulation project success. In *Proceedings of 1993 Winter Simulation Conference*, ed. G. W. Evans, M. Mollaghasemi, E. C. Russell, and W. E. Biles, p.58 – 64. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Overstreet, C.M. and Nance, R.E. 1985. A specification language to assist in analysis of discrete event simulation models, *Communications of the ACM*, 28(2):190-201, February.
- Page, E. H. et al. 1999. Panel: strategic directions in simulation research, In *Proceedings of the 1999 Winter Simulation Conference*, ed., P. A. Farrington, H. B. Nembhard, D. T. Sturrock, and G. W. Evans, 1509-1520. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Pegden, C.D., R.E. Shannon and R.P. Sadowski, 1995. Introduction to simulation using SIMAN, 2nd Ed., New York: McGraw-Hill.
- Pidd, M. 1996. Five simple principles of modelling, In *Proceedings of the 1996, Winter Simulation Conference*, ed. J. M. Charnes, D.M. Morrice, D. T. Brunner, and J. J. Swain, p. 721-728. Institute of Electrical and Electronics Engineers, Piscataway, N.J.
- Rextad, E. and Innis, G.S. 1985. Model simplification – three applications”, *Ecological Modelling*, 27(½): 1-13.
- Robinson, S. 1994. Successful simulation – a practical approach to simulation projects, Maidenhead, UK: McGraw-Hill.
- Salt, J. D. 1993. Keynote address: simulation should be easy and fun!, In *Proceedings of the 1993 Winter Simulation Conference*, ed. G. W. Evans, M. Mollaghasemi, E. C. Russell, and W. E. Biles, 1-5. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Simon, H.A. 1964. The architecture of complexity”, *General Systems Yearbook*, 10: 63-76.
- Wallace, J.C. 1987. The control and transformation metric: toward the measurement of simulation model complexity, In *Proceedings of the 1987 Winter Simulation Conference*, ed. A. Thesen, H. Grant, and W. D. Kelton, 597-603. Institute of Electrical and Electronics Engineers, Piscataway, New Jersey.
- Ward, S.C. 1989. Arguments for constructively simple models. *J. Opl. Res. Soc.* 40(2): 141-153.
- Webster et al., 1984. Determining the level of detail in a simulation model - A case study. *Computers and Industrial Engineering*, 8(3/4): 215-225.
- Willemain, T.R. 1994. Insights on modeling from a dozen experts. *Operations Research*, 42 (2): 213-222.
- Willemain, T.R. 1995. Model formulation: what experts think about and when. *Operations Research*, 43 (6): 916-932.
- Yin H.Y. and Zhou Z.N. 1989. Simplification techniques of simulation models, In *Proceedings of Beijing International Conference on System Simulation and Scientific Computing*, 782-783.
- Yucesan, E. and Schruben, L. 1998. Complexity of simulation models: A graph theoretic approach, *INFORMS Journal on Computing*, 10(2): 94-106.
- Zeigler, B.P. 1976. Theory of Modelling and Simulation, John Wiley and Sons, Inc., New York.
- Zeigler, B.P. 1984 Multifaceted Modelling and Discrete Event Simulation. London: Academic Press.

#### AUTHOR BIOGRAPHIES

**LEONARDO CHWIF** graduated in Mechanical Engineering (Mechatronic Specialization) in 1992 at the University of Sao Paulo and got his MSc degree in 1994 and his Ph.D. in Simulation in 1999 from the same University. He spent a session at Brunel University as a

research visitor at the Centre for Applied Simulation Modelling. Upon graduation Dr. Chwif joined the Brazilian branch of Mercedes-Benz truck manufacturer and then he joined the Brazilian branch of Whirlpool Corporation. His research interests includes simulation, optimization and simulation model representation techniques. His email is <leochwif@usp.br>.

**MARCOS RIBEIRO PEREIRA BARRETTO** graduated in Electronics Engineering in 1983. He got his MSc degree in 1988 and his Ph.D. in 1993, all from the University of Sao Paulo. He is currently Assistant Professor at the Mechanical Engineering Department of the Polytechnic School of the University of Sao Paulo. His research interests include manufacturing integration and CIM technology. His email is <mrpbarre@usp.br>.

**RAY J. PAUL** has been Professor of Simulation Modelling at Brunel University since 1992, Head of the Information Systems and Computing Department 1993-1998, and Dean of the Faculty of Science since 1999. He previously taught information systems and operational research for 21 years at the London School of Economics. He has published widely in book and paper form (three books, over 200 papers in journals, books and conference proceedings), mainly in the areas of the simulation modeling process and in software environments for simulation modeling. He has acted as a consultant for a variety of U.K. government departments, software companies, and commercial companies in the tobacco and oil industries. He is currently running a simulation research group, the Centre for Applied Simulation Modelling, made up of five faculty members and eight research students. His email and web addresses are Ray.Paul@brunel.ac.uk and <www.brunel.ac.uk/~csstrjrp>.