# Maturing Phase of the Modeling and Simulation Discipline

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*"The smaller a man, the closer his horizons."*
*John McLeod*

**Abstract**：Modeling and simulation (M&S) is multifaceted. It is used as an enabling technology for a multitude of application areas in many disciplines. There has been tremendous developments both in M&S as well as in other disciplines due to the contributions of M&S. In the article, perceptions of M&S from different points of view are offered to reveal the richness of the possibilities it offers and its possible synergies with other related disciplines. Perception of M&S within the tool hierarchy reveals the parallel of M&S tools with physical and software engineering tools at three levels. Professional concerns are presented under three headings: (1) milestone achievements, (2) ongoing developments, and (3) challenges. Application categories of M&S show the richness of the discipline. An ongoing study to codify the M&S body of knowledge is also highlighted.

**Keywords**：progress in modeling and simulation profession; body of knowledge of modeling and simulation

## 1. Introduction

As the topics covered in the conferences of over 50 associations of modeling and simulation (M&S) would testify, simulation is omnipresent in hundreds of application areas [1]. In universities, academic courses with M&S content are offered in engineering, science, social and behavioral sciences, business, international relations, and many other disciplines abound; and simulation has an important place in the teaching/ learning processes in every level of education [2]. This aspect of M&S is also indicative to the fact that it is an essential subject in gaining mastery even in other disciplines. Indeed, M&S is an enabling technology for many disciplines.

We are witnessing the maturing phase of the M&S discipline. Currently, active and concerned simulationists from academia, government, industry, and research establishments continue to take an active role in this process.

The aim in this article is to emphasize and exemplify the maturing of modeling and simulation discipline. For this purpose, the following is done: (1) a broad view of M&S from several perspectives is offered, (2) the synergistic relationships of M&S with several disciplines such as software engineering, artificial intelligence (AI) and, system theories is reviewed, (3) recent professional concerns and on-going concerted activities are pointed out, (4) application categories of M&S is delineated, and (5) a body of knowledge study is mentioned.

Section 2 considers M&S from different perspectives. Section 3 presents M&S within the tool hierarchy. Section 4 summarizes recent professional concerns. Section 5 describes application categories of M&S and section 6 refers to a body of knowledge study of M&S.

## 2. M&S from Different Perspectives

The term simulation (used in English, French, German, and Danish) and its variants simulação (in Portuguese), simulacíon (in Spanish), simulatie (in Dutch), and simulazione (in Italian) are derived from the term simulare which is used in Latin since the $14^{th}$ century and which is based on similis which in turn means similar. "The term "simulation" can be used: (1) as a non-technical term, (2) as a technical term that denotes an *activity or process*, (as in the phrase "modeling and simulation" and (3) as a technical term to denote an *object/artifact"* [3].

As a non-technical term, *simulation* (or more correctly, the adjective, "*simulated*") means not real, imitation, feign or counterfeit; e.g., simulated leather. While this non-technical usage is entirely legitimate, it needs to be distinguished from the various technical usages which all share the common feature of encompassing the notion of a *model* and/or some special model-based activities.

"As a technical term, simulation can be a noun or a verb. "As a noun, the term "*simulation*" could be used to mean at least one of the following artifacts: *simulation study*, *simulation model, simulation program*, or *simulation result*. To avoid ambiguity, it is good practice to use the word simulation as part of a noun phrase which clarifies the intent. When simulation is used alone, the meaning has to be inferred from the context. Some associated concepts are clarified below:

A *simulation study* refers to a comprehensive and carefully designed set of (simulation) experiments. The level of detail (*granularity*) of the model associated with a simulation study is generally bounded by the stated goals of the study.

Typically the model associated with a simulation study is expressed within a computer program and this computer code embodiment of a model is called a *simulation model*.

A *simulation program* contains in addition to a simulation model, other information, such as experimental conditions, parameter values, and model behavior generation mechanisms.

Simulation can also be used to mean '*simulation results.*' For example, in the phrase: 'the simulation indicates that the ground forces acting alone cannot stop the enemy's advance,' simulation is used to mean the results produced by a simulation study." [4].

As a verb, simulation can be perceived from different perspectives. Possible perceptions of simulation and consequences are summarized in Table 1. The perspectives are: computerization, experimentation, representation, philosophy of science, and abstract level which is in line with experimentation view.

*Computerization view* is remnant of the old days of computers and induces many limitations in M&S. Even software engineering discipline is trying to mature from "code-centric" software engineering to "model-centric" software engineering paradigm [5].

*Experimentation paradigm* implies the existence of *a* dynamic model of the system of interest and goal-directed experimentation with this dynamic model.

*Representation or imitation view* implies that simulation is a representation of a system. This view is different from emulation which denotes use of a system in lieu of another system. There are two major categories: (1) Simulation operates independent of the operations of the real system. This includes stand-alone simulation and virtual simulation. (2) Operations of simulation and the real system are interwoven. This category involves live simulation and integrated simulation for the use of simulation to enrich and support real system operations.

Simulation has an important place in *philosophy of science*: "Experimentation is one of the key concepts in scientific thinking since Francis Bacon (1561-1626) who advocated it in 1620 in his Novum Organum. (New Instrument). Bacon's work was a categorical departure from and reaction to "Organon" (the Instrument) which was the title of logical works of Aristotle (384-322 B.C.) which itself had an 'unparalleled influence on the history of Western thought.'" [6]. As one of the superiorities of simulation over real-system experimentation is that, simulation is possible in all cases when experimentation on real system cannot be performed. Furthermore, in simulation, experimental conditions can include cases that cannot and should not be performed on real systems.

In line with experimentation view, *at abstract level*, simulation can be conceived (1) as model-based knowledge processing, (2) more specifically, as model-based knowledge generation process, and (3) a model-based experiential knowledge generation process. Associated with all these three views, there are possibilities of establishing relationships with other relevant knowledge processing processes [7], [8]

It is well known that simulation is used when the real system cannot or should not be used for experiments. Under all these conditions, simulation supports scientific method by allowing to make experimentations.

As outlined from SimServ [9], some reasons to use simulation follow:

- The real system *does not exist* (as in design problems)
- The real system is *not accessible* for experiments (as in deep see or space exploration problems)

**Table 1**. *Possible Perceptions of Simulation (as a verb)*

<table>
<tr><th colspan="2">Perspective</th><th>Simulation is perceived as</th><th>Consequence</th></tr>
<tr><td colspan="2">Computerization (Execution of a computer program)</td><td>• Simulation is the execution over time of models representing the attributes of one or more entities or processes.<br>• Simulation is a method of implementing a model over time.</td><td>These definitions do not allow elaboration of any aspect of simulation and its relationships with other disciplines.</td></tr>
<tr><td colspan="2">Experimentation</td><td>Simulation is goal-directed experimentation with dynamic systems.</td><td>• Stand-alone simulation<br>• Constructive simulation (gaming simulation)</td></tr>
<tr><td colspan="2">Representation (imitation)</td><td>Simulation is representation of a system. (This is different than emulation which is use of a system in lieu of another one.)</td><td>Simulation operates independent of the operation of real system:<br>• Stand-alone simulation<br>• Virtual simulation<br>Operations of simulation and the real system are interwoven:<br>• Integrated simulation<br>• Live simulation</td></tr>
<tr><td colspan="2">Philosophy of science</td><td>• Allows experimentation (with models) when experimentation with real system is not possible or feasible.<br>• Enriches experimentations by allowing experimentation (with models) done under conditions not feasible with real system.</td><td>Simulation extends the possibilities to make simulation.<br>Simulation supports and enriches modern scientific thinking (Francis Bacon (1620 – Novum Organon)<br>.</td></tr>
<tr><td rowspan="3">Abstract level: as a process (In line with experimentation</td><td>Model-based activity</td><td>Simulation is model-based knowledge processing</td><td>Establish relationship with other model-based knowledge processing<br>• symbolic model processing</td></tr>
<tr><td>Knowledge generation</td><td>Simulation is a model-based knowledge generation process</td><td>Establish relationship with other knowledge generation techniques:<br>• using real system:<br>- observation<br>- instrumentation<br>• using models:<br>- optimization<br>- inferencing: (statistical inferencing; logical inferencing (induction, deduction)</td></tr>
<tr><td>Experiential knowledge generation</td><td>Simulation is a model-based experiential knowledge generation process</td><td>Establish relationship with other experiential knowledge generation processes and techniques</td></tr>
</table>

- The *dynamics and response* of the real system is too slow or too fast for observation (e.g., geological studies, economic studies; particle physics)
- The experiment would be *dangerous* (e.g., extreme cases in pilot training, study of a failure in a levee)
- The experiments would be *unacceptable* by public (experimenting cases where public would be affected directly, e.g., experimenting different public transportation policies)
- The experimenting with real system is expensive (e.g., use of physical prototypes instead of computerized simulations)
- The proper conditions for the experiment cannot be fulfilled.
- The variables of the system cannot be controlled.
- Process variables cannot be measured.
- Measurements of the real system are noisy.

## 3. M&S within the Tool Hierarchy

As expressed previously [10], tools are important from several points of view. "The information era that we have started to live in [11], [12], [13] requires appropriate computerized tools and technologies as well as an appropriate mental disposition to use them intelligently. 'The emergence of the knowledge economy is not, in other words, part of the 'intellectual history' as it is normally conceived. It is part of the 'history of technology,' which recounts how man puts tools to work. [14]. "Conception and realization of tools are paramount in fostering a technology. For example, the realization of Watt's steam engine to which so many of the achievements of the Industrial Revolution depend, is due to the improvements of the machine tool developed by Wilkinson (ca 1776) to produce 'cylinders and pistons that fitted tightly and thus cured the leakage of steam which had been the fatal defect of earlier steam engine [15].

There is a parallel of the maturing of the M&S tools with the maturing of the physical and software tools. Table 2 highlights the three levels of physical, software, and M&S tools and the additional feature needed to mature from a level to the next. The three levels of tools can be labeled as manual tools, power tools, and cybernetic tools [16].

### 3.1 Physical Tools

History of physical tools goes back to the stone age and started with several types of stone tools and continued with metallic tools (e.g., iron, bronze).

*Manual tools* matured to power tools by the addition of energy, i.e., ability to perform work. *Power tools* include simple power tools, machine tools, integrated (or transfer) machines.

The third level of physical tools can be labeled as *cybernetic tools* which are knowledge processing machines and consists of two types of machines (and mechanisms in simpler forms) or systems: (1) machines, mechanisms, or systems for knowledge processing and (2) machines or systems with knowledge processing abilities. The first group includes computers. The second group consists of computer-embedded machines or systems and often called smart machines or smart systems due to their knowledge processing abilities.

### 3.2 Software Tools

*Manual software tools* include hand-coded programs and non-automated documentation.

*Computer-aided programming* or in general *computer support* in software life cycle is the essence of power tools for software engineering. They include software tools, software tool kits, software environments, and integrated computer-aided software *engineering environments.*

*Advanced knowledge processing ability*, included by Artificial Intelligence and software agents, makes it possible two categories of synergies of artificial intelligence and software engineering: AI in software engineering, or agents in software engineering and AI in software environments or agents in software environments.

### 3.3 M&S Tools

Similar to physical and software tools, M&S tools can be conceived at three levels: manual tools, power tools, and cybernetic tools.

*Hand-coded M&S programs* (and in the early days of analog and hybrid simulations, hand-wired control panels) are the manual M&S tools and are representative of simulation as an art/craft era. At this level of M&S tools, the role of computers is to generate and to support display of model behavior.

**Table** 2. *M&S tools within the tool hierarchy*

| Level | Physical tools | Software tools | M&S tools |
|---|---|---|---|
| 1. Manual tools | • stone tools<br>• metallic tools<br>• … | • hand-coded programs<br>• non-automated documentation (including specification and processing of requirements) | • hand-coded M&S programs (simulation is an art / craft era) |
| Additional features | • (*Energy*) Ability to perform work | • *Computer-aided* programming<br>• *Computer-support* in software life cycle | • *Computer-aided* M&S programming<br>• *Computer support* in M&S (in areas other than model behavior generation) |
| 2. Power tools | • simple power tools<br>• machine tools<br>• integrated machines (transfer machines) | • software tools<br>• software tool kits<br>• software environments<br>• integrated computer-aided software engineering tools | • M&S tools (e.g., program generators, symbolic processors of models & other M&S components)<br>• M&S tool kits<br>•.M&S environments<br>• integrated environments for M&S<br>• computer-aided design and/or problem solving environments with simulation abilities |
| Additional features | • *Knowledge processing* ability | • *Advanced knowledge processing* ability<br>- Artificial Intelligence (AI)<br>- Software agents | |
| 3. Cybernetic tools | **Knowledge processing machines**<br>• Machines/systems for knowledge processing<br>-<br>- computers (virtual machines) | • AI in software<br><br>• AI in software environments | • Simulation of intelligent entities<br><br>AI for simulation<br>• AI- supported simulation<br>• AI-based simulation |
| | • Machines/systems with knowledge processing abilities<br>- Computer-embedded machines/systems (smart machines/ systems) | • Agents in software<br><br>• Agents in software environments | Agent-directed simulation<br>• Simulation for agents: simulation of intelligent entities modeled as agents (agent simulation)<br><br>• Agents for simulation:<br>- agent- supported simulation<br>- agent- based simulation |

*Computer-aided M&S programming* or in general *computer support* in M&S in areas other than model behavior generation are the essence of the realization of power tools for M&S. The realization of this phase was made possible by the availability of relatively more powerful computers and the accompanying software and by being able to conceptualize M&S as a model-based activity [17]. Power tools for M&S include: M&S tools (e.g., program generators, symbolic processors of models and other M&S components), M&S tool kits, M&S environments, integrated M&S environments, and more comprehensive environments such as computer-aided design or computer-aided problem solving environments with simulation abilities.

Advanced knowledge processing ability, included by Artificial Intelligence and software agents, makes it possible two categories of synergies of artificial intelligence and simulation: namely, (1) simulation for AI or agents and (2) AI or agents for simulation. The latter has two possibilities: AI-supported and agent-supported simulations and AI-based and agent-based simulation. The synergy of simulation and agents, i.e., agent-directed simulation is depicted in Figure 1 [18]. Possible synergies of simulation, system theories, software engineering, and artificial intelligence are outlined in Table 3..

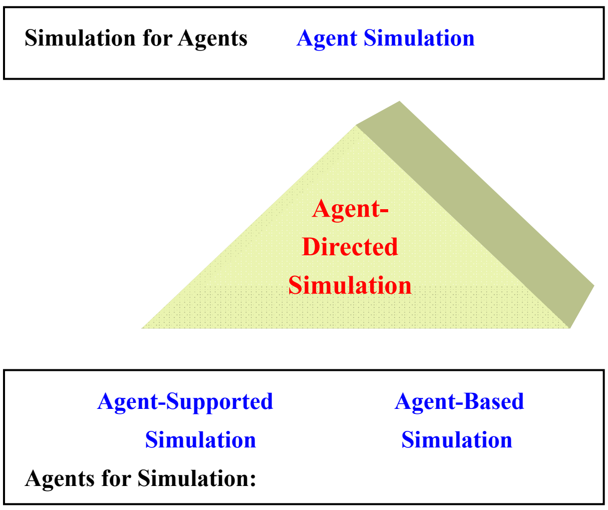


**Fig. 1** *Types of agent-directed simulation*

## 4. Recent Professional Concerns

M&S is a vital discipline and an enabling technology for many other disciplines in hundreds of application areas. In addition to scientific, methodological, and technological advancements accumulated over the years and continue to occur, we started to witness concerns, activities, and advancements as a profession. In the sequel, a brief account is given under three headings: (1) milestone achievements, (2) ongoing developments, and (3) additional challenges.

### 4.1 Milestone Achievements

Already there are several milestone achievements in the maturing process of the M&S profession:

• **SimSummit** is established, under the leadership of W. Waite, as a forum to discuss, promote, and resolve several important issues related with M&S profession [19]. Several important associations and groups are already represented within the SimSummit.

• ***A Code of Professional Ethics*** is already developed under the auspices of the Society for Modeling and Simulation International and full support of SimSummit. The Code [20], its Rationale [21], and additional information are available [22], [23]. A good number of associations and groups have adopted the Code of Ethics [24] and the number of professional groups adopting it is growing.

• ***Certification Program:*** "As modeling and simulation technology has matured, so has the modeling and simulation profession. In 2002, two parallel ceremonies took place in Orlando, at the I/ITSEC planning meeting, and in San Antonio, at WMC'02, to honor the first ever class of certified modeling and simulation professionals. " [25]. The Modeling and Simulation Professional Certification Commission (M&SPCC) [26], under the auspices of the National Training Systems Association (NTSA) [27], is overseeing the certification process of the M&S professionals. Approved M&S professionals are acknowledged as "Certified Modeling and Simulation Professional - CMSP" [28].

• **Academic Programs:** Several academic programs, both graduate and undergraduate level, exist and the list is growing [29] [30].

• **Standardization**: Simulation Interoperability Standards Organization (SISO) exist to promote and coordinate the standardization activities in M&S [31].

**Table 3** Possible Synergies of Simulation, System Theories, Software Engineering, and Artificial Intelligence

| Contribution of | To | Contribution |
|---|---|---|
| Modeling & Simulation | System Theories | • Basic tool of inquiry for complex problems |
| | Software Engineering | • Simulation of software, hardware<br>• Paradigm for module interfacing |
| | Artificial Intelligence | • Simulation for AI:<br>- Cognitive simulation (i.e., simulation of intelligent entities)<br>• Simulation for agents<br>- Agent simulation (i.e., simulation of entities modeled as agents) |
| System Theories | Modeling & Simulation | • Bases for system design, analysis<br>• Advanced modeling formalisms<br>• Bases for symbolic model processing |
| | Software Engineering | • Formalisms to design complex software systems as special cases of methodologies to design complex systems |
| | Artificial Intelligence | • Bases for modeling cognitive systems such as, learning systems, understanding systems, and goal-directed systems. |
| Software Engineering | Modeling & Simulation | • Computer-aided modeling<br>• Simulation program generators<br>• Software architectures for modeling and simulation<br>• Modeling smart systems (systems/machines/mechanisms which can perform their functions better with the knowledge processing abilities, even though their main functionalities are not knowledge processing. |
| | System Theories | • Computerization of system theoretic concepts (in modeling, in model processing): CAST – Computer-aided System Theory.<br>• Application of software engineering concepts in system theories (e.g., model robustness, model integrity) |
| | Artificial Intelligence | • Software for AI applications |
| Artificial Intelligence | Modeling & Simulation | • AI for simulation:<br>- AI-supported simulation (for user/system interfaces)<br>- AI-based simulation (for the generation of model behavior, e.g., rule-based simulation, qualitative simulation)<br>• Agents for simulation:<br>- Agent-supported simulation (for user/system interfaces)<br>- Agent-based simulation (for the generation of model behavior)<br>• Modeling intelligent systems (systems/machines/mechanisms which can perform their functions better with the advanced knowledge processing abilities, even though their main functionalities are not knowledge processing. |
| | System Theories | • Intelligent models (Several types of intelligence) |
| | Software Engineering | • Intelligent software; • AI in software life cycle |

### 4.2 Ongoing Developments

• **Body of Knowledge**: The Body of Knowledge of M&S (M&SBOK) is being coded to be scrutinized by the M&S professionals and to be refined accordingly [32]. To provide an inventory of concepts and terms in M&S, a trilingual dictionary is prepared [33].

• **Curricula**: A Technical Committee of SCS, under the leadership of W. Tucker, is working to develop curricula for M&S education and workforce development. The Education, Training, and the Profession Technical Council of the SCS is also active in this are [34].

• **Job Categorization**: The job categorization of the M&S professionals is being advocated and progress is being made [35] [36].

### 4.3 Additional Challenges

• The **mutual feedbacks** of the curricula development and M&SBOK studies are very important. Each one of them is essential for the development of the other one. Using a well defined M&SBOK to refine graduate and undergraduate M&S curricula to offer standard educational material at national and international levels can help educate the next generation of simulation professionals and allow course equivalencing as well as student and professor exchanges. And, curricula requirements will have an effect in the refinement of the M&SBOK.

• Development of detailed **job-titles** and **job categorizations** is very important from several points of views. One of them is the determination of their educational needs.

• It is still essential to be able to perceive M&S from a **broad perspective** and the possibilities of that its synergy with related field offer. "Model-based simulation is like a gem: it is multifacetted. Some of the specialists too close to one of the facets, perceive only that single facet and the reflection of their success of their career through it. The more they see the latter, the more, it seems, they are enamoured with that aspect of modelling and simulation instead of exploring new horizons. If it was to this attitude, nobody would have discovered the New World. The fable of the elephant and the blindfolded men is a well- known metaphor in eastern cultures, to illustrate how easy it is to confuse the parts with the whole" [37].

• **Importance of consequences** of poorly or inappropriately carried out M&S studies were elaborated in another article [38]. In 2005, unfortunately one is obliged to add another aspect of the seriousness of the implications of *ignoring results of M&S studies*: Simulation studies were performed even during 2004, about the effects of hurricanes flooding New Orleans [39] [40] [41]. Timely acting on the recommendations would have avoided human misery and tremendous cost.

The results of properly performed M&S studies should not be ignored by responsible decision makers. With this type of serious implications of M&S studies, ethical imperatives of simulation professionals and simulation institutions should be recognized and demanded. Furthermore, it may be the right time, to consider certification as an M&S professional as a requirement to be involved in important applications. This may be similar to the requirements and certification process of certified engineers.

• **Capability maturity model** and its variants are very important in software engineering [42] [43]. It would be highly desirable to develop similar capability maturity assessment frameworks for M&S organizations. Similar to People Capability Maturity Model used in software engineering [44], People Capability Maturity Model in M&S would also be very useful.

## 5. M&S: Application Categories

In all applications of M&S, two main categories of simulation activities can be distinguished depending whether or not simulation program runs independently from the system it represents. Hence, there are stand-alone and integrated use of simulation. The latter can be used to enrich and support real-systems. Their distinguishing characteristics and main purpose of usage are outlined in Figure 2. Figure 3 and Figure 4 outline aspects of stand-alone simulation for training and decision support, respectively. For the use of simulation in education, see references at [45].

## 6. M&S: Body of Knowledge

A simulation professional needs to be knowledgeable in the following categories of knowledge: (1) Application area(s), (2) Supporting

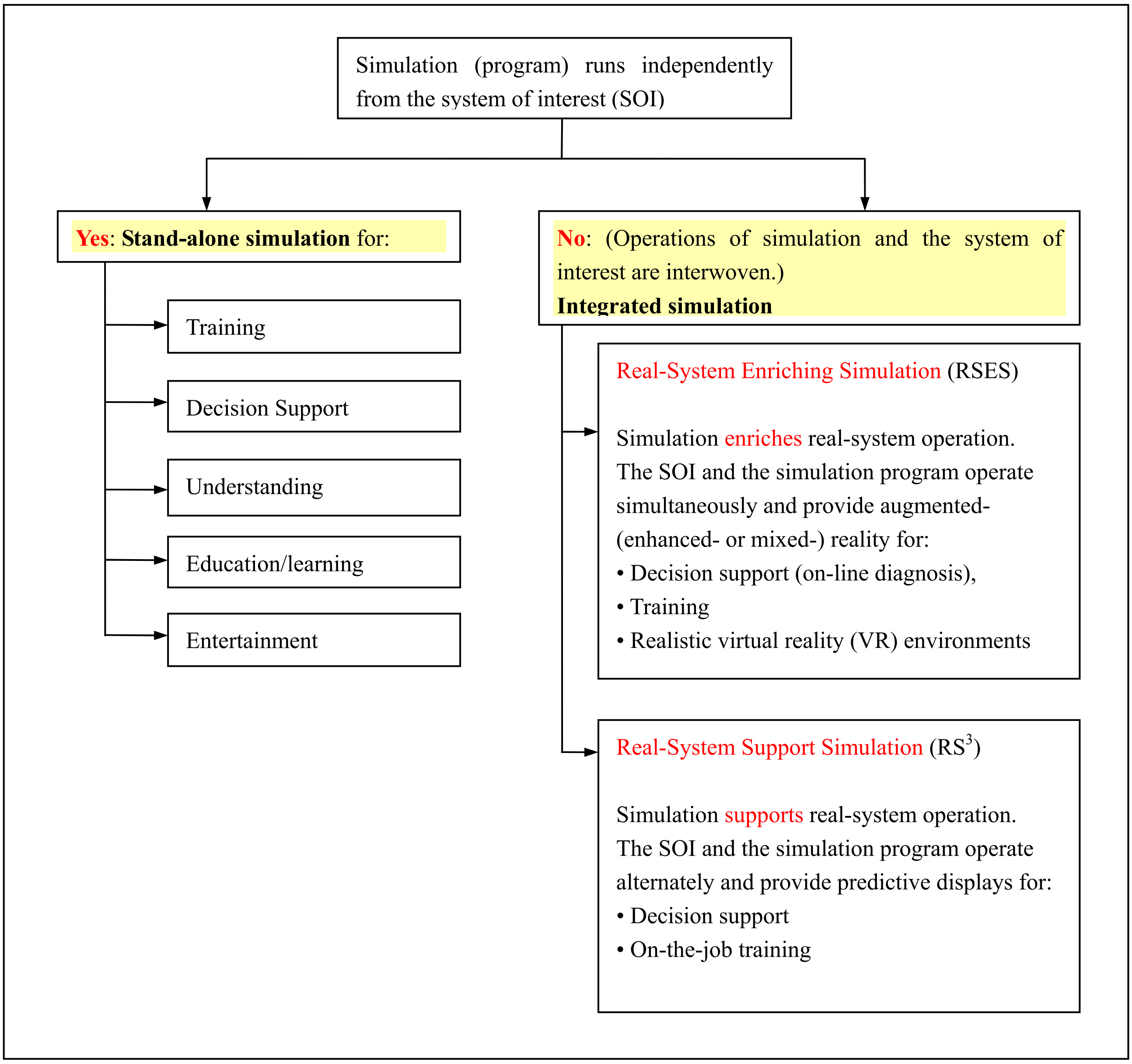


**Fig. 2** M&S: *Application Categories*

Stand-alone Simulation for **Training**

**Aim**: In line with the adage: "**Train as you operate**": train as you fight, resolve conflicts, support peace, negotiate, etc.

To enhance **decision making** and/or **communication skills**

**Constructive simulation**

**Gaming simulation**

- *Zero-sum simulations*
  - War simulation, battle simulation at different levels
- *Non-zero-sum simulations*
  - Peace operations simulation such as (peace keeping, peace support, Non-Article V operations)
  - Conflict management simulation
  - Coopetition simulation (focused cooperation of otherwise competitive groups)
    - -- Holonic simulation (with Holonic agents)

**Interoperable war gaming**

- Applications of distributed simulation (HLA, TENA)

**To provide real-life-like experience opportunities**
(in a controlled environment)

- To get experience in combat situations
  (Real operator uses real equipment with real and/or virtual weapon)

**Live simulation**

- To get experience at several levels of integrated situations
  - Integration of constructive simulation with C4ISR
  - Integration of several types of weapon on a platform (such as a submarine)
  - simulation of **systems of systems; federations of federations – hyper federations**
- Linkages to live simulation
  - Augmented/enhanced reality simulation
    - -- Virtual UAVs (with auto pilots) in a live Simulation
    - -- Virtual simulator (virtual aircraft) (to be perceived by HMDs by the real pilots in a dogfight in pilot training
    - -- Linkage of live, virtual, and constructive simulations

**Augmented (enhanced) live simulation**

**Aim**: Proficiency of use of single equipment or vehicle

To enhance **motor skills**

- To use single **vehicles** such as aircrafts, helicopters, tanks, submarines
- To use single **equipments** as in weapon system simulators (e.g., torpedo simulator)

**Virtual simulations**

- **Simulators** (with limited environmental interactions)
- **Virtual simulators** (all software) (to be perceived, for example, by head-mounted displays (HMDs))

**Fig. 3** *Use oif M&S in Training*

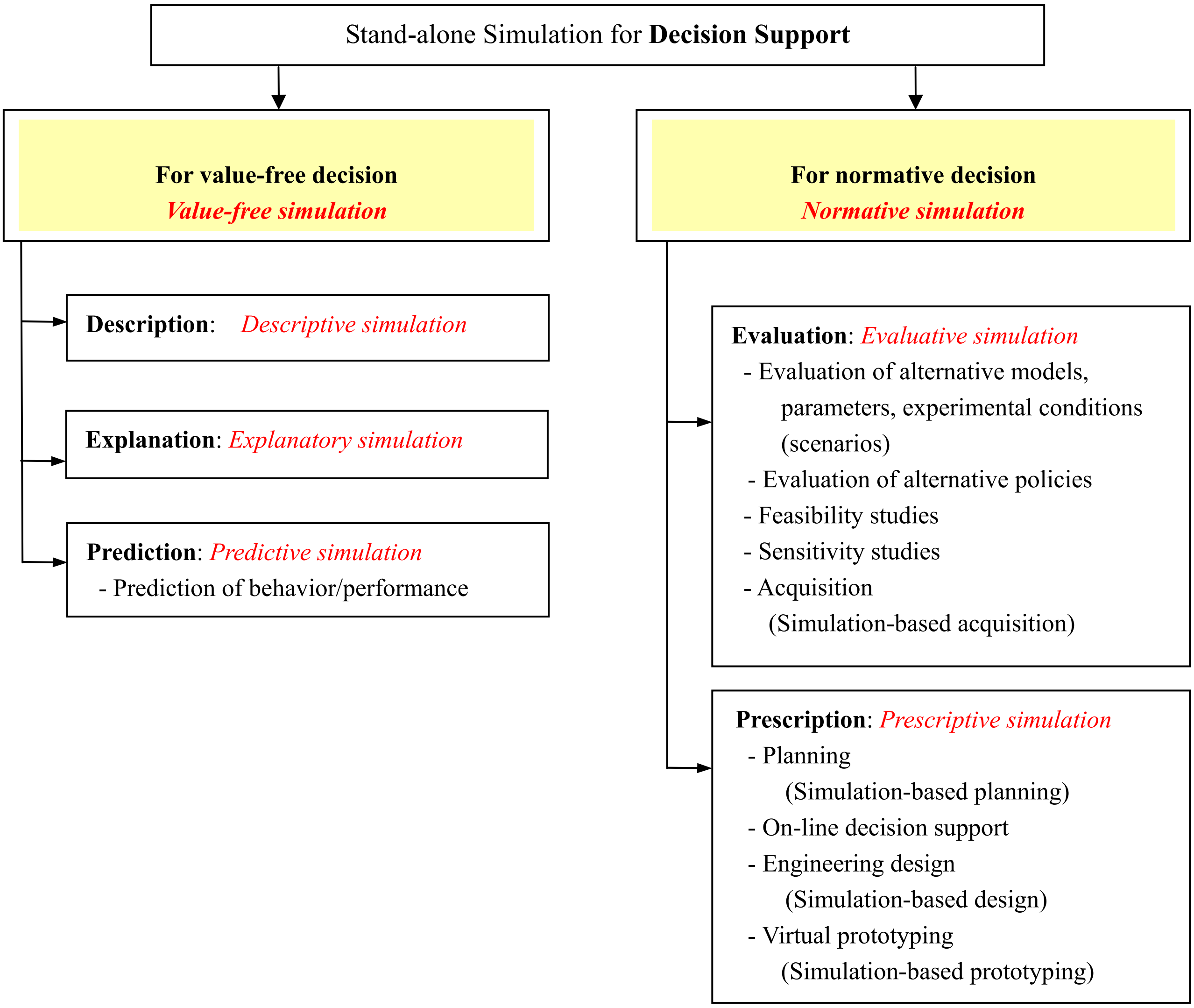


**Fig. 4** *Use of M&S in Decision Support*

Domains, and (3) Core M&S areas. Supporting Areas are outlined in Table 4 [46].

**Table 4.** *Core Areas of Supporting Domains*

| Area |
|---|
| Mathematics – differential equations |
| Mathematics – numerical analysis |
| Queuing theory |
| Probability and Statistics |
| Physics |
| Software engineering |
| Artificial intelligence |
| Software agents |
| Systems Engineering |
| Project management |
| Interpersonal skills |
| Oral and written reporting, documenting |

Core areas of the M&SBOK are highlighted in Table 5.

**Table 5** *Core Areas of the M&SBOK*

| |
|---|
| Input data |
| Models and modeling |
| Model processing |
| Experimentation |
| Model behavior |
| Behavior generation |
| Behavior processing |
| M&S infrastructure |
| Computerization |
| User/system interfaces |
| Reliability and ethics |
| M&S history |

The details of the M&SBOK is being developed Some taxonomies [47] of simulation, simulation languages, models, symbolic model processing, model behavior and behavior generation and processing are also being revised to provide detailed information in the M&SBOK. A dictionary of M&S including the equivalents of about 4000 terms in English, French, and Turkish is in preparation [48].

Highlights of models and modeling are given in Table 6.

**Table 6** *M&SBOK: Models and Modeling*

| |
|---|
| conceptual modeling |
| basis for modeling and model processing: |
| system theories, |
| modeling formalisms, |
| modeling methodologies, |
| model specification languages and environments |

Model processing includes building and using model bases and model repositories, model analysis, and model transformation [49]. Model analysis consists of model characterization (Descriptive model analysis) and model evaluation (Evaluative model analysis).

Table 7 gives the highlight of experimentation knowledge.

**Table 7** *M&SBOK – Experimentation*

| |
|---|
| Simulation run |
| Length of the run |
| Number of runs |
| Antithetic run |
| Warm-up period |
| Steady-state period |
| Statistical design of experiments |
| Specification of experimental conditions |
| Experimental frame |
| Applicability of experimental frame to a model |
| Scenario specification |
| Composable and synthesizable scenarios |
| (Composable/ Reconfigurable) Synthetic environments |

The details of the M&SBOK are being worked out and a detailed draft will be available for the perusal of concerned M&S professionals.

## 7. Conclusions

After many scientific, methodological, and technological advancements, we are witnessing the maturity of the M&S discipline. Some challenging areas are pointed out.

## References


[1] linksMS. http://www.site.uottawa.ca/~oren/links-MS.htm

[2] simEd. http://www.site.uottawa.ca/~oren/simEd.htm

[3] T.I. Ören, L.G. Birta, T. Pearce, J–M. Thizy, and G. Wainer (2002). *Simulation Science knowledge, HLA, and VV&A: Current Views, Challenges, and Recommendations for SECO*. Advisory Report to the Canadian Forces Experiment Center. Ottawa, ON, Canada.

[4] same as [3]

[5] From Code Centric to Model Centric Software Engineering, Nov. 8, 2005: http://www.enabler.com/en/skills/ecmda/enabler-ws.html

[6] T.I. Ören (2002b). Future of Modeling and Simulation: Some Development Areas. *Proceedings of the 2002 Summer Computer Simulation Conference*, pp. 3-8. http://www.site.uottawa.ca/~oren/pubs/pubs-2002-05-future.pdf

[7] T.I. Ören (1990). A Paradigm for Artificial Intelligence in Software Engineering. In: *Advances in Artificial Intelligence in Software Engineering* - Vol. 1, T.I. Ören (ed.), JAI Press, Greenwich, Connecticut, pp. 1-55.

[8] T.I. Ören (1983). Quality Assurance of System Design and Model Management for Complex Problems. In: *Adequate Modeling of Systems*, H. Wedde (ed.). Springer-Verlag, Heidelberg, W. Germany, pp. 205-219.

[9] SimServ http://www.sim-serv.com/simulation.php

[10] T. I. Ören (1984). Model-Based Activities: A Paradigm Shift. In: *Simulation and Model-Based Methodologies: An Integrative View*, T.I. Ören, B.P. Zeigler, M.S. Elzas (eds.). Springer-Verlag, Heidelberg, Germany, pp. 3-40.

[11] D. Bell (1976). Welcome to the Post-Industrial Society. *Physics Today*, Feb. 1976.

[12] P.F. Drucker (1968). *The Age of Discontinuity*. Harper Colophon edition (1978), New York, 402 p.

[13] T.I. Ören (1984). Model-based Information Technology: Computer and System-theoretic foundations, *Behavioral Science*, 29:3 (July) 179-185.

[14] same as [12].

[15] same as [12].

[16] same as [7]

[17] T.I. Ören, B.P. Zeigler (1979). Concepts for Advanced Simulation Methodologies. *Simulation*, 32(3), pp. 69-82.

[18] L. Yilmaz, L. and T.I. Ören (2005 Submitted) Intelligent Agents, Simulation, and Gaming, *Sim&Gaming*.

[19] SimSummit. http://www.sim-summit.org/

[20] Code. http://www.scs.org/ethics/scsEthicsCode.pdf

[21] Rationale. http://www.scs.org/ethics/scsEthicsCodeRationale.pdf

[22] SimEthics – SCS. http://www.scs.org/ethics/

[23] SimEthis – TIO. http://www.site.uottawa.ca/~oren/SCS_Ethics/ethics.htm

[24] Organizations that adopted the code of Ethics. http://www.scs.org/ethics/

[25] UAH – The University of Alabama in Huntsville http://www.coned.uah.edu/seriesinfo.cfm?filename=modsim

[26] M&SPCC - Modeling and Simulation Professional Certification Commission. http://www.simprofessional.org/about.html

[27] NTSA. http://www.trainingsystems.org/about.cfm

[28] M&SPCC http://www.simprofessional.org/pdf/MSPCC_Application_Instructions.pdf

[29] H.S. Sarjoughian (2004). 2004 Annual Report: *Education, Training, and the Profession Technical Council.* http://www.acims.arizona.edu/EDUCATION/EducationCouncilReportBOD04.htm

[30] SimEd. http://www.site.uottawa.ca/~oren/simEd.htm

[31] SISO – Simulation Interoperability Standards Organization. http://www.sisostds.org/index.php

[32] T.I. Ören (2005 - Invited Tutorial – In Press). Toward the Body of Knowledge of Modeling and Simulation (M&SBOK), In: *Proc. of*

*I/ITSEC (Interservice/Industry Training, Simulation Conference).* Nov. 28 - Dec. 1, Orlando, Florida.

[33] T.I. Ören and The French Team: L. Torres (coordinator), F. Amblard, R. Duboz, D. Hill, et al. (a group of scientists from LSIS and Versim) (2005 – In Preparation). *Modeling and Simulation Dictionary: English-French-Turkish*. Marseille, France. With the support of Centre Nationale de La Recherche Scientifique, I3, Université Paul Cézanne - Aix-Marseille III, LSIS.

[34] same as [29].

[35] V. Amico and L. Amico Grace (2002). Simulation in Search of Recognition in the Economy. Simulation. *Proceedings of SCSC 2002.* http://www.scs.org/scsarchive/getDoc.cfm?id=1786

[36] V. Amico and L. Amico Grace (2004). *Proposed Revisions to the NAICS Codes for Modeling and Simulation*. Modeling and Simulation,.Vol. 3, nb. 3, July-Sept., pp.6-8.

[37] T.I. Ören (1984). Forward to the book: *Multifaceted Modelling and Discrete Event Simulation*, by B.P. Zeigler. Academic Press London, England.

[38] T.I. Ören (2002 - Invited Plenary Paper). Growing Importance of Modeling and Simulation: Professional and Ethical Implications. *Proceedings of the Asian Simulation Conference / the 5th International Conference on System Simulation and Scientific Computing*, Cheng, Zongji et al., eds., Nov. 3-6, 2002, Shanghai, China. International Academic Publishers / Beijing World Publishing Corp. Vol.1, pp. 22-26.

[39] FEMA Predicted a "Catastrophic Hurricane" Could Strike New Orleans and Cause a "Mega-Disaster" http://yubanet.com/artman/publish/article_24891.shtml

[40] CBC - Simulation Predicted Storm's Havoc http://www.cbsnews.com/stories/2005/09/09/katrina/main831644.shtml

[41] Undernews http://prorev.com/2005/08/why-new-orleans-is-worried.htm

[42] Capability Maturity Model http://www.sei.cmu.edu/cmmi/

[43] SW-CMM – Software Capability Maturity Model. http://www.sei.cmu.edu/cmm/

[44] P-CMM – People Capability Maturity Model. http://www.sei.cmu.edu/cmm-p/version2/

[45] same as [2].

[46] same as [32].

[48] same as [33].

[49] same as [8].

(All Internet sites are accesses on (2005-09-10).

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