Introduction

In fields such as aeronautics, transport, telecommunications, banking, or defense, systems are becoming increasingly complex, containing more and more components, with significant heterogeneity and disparate lifecycles. The update process that follows the increasingly rapid obsolescence of sub-systems requires *a priori* mastery of architectures of systems of which we do not know the component configuration. Risk mitigation in the different phases of the project (from the expression of need to implementation, or even withdrawal, considering environmental protection constraints) thus becomes an essential consideration throughout the whole lifecycle of the system.

Needs have also evolved. Demands in terms of performance, interoperability, cost, security, and reliability have reached a level where each project becomes a technical and managerial challenge. It is, therefore, necessary to attain new levels of flexibility and reactivity in exploring system concepts. The changeable nature of the environment and the necessary capacity of the system to adapt to different evolutions contribute to its complexity. Moreover, the generalization of information and communication technologies pushes towards the interconnection of systems, leading to *systems of systems*, reinforced by the context of globalization of exchanges giving rise to shared developments between economic partners: this raises questions of integration, coherency, and interoperability of one system with a higher-level system. Finally, budget, time, profitability, and time to market constraints require mastery of acquisition costs: the utility of reuse becomes evident.

With such a wide variety of constraints, particular tools and processes are needed in the area of system engineering and system-of-systems engineering. Among these tools, modeling and simulation have already proven their utility and demonstrated possibilities of reducing cycle time, resource usage, and risks associated with system acquisition, while improving the quality of the systems in question and reducing global possession costs. However, the expected gains can only be achieved if modeling and simulation are used in the light of suitable processes, which typically take their inspiration from convergent engineering.

This work is neither an encyclopedia nor a simulation manual, although it does contain certain didactic aspects. It aims to allow the reader – be they an engineer, project manager, sponsor, or manager – to acquire a basic grounding in the field of simulation and to understand how simulation can help in mastering the challenges of complex systems and systems of systems. This work will also show situations in which simulation does not help; simulation not only has many qualities but also has specific limitations and constraints.

Each chapter may be read independently, but we would strongly recommend reading Chapter 1 first. Chapter 1 gives a first cultural overview of simulation. A brief historical summary shows the origins of the discipline, followed by an explanation of the broad basic principles of simulation. Examples taken from areas particularly concerned with complex system problems (e.g. aeronautics and defense) give an initial glimpse of the uses of simulation by large companies

Chapter 2 describes a typical model and simulation engineering process, followed by a detailed explanation of each step, illustrated by numerous examples to assist understanding.

Chapter 3 is dedicated to the reliability of data, models, and simulations. When decisions (e.g. design choices) are based on the results of a simulation, it is important to know how far the results of the simulation in question can be trusted. This consideration is of fundamental importance and demands particular attention, as much from the developer of the simulation as from the user or purchaser.

Chapter 4 deals with techniques used in modeling different aspects of a system. This section is slightly more technical, but it is important to understand what demands can reasonably be made of a simulation (and what we can reasonably expect to pay), and what this implies, for example, in terms of data collection, technology, development time, or processing power.

Chapter 5 tackles the specific case of complex systems. Without going into the mathematical detail often found in articles dealing with complexity, the principal characteristics are pointed out, information that we should keep in mind when concerned with the modeling and simulation of systems of this kind. In spite of being aware of precautions necessary when using complex systems, frequent users of models and simulations can easily revert to old habits, ignoring the traps and limitations found when using simulations.

Chapter 6 covers the software engineering aspect of simulations and describes how simulations are built, based on a foundation software infrastructure known as a host structure, which notably provides the core of the simulation, the simulation driver. This chapter provides an understanding of the development and operation of simulations from an IT viewpoint alongside strategies for use when developing and acquiring a simulation system.

Chapter 7 is based on Chapter 6 by dealing with a particular architecture, that of distributed simulations, which are particularly well suited to modeling complex systems and systems of systems, but which have their own specific set of problems. A good deal of work is currently being undertaken on these simulation construction techniques, which present numerous possibilities for development as long as they are used correctly.

Chapter 8 concerns a new concept in system capacity and system-of-system engineering: "battle labs", laboratories of engineering, system and system-of-system architecture. Battle labs use a variety of tools and techniques, including simulation, in addition to processes and an organization. Although the battle lab concept is relatively new, their great potential is already evident.

Finally, Chapter 9, which serves as a conclusion, goes back over certain cost aspects linked to simulation, used in an integrated manner in the engineering process for increasingly complex systems.

We, the editors, hope that this work will assist the reader in understanding simulation in the context of complex system and system-of-systems engineering, a area in which it constitutes a valuable tool, albeit one with its own specificities, pitfalls, and limits, the mastery of which is essential to use the tool to its full potential.

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1 Armed Forces, DGA (Defense Procurement Directorate) and Defense Industry on Modeling and Simulation.

Finally, we would like to dedicate this work to the memory of our colleagues and friends Guy Zanon and Pierre Bouc, early contributors on distributed simulation and the validation of simulation, who actively participated in the development of the concepts presented in Chapters 3 and 7.

We hope you enjoy reading this work and gain as much pleasure from reading it as we did in writing it.

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and
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