Simulation Foundations, Methods and Applications

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Body of Knowledge for Modeling and Simulation

A Handbook by the Society for Modeling and Simulation International

THE SOCIETY FOR
MODELING & SIMULATION
INTERNATIONAL

Simulation Foundations, Methods and Applications

The modelling and simulation community extends over a range of diverse disciplines and this landscape continues to expand at an impressive rate. Modelling and simulation is fundamentally a computational tool which has an established record of significantly enhancing the understanding of dynamic system behaviour on one hand, and the system design process on the other. Its relevance is unconstrained by discipline boundaries. Furthermore, the ever-increasing availability of computational power makes feasible applications that were previously beyond consideration.

Simulation Foundations, Methods and Applications hosts high-quality contributions that address the various facets of the modelling and simulation enterprise. These range from fundamental concepts that are strengthening the foundation of the discipline to the exploration of advances and emerging developments in the expanding landscape of application areas. The underlying intent is to facilitate and promote the sharing of creative ideas across discipline boundaries. The readership will include senior undergraduate and graduate students, modelling and simulation professionals and research workers.

Inasmuch as a model development phase is a prerequisite for any simulation study, there is an expectation that modelling issues will be appropriately addressed in each presentation. Incorporation of case studies and simulation results will be strongly encouraged.

Titles can span a variety of product types, including but not exclusively, textbooks, expository monographs, contributed volumes, research monographs, professional texts, guidebooks and other references.

These books will appeal, varyingly, to senior undergraduate and graduate students, and researchers in any of a host of disciplines where modelling and simuation has become (or is becoming) a basic problem-solving tool. Some titles will also directly appeal to modelling and simulation professionals and practitioners.

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Springer

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To the many distinguished simulationist colleagues
whom I had the chance to collaborate with since 1963
and to Füsun, my wife and my lifelong friend.

Tuncer Ören

To all our fellow participants in the modeling and simulation adventure:
may we help the world keep up more competently with the technology it keeps advancing.

Bernard P. Zeigler

To the many pioneers of modeling and simulation who paved the way to
make us a scientific discipline, and to my family—Andrea, Florian, and Christopher—who had to share me so often with my passion for these scientific endeavors.

Andreas Tolk

Preface

Any scientific Body of Knowledge is a comprehensive and concise representation of concepts, terms, and activities needed to explain a professional domain by representing the common understanding of relevant professionals and professional associations. Defining this body for Modeling and Simulation (M&S) is essential for the discipline of M&S. These concepts must include the science-philosophical foundations and implications, the understanding what models are and how their implementation in form of simulations can be used to support the many application domains, such as gaining experience for training and education, as well as experimentation for analysis, design, control, and optimization, within increasing number of computational disciplines.

But is Modeling and Simulation really a discipline? To some people, *simulation* is a very useful technique for representing a system under study to enable computational experimentation with a view to improve system performance. In this perspective, *modeling*, the representation itself, is of secondary importance—merely a necessary means to an end. For other users, simulation provides a virtual environment that allows to train people. The defense simulation community is a good example for this type of simulation use, but also the aviation community using flight simulators to educate and qualify their pilots. These users look at simulation as a powerful computational tool.

In contrast, underlying the SCS Modeling and Simulation Body of Knowledge (M&SBoK) is the assertion that there is a discipline called *Modeling* and *Simulation* (M&S). Moreover, this discipline provides visibility into the holistic nature, and the conjoint activities, of model creation and simulation experimentation. At the core of the M&S discipline is the identification of the elements manipulated by its associated activities: real system data, experimental frame, model, and simulator, as well as the relationships that must bind these components together to form a meaningful composition.

There is a huge paradigm shift from M&S as a computational tool to the M&S as discipline world view. Taking this shift, the M&S framework ontology (the four elements and their relations) effectively lays the foundation for computational experiments, clearly stating boundaries, and interactions, of systems, data, and representation. This shifts the focus from simulation to modeling, placing the model at the center, making the model the curated artifact of knowledge that must be

maintained, enhanced, and reused over time. This viewpoint allows the application of simulation in many computational sciences to help gaining new knowledge by creating numerical insight into the dynamic behavior of the modeled entities, the use of M&S as an epistemological tool.

These views are not mutually exclusive. Contrarily, they represent multiple facets of the variety how M&S is and can be used. M&S supports many disciplines, computationally as well as epistemologically. The simulation engineer must be aware of the whole picture to serve their communities best. They must understand the application domains and must be able to support the best conceptualization and capture this in a model that is implemented as a simulation. If the application domain uses IT support, the simulation engineer should be aware of interfaces that can support the data information exchange needs. The M&SBoK provides a first collection of such knowledge and surely needs to be a living document that is augmented over time.

In this initial Guide to M&SBoK, Chap. 1 sets out the concepts of the M&S framework ontology that lay the groundwork for subsequent discussion. Chapter 2 covers the core areas of M&S and provides an overall big picture portrait of this emerging discipline and how it supports other knowledge domains. Chapter 3 covers the traditional view of simulation as experimentation. Indeed, there is no other discipline that can provide powerful simulations providing numerical insight into complex dynamic systems. And yet, the epistemology of M&S is the brain power that enables these tools. Simulation is the muscle; modeling is the soul!

Chapters 4 and 5 introduce simulation as *experience*, both in the technical and entertainment arenas. Chapters 6–10 cover the internals of the M&S disciple, its mechanics, ethics, and economics, while Chaps. 11–16 concern the external relationships, how M&S is taking its place among, and increasingly central to, the recognized disciplines in science, technology, and the arts. Finally, Chaps. 17–19 review the development of M&S over time and set forth the trends, aspirations, and challenges of the future.

It is expected that the M&SBoK will grow over time. This first version is a first set of core concepts, but as the application domains of simulation grow, so will the body of knowledge. We already see growing fields that need to be addressed in more detail, such as complexity, deep uncertainty, and quantum simulation. We assume that in the next iteration, we will see how M&S can be increasingly used to address complex system, which comprises a variety of heterogenous entities, often highly interdependent and connect in nonlinear fashion. We assume to see an increasing use to address the challenge of deep uncertainty in operations research, which requires multi-model approaches and a new paradigm to conduct simulation-based optimization to understand the topology of the solution space instead of looking for point-solutions. And finally, with quantum computing becoming increasingly available, simulation engineers have to address how we use this new resource: like we developed concepts for parallel and distributed simulation we will have to address quantum computing-based simulation soon to be ready as the community of simulation engineers when the time comes.

We like to express our thanks to the Virginia Modeling, Analysis, and Simulation Center (VMASC) of Old Dominion University, Norfolk, Virginia, as they committed to provide a website hosting any errata as well as supplemental material for the M&SBoK. The website can be accessed at http://vmasc.org/partnerships/msbok.

In summary, we are convinced that we are indeed an M&S discipline. We have our professional societies, our journals, our code of ethics, and our common knowledge. We address many of these concepts, we are grateful to the many contributors to create this foundational initial version, and we are excited about the future and the new insights to come and to be integrated to witness to the growing contributions of M&S to solve the challenges of our society.

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