Toward the Body of Knowledge of Modeling and Simulation

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ABSTRACT

A Body of Knowledge (BOK) for modeling and simulation (M&S) can be very useful to provide a comprehensive and integrative view of the discipline, for assessment of professionals and organizations, for self-assessment as well as for curriculum development for academic or professional development courses and degree programs. Body of Knowledge of some related disciplines as well as early studies on the M&SBOK are pointed out. To properly establish the scope of M&SBOK, some definitions of simulation are revised and a paradigm shift is pointed out to conceive simulation studies as "Simulation Systems Engineering" especially for the simulation of large and complex systems. Possible uses of M&SBOK are listed. A systematic top-down decomposition of M&SBOK is presented by a series of tables. The outline consists of the three aspects of relevant knowledge which are: M&S knowledge from application and engineering perspectives and core elements of supporting domains. For some omitted details references are given. The details will be added in the future versions of the M&SBOK.

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INTRODUCTION

Body of Knowledge is: (1) "Structured knowledge that is used by members of a discipline to guide their practice or work." (2) "The prescribed aggregation of knowledge in a particular area an individual is expected to have mastered to be considered or certified as a practitioner." (BOK-def). Waite's pragmatic view is also worth noting: "BOK is a stepping stone to unifying community" (Waite 2004).

Development of the Body of Knowledge for the modeling and simulation (M&S) profession is an activity for which time is ripe from several perspectives:

(1) There is enough science, technology, and crafts-manship accumulated (Zeigler and Ören 2003).
(2) For some time some practitioners in related fields, such as Operations Research, not being able to realize its fundamental superiorities, considered simulation "as the method of last resort." Since a long time, the matter has been clarified (Ören 1984a) and now the supremacy of simulation has been well established (Fishwick 1994).
(3) There are over 60 associations for M&S profes-sionals: 21, by country; 10, by region/language; 18, international; and 13 networking of professional groups in M&S (Links-MS). Some of them have several conferences each year. Interservice/Industry Training, Simulation & Education Conference (I/ITSEC), for example, attracts over 16000 (sixteen thousand) participants for its annual events.
(4) There are large number of professionals active in M&S. Some of them are members of the above mentioned professional societies and for some, M&S is so much interwoven in their professional lives that, similar to using mathematical tech-niques and not considering oneself a mathe-matician, they do not consider themselves simu-lation professionals and mostly are not attending simulation conferences.
(5) In academia, for each M&S course –undergraduate or graduate– there are several other non-simulation courses with strong M&S content (Links-SimCourses-Ottawa).
(6) Simulation is used in many important application areas (Ören 2002a).

To support the development of a Body of Knowledge for Modeling and Simulation (M&SBOK), a brief review of the BOK of some related disciplines as well as early studies on the establishment of M&SBOK are pointed out.

BOK of Some Related Disciplines

For the following disciplines, their respective BOKs are well established or under development:

- Systems engineering (G2SEBoK)
- Information systems engineering (ISEBOK)
- Software engineering (SWEBOK)
- Information technology (ITBOK)
- Project management (PMBOK-1, PMBOK-2)
- Body of Quality Knowledge (BOQK)
- New Product Development Body of Knowledge (NPDBOK)

An interesting aspect of these disciplines is that they are, like M&S, applicable in wide areas of disciplines and applications.

Early Studies on the M&SBOK

Due to its importance and timeliness, several studies on M&SBOK preparation have been under way. Some of them are:

An early study was developed by the Technical Committee on Simulation of the IEEE Computer Society (CS-TCSim-BOK). However, this study did not have an impact on the discipline.

One of the on-going efforts is the establishment of a clearinghouse as well as contribution to the M&SBOK studies by an avid supporter of the M&SBOK studies, i.e., B. Waite (Aegis Docushare). However, the clearinghouse is not yet accessible to public. Several Workshops are also organized (Waite and Skinner 2003, Waite 2004).

Fairchild (2002) presented his version of M&SBOK by partitioning it in five areas: (1) Simuland: What is simulated, (2) Purpose: Why it is simulated, (3) Technique: How it is simulated (solution method, execution control, interfacing –inputs and outputs–, classical mathematics, and soft computing), (4) Programmatics: How it is controlled (technology and management).

Birta published an M&SBOK (Birta, Birta 2003) which caused Elzas to publish a critique (Elzas).

Studies elaborating on an "ideal simulationist" such as reports (Madewell and Swain 2003, Rogers 1997) and their critiques also contain valuable information.

Possible Uses of the M&SBOK

Stakeholders in M&S include simulation theoreticians, methodologists, technologists, tool/environment developer, systems engineers, analysts, software engineers, programmers, industrialists, customer/sales representatives, users, and people which might be affected by the results of simulations. Amico and Amico Grace (2004) are involved in the revision of simulation related position codes. Rogers (1997) reports a panel's findings about M&S professionals.

As summarized in Table 1, the MSBOK can be useful to different stakeholders of simulation.

Table 1. Possible Uses of the M&SBOK

Stakeholder	Possible uses
Novice	Explore the discipline Determine applicability
Practitioner	Expansion of knowledge Specific problem solving Identification and evaluation of techniques
Learner	Expansion of knowledge Verification of derived knowledge Accomplishment of corporate or certificate requirements
Academician	Referencing Expansion of knowledge Curriculum / course development (including degree programs, academic / professional development courses)
Industrialist	Exploring opportunities / Satisfying needs Offering professional development courses Personal selection
Funding agencies (grant officiers)	Explore the discipline Determine timeliness and applicability of proposals Evaluation of alternatives
Licencing / Certification (of individuals / organizations)	Determination of professional standards for: individuals commercial organizations academic degree programs
Acquirer/User of Product Service	Source selection Evaluation of products, services, techniques, vendors/providers
Market	Formation of market, niche markets, and workforce

Depending on the interest areas and level of aspiration, one can select from the following tables a subset of the M&S knowledge to master. Detailed knowledge in the specialization areas needs to be assimilated. Furthermore, a general knowledge about the possibilities offered by M&S would widen the horizon of any person interested in M&S.

SCOPE OF M&S

To be able to properly perceive the scope of M&S as a basis for the development of an M&SBOK, some definitions and types of usages of simulation are reviewed, evolving roles of computers in M&S is outlined as well as demand-based push and advancement-based pull are outlined.

Some Definitions of Simulation

"Simulation" is perceived differently by different groups/people. In an early study, over 20 definitions were compiled by Pritsker (1979). A few current definitions of simulations are:

DMSO VV&A glossary (DMSO VV&A Glossary) provides four definitions of the term simulation:

"A method for implementing a model over time." (DoDI).

"A technique for testing, analysis, or training in which real-world systems are used, or where real-world and conceptual systems are reproduced by a model." (DoDD, DoDI)

"An unobtrusive scientific method of inquiry involving experiments with a model rather than with the portion of reality this model represents."

"A simulation is a method for implementing a model. It is the process of conducting experiments with a model for the purpose of understanding the behavior of the system modeled under selected conditions, or of evaluating various strategies for the operation of the system within the limits imposed by developmental or operational criteria. Simulation may include the use of analog or digital devices, laboratory models, or 'testbed' sites. Simulations are usually programmed for solution on a computer; however, in the broadest sense, military exercises, and wargames are also simulations." (SISO FISG)

The NATO Modeling and Simulation Master Plan (NATO MSMP) provides the following definition of simulation:

"The execution over time of models representing the attributes of one or more entities or processes.".

Intermath: The definition of simulation is given as "An experiment that models a real life situation" (Intermath). This definition is a good example to incorrect and misleading definitions. An experiment does not model a system; an experiment can be carried out using a model.

Except this last definition and similar ones –that one can easily refute– each one of the definitions focus on some aspect of simulation. As it is expressed in the forward of a book by Zeigler (1984):

> "Model-based simulation is like a gem: it is multifaceted. Some of the specialists too close to one of the facets, perceive only that single facet and the reflection of their success of their careers 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" (Ören 1984b).

To be encompassing all aspects of M&S, more comprehensive definition would be desirable as starting points for M&SBOK studies. As a process, the term simulation has two meanings. Traditionally simulation means "imitation" and has been used since the 14th century.

As a technical term "simulation is goal-directed experimentation using dynamic models." The technical meaning covers any type of simulation regardless whether it is computerized or not and whether it is carried out on pure software or hardware/software. Furthermore, the technical definition eases the top down decomposition of the entities and activities involved. This larger framework also embraces live, virtual, and constructive simulations. (Ören 2002a).

"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.'" (Ören 2002b).

Hence, the technical definition also ties simulation to the origins of modern scientific thinking. However a programmer's view of simulation would be biased to the execution of the simulation program and would hinder this important aspect. The superiority of performing the experiments on a model rather than on the real system is also well established. In the existing studies of M&SBOK several aspects of both of these meanings are used.

Application Areas

Since M&S can be applied in any field where experimentation with dynamic models can be desirable, application domain include, to name a few, all types of engineering areas as well as most non-engineering areas such as arts, biology, chemistry, management, medicine, and physics, social and political sciences, psychology (including neuroses) as well as education and entertainment.

The fact that almost all important fields have M&S component is also reflected in university level course offerings. For example, in Ottawa (Ontario, Canada), over 10 M&S courses are offered in the two universities. However, there are over 50 non-M&S courses with strong M&S components offered in the same two universities (links-EdSim).

In military applications, most recommended topics are: war gaming, missile defense, C4ISR, commu-nication and computers, scene generation, visuali-zation, animation, and seeker, sensor, and signal processing (Madewell and Swain).

Evolving Roles of Computers and Systems Science in M&S

Advancements in computer hardware, software, artificial intelligence, and software agents have been reflected in the gradual maturity of M&S. A highlight of the developments follow:

The first flight simulator, "Link Trainer, patented in 1929, was used in amusement parks in the 1930s" (Amico and Amico Grace 2004.)

In the early days, i.e., in 1950s and 1960s, computers were used only to generate model behavior. This was associated with limited abilities to process and display model behavior.

Later, computers were used to generate simulation programs; first by programming by questionnaires, later by transforming high level and non-executable specifications into programs written in compilable or interpretable languages.

The impact of systems science on M&S has also been phenomenal. As Elzas posits: One may conclude that the *structured*, system theory based, *approach to M&S* has been amply able to show its merits in a great number of applications in the past years and that one may count on the fact that *the need to hand-build a simulation program* (or code so you will) *is a thing of the past*" (Elzas 2003).

Computers were then used also to process symbolically models and other elements of simulation studies.

Advanced display techniques coupled with behavior generation (trajectory or structural behavior) abilities of simulation helped the realization of simulation-based virtual/augmented/mixed reality studies.

Advanced M&S environments evolved into simulation-based problem solving environments.

The synergy of artificial intelligence (AI) and M&S is maturing in AI-directed and agent-directed simulations. In the last one for example, the synergy of agents and simulation facilitates: (1) simulation for agents, i.e., agent simulation or simulation of systems represented or involving components modeled by software agents; as well as (2) agents for simulation, i.e., use of agents for simulation which offers two groups of possibilities: (i) agent-supported simulation (for front-end and/or back-end interface functions, to process elements of an M&S system symbolically, for example to assure built-in quality; or to provide advanced cognitive abilities to some components, such as learning, understanding, etc; and (ii) agent-based simulation where agents can be used to generate model behavior. The parallel to this last possibility, in AI-based simulation is qualitative simulation and knowledge-based simulation.

This evolution in M&S provides capabilities for simulation of more complex phenomena including human personality simulation as well as social simulations and conflict simulation.

Demand-based Push and Advancement-based Pull

In preparing the M&SBOK, one has to take into account that M&S knowledge does not have a fixed boundary since new knowledge is being generated and interest areas are shifting rapidly based on the demand-based push and advancement-based pull. It is a healthy state of the affairs that the demand-based pull provides strong impetus for the development of the state-of-the-art. And the fact that, theoretical and methodological advancements provide vital paradigms for advanced users to select paths to follow. Bold new concepts may provide useful new paradigms.

Demand-based Push

Higher expectations from the advanced user's community such as Numrich's assertion is a desirable sign for the M&S discipline: "We raised the bar; now we have to have to leap to new heights" (Numrich 2004). Some other points raised by Numrich are:

- Complexity of today's environments
- Emerging integration environments, federation of federations similar to system of systems
- Respond to increased demands for rapid, reconfigurable, adaptive M&S capability
- HLA is necessary but not sufficient, composable frameworks address needs beyond HLA (Numrich 2004).

Some other challenges to push the existing capabilities of M&S can be found in the literature (ICGCMS 2002, Ören 2002b, Goad 2004).

Advancement-based Pull

Interest areas in M&S are shifting with the advancements in enabling technologies such as types of computers, advances in software engineering, and application of system theoretic bases, System-theory based simulation has been advocated since early 1970s (Ören 1971; Zeigler 1976, 1984). The fact that DEVS (Discrete Event System Specification) formalism developed by Zeigler (1984) is well accepted by the simulation community (both researchers and advanced practitioners) is one of the signs of maturity of the field of M&S.

A PARADIGM SHIFT: FROM M&S TO SSE

In the early days when analog and hybrid computers were used and even in the early days of the use of digital computers, the term "simulation" was used. Only very few were referring to modeling and simulation (Zeigler 1976, Zeigler et al. 1979). Afterwards, to stress modeling process and the associated activities and environments, the term "modeling and simulation," –M&S, for short– is used by large number of simulationists. Currently, a very commendable shift of paradigm is being adopted to cover all aspects of simulation studies. This is to conceive M&S –within a larger perspective– as the Simulation Systems Engineering (SSE).

An analogy is in order. To build a cottage, the knowledge of a craftsman is often sufficient. However, it would be naïve to think that his knowledge and talent can be sufficient in building a skyscraper. Similarly, the sophisticated simulation studies cannot be realized –in a reliable, efficient, and cost-effective way– with talented craftsmanship only. One needs an engineering approach which would be, by definition, based on scientific knowledge, especially simulation systems engineering.

Some Examples of the Synergy of M&S and Systems Engineering

The following are some of the examples/clarifications:

Even from early days, simulation is used to solve system problems. And system theories provide solid bases to model several types of systems including adaptive, variable structure, and goal-driven systems as well as algorithms to process system models.

IBM's Systems Journal included an article titled "Simulation in systems engineering" even in its first issue (Smith, 1962).

The article titled: "The Use of Systems Engineering Processes and Tools to Develop a System Dynamic Simulation Model of Engineering Support During the Development Phase of an Acquisition Program" starts with the following sentence: "Due to the increase of system complexity and the existing draw down of manpower allocations, today's acquisitions environment desperately needs a systems approach to decision making" (Bartolomei).

One of the NASA's project is titled: "NASA Capability Roadmap Review: Modeling and Simulation, Systems Engineering, and Cost and Risk Analysis Panel" (NASA)

Systems Analysis, Simulation group of Fraunhofer Institute declares its aims as follows: "The work of the SAS group is concerned with the design and implementation of simulation systems for complex problems relating to the natural environment and technology. In both of these areas, overall system behaviour is often determined by complicated interactions between its individual components. To understand such systems and predict their future development, system analysis, system engineering and simulation methods must be used. The SAS group's work covers all development phases of a simulation system, from problem analysis and design to model coupling to pilot application" (Fraunhofer SAS)

NDIA's Modeling and Simulation Committee is at its Systems Engineering Department (NDI-M&SCom).

The U.S. Army's Aviation and Missile Command (AMCOM) has selected The University of Alabama in Huntsville to create an academic and research program for rotorcraft development. The center's name is: "The Rotorcraft Systems Engineering and Simulation Center. … The Rotorcraft Systems Engineering and Simulation Center will contribute to America's capability for rotorcraft design and development" (RSESC).

The description of the modeling and simulation resource repository of the Canadian SECO (Synthetic Environment Coordination Office) reads: "Manpower modeling based on systems engineering methodology (SECO repository).

Waite's article is titled: "High Level Architecture (HLA) as a Basis of Systems-Engineering Automation for Simulation Based Acquisition (SBA)" (Waite). Another study along this line is titled: "System Engineering and Integration Aspects of a Multi-National HLA Federation Development" (Brassé et al. 2001). Another article is titled: "Closed-Loop Simulation-Based, Systems Engineering Approach to Life Cycle Management of Defense Systems" (Connors et al. 2002).

One of the projects of MITRE is titled: "Distributed Simulation Systems Engineering: How to Play War" (MITRE-DSSE)

Systems Engineering and Simulation Systems Engineering

The following is given at the Systems Engineering page of MITRE: "At MITRE, we know that systems engineering requires the ability to see the big picture—which combines in-depth technical and business capabilities with an understanding of the cultural and communications challenges unique to each of our customers. Systems engineering considers the needs of all stakeholders with the goal of providing a quality product on time, on budget, that meets the needs of each customer's circumstances. … Systems engineering is an interdisciplinary process of understanding operational needs and translating them into a full set of capabilities to be delivered to the customer. It involves concept definition, design, development, implementation, and testing and validation of a system or family of systems. At MITRE, the systems engineering function is tied closely to the needs and decision-making processes of our sponsors and is conducted across entire programs" (MITRE-SE).

The definitions of "system" and systems engineering adopted by the International Council of Systems Engineering (INCOSE) follow.

> "A system is a construct or collection of different elements that together produce results not obtainable by the elements alone. The elements, or parts, can include people, hardware, software, facilities, policies, and documents; that is, all things required to produce systems-level results. The results include system level qualities, properties, characteristics, functions, behavior and performance. The value added by the system as a whole, beyond that contributed independently by the parts, is primarily created by the relationship among the parts; that is, how they are interconnected" (INCOSE-def).

> "Systems Engineering is an engineering discipline whose responsibility is creating and executing an interdisciplinary process to ensure that the customer and stakeholder's needs are satisfied in a high quality, trustworthy, cost efficient and schedule compliant manner throughout a system's entire life cycle" (INCOSE-def).

> "Systems Engineering is an interdisciplinary process that ensures that the customer's needs are satisfied throughout a system's entire life cycle. This process is comprised of the following seven functions.

> ***S****tate the problem.* Stating the problem is the most important systems engineering task. It entails identifying customers, understanding customer needs, establishing the need for change, discovering requirements and defining system functions.

> ***I****nvestigate alternatives.* Alternatives are investigated and evaluated based on performance, cost and risk.

> ***M****odel the system.* Running models clarifies requirements, reveals bottlenecks and fragmented activities, reduces cost and exposes duplication of efforts.

> ***I****ntegrate*. Integration means designing interfaces and bringing system elements together so they work as a whole. This requires extensive communication and coordination.

> ***L****aunch the system.* Launching the system means running the system and producing outputs -- making the system do what it was intended to do.

> ***A****ssess performance.* Performance is assessed using figures of merit, technical performance measures and metrics -- measurement is the key. If you cannot measure it, you cannot control it. If you cannot control it, you cannot improve it.

> ***R****e-evaluation.* Re-evaluation should be a continual and iterative process with many parallel loops.

> This process can be summarized with the acronym SIMILAR" (INCOSE-SIMILAR).

The reader is encouraged to visit the Web site of INCOSE for in-dept information. Indeed, M&S studies may benefit from: clear and thorough **S**tatement of the problem, **I**nvestigating the alternatives, **M**odeling the system (which is a sine quo non step in M&S), **I**ntegration, **L**aunching the system, **A**ssessing performance, and **R**e-evaluation.

The Question

The following question needs to be discussed before a BOK for the simulation discipline is finalized: Should the BOK be only for simulation, for modeling and simulation, or for simulation systems engineering?

This question evokes Lewis Carrol's dialogue in his Alice's Adventures in Wonderland: "Would you tell me, please, which way I ought to go from here? That depends a good deal on where you want to get to. Said the Cat. I don't much care where / Said Alice. Then it doesn't matter which way you go, said the Cat" (Carroll 1865)

The following quotation from John McLeod, founder of the Society for Modeling and Simulation International (SCS) may be a good advice, since a larger scope can be applicable even for simple cases but would not ignore more complex and pragmatically important issues: “The smaller a man, the closer his horizons” (McLeod 1968, p. 321).

With the increasing importance and scope of M&S studies, simulation systems engineering approach may be the only viable way of engineering simulation applications.

ELEMENTS OF THE M&SBOK

Instead of offering an ad hoc listing of topics as a proposed M&SBOK, a framework can provide a basis that can be enhanced by systematic reviews. Each aspect of the framework can then be elaborated on at several levels. For this reason, in specifying the elements of the M&SBOK, a top-down decomposition is followed. For this purpose, first core elements of the M&SBOK and the related supporting domains are identified. They have to be elaborated separately, benefiting from critical view of other M&SBOK studies as well as M&S taxonomies (Ören-M&S-taxonomies) and ontologies (Fishwick and Miller 2004). M&S knowledge, knowhow, products, and services can be considered from two perspectives, namely, from application (their usage) and engine-eering (their generation and provision) points of views.

M&SBOK: APPLICATION PERSPECTIVE

For hundreds of application areas, M&S is often the only tool to solve complex problems and an enabling technology to explore feasible solution(s). As seen in Table 2, these application areas can be grouped under five categories:

Table 2. Application Categories of M&S

• Training
• Decision support
• Understanding
• Education and learning
• Entertainment

In all these applications, 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 as well as real-system enriching and real-system support simulation activities. Their distinguishing characteristics and main purpose of usage are outlined in Table 3.

Table 3. Major Types and Main Reasons of Usage of M&S

Simulation (program) runs independently from the system of interest (SOI)
Stand-alone simulation for • Training • Decision support • Understanding • Education/Learning • Entertainment
Simulation operates together with the SOI)
Real-System Enriching Simulation (RSES) - to Enrich real-system's operation (The SOI and the simulation program operate simultaneously and provide (augmented / enhanced / mixed) reality) for: • Decision support (on-line diagnosis) or Training • Realistic virtual reality (VR) entertainment
Real-System Support Simulation (RS^3) - Support real-system's operation (The simulation program operate alternately with the SOI and provides predictive displays) • For decision support • On-the-job training

In stand-alone simulation activities, the simulation program runs independently from the system of interest. There are five categories of purpose for this type of usage as shown in Tables 2 and 3.

When the simulation program operates together with the system of interest it can *support* or *enrich* real sys-tem operations. *To support real system operation,* the system of inte-rest and the simulation program operate alternately to provide predictive displays. *To enrich the real system operation,* the system of interest and the simulation program operate *simultaneously* to assure *on-line diagnosis* or *augmented reality* (enhanced reality) operation. An example to the last possibility is using virtual aircrafts –referred to as AI-aircrafts– in a dogfight in pilot training. In the sequel, we elaborate on each one of the five categories of usage of M&S.

Use of M&S in Training

In training applications (see Table 4), the goal is not to use M&S. In these applications, M&S is an invaluable and often the only feasible enabling technology to achieve the original aims such as building and enhancing motor skills to use complex and often expensive equipment and vehicles. Some other aims are in line with the adage: "Train as you fight" or in a generalized form: "Train as you operate." Providing real-life-like experience opportunities in a controlled environment is another goal that can be achieved, in a cost-effective way, only by proper use of M&S.

Table 4. Use of M&S in Training

Aim: **use a single** equipment, vehicle

To build and/or enhance motor skills
• To use single **vehicles** such as aircrafts, helicopters, tanks, submarines
• To use single **equipments** such as weapon system simulators (e.g., torpedo simulator)
Virtual simulation
• **Simulators** (with limited environmental interactions)
• **Virtual simulators** (all software)
(to be perceived, for example, by HMDs)

Aim: In line with the adage: "**Train as you fight**" or in a generalized form: "**Train as you operate**"; hence train as you fight, resolve conflicts, support peace, and negotiate.
(Also be flexible to respond to changing needs as stated by Numrich "redefining the war – changing the way we think" (Numrich 2004)).

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)
Interoperable war gaming
• Applications of distributed simulation (HLA)

To provide real-life-like experience opportunities (in a controlled environment)
• To get experience in combat situations
(Real operator uses real equipment with [real &] virtual weapon)
• 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)
(systems of systems; federations of 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
Live simulation
Augmented (enhanced) live simulation

A systematization of use of real or virtual (simulated) equipment by by real or virtual operators is given in Table 5.

Table 5. Relationship of operator/equipment in augmented reality simulation

		Equipment	
		Real	Virtual (simulated)
Operator	Real	Real operator uses real equipment with [real &] virtual weapon (**live simulation**)	Real operator uses virtual (simulated) equipment (**virtual simulation**)
	Virtual	Virtual operator uses real equipment (automated (virtual) pilot)	Virtual operator uses virtual equipment (real operators can interact via HDMs; e.g., AI airplane in dogfight in pilot training)

Use of M&S in Decision Support

Use of M&S in decision support is outlined in Table 6.

Table 6. Use of M&S in Decision Support

Types of Decision	Type of Simulation
Value-free decision Description Explanation Prediction	***Value-free simulation*** • *Descriptive simulation* • *Explanatory simulation* - Proof of concept • *Predictive simulation* - Prediction of behavior/ performance
Normative decision Evaluation Prescription	***Normative simulation*** • *Evaluative simulation* - Evaluation of alternative models, parameters, experimental conditions (scenarios) - Evaluation of alternative policies - Feasibility studies - Sensitivity studies - Acquisition (Simulation-based acquisition) • *Prescriptive simulation* - Planning (Simulation-based planning) - On-line decision support - Engineering design (Simulation-based design) - Virtual prototyping (Simulation-based prototyping)

Use of M&S in Understanding

Simulation Societies Journal "Simulation had the motto "Simulation for understanding." For a taxonomy of understanding see (Ören 2000). The use of M&S for understanding includes test of hypotheses about the structure and functioning of complex systems, especially in natural sciences, social sciences, and human behavior modeling.

Use of M&S in Education/Learning

Simulation is extensively used in teaching/learning systems with dynamic behavior. (Links-Sim4Ed).

Use of M&S in Entertainment

Simulation provides realistic representation for entities having dynamic behavior (IJIGS).

M&SBOK: ENGINEERING PERSPECTIVE

Table 7 outlines the core areas of M&SBOK from the engineering perspective of service and/or product developers and providers.

Table 7. 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

In the sequel each one of the core areas of M&S are outlined. For most of the areas more detailed top-down decomposition will be provided in forthcoming versions of the M&SBOK.

M&SBOK – Input Data

The aspects of input data are highlighted in Table 8.

Table 8. M&SBOK – Input Data

Types, Structure, Analysis, Conditions under which: Instrumented, Observed, Collected

M&SBOK – Models and Modeling

Variables

A multilingual –English, French, Turkish– M&S dictionary, scheduled to be published this year in France (Ören & the French team: Torres et al.) contains –in a systematic way– over 4000 terms and provides an inventory of terms and concepts germane to M&S discipline. As an example, Table 9 contains, the types of "variables" contained in the dictionary. To save space the word variable is omitted at the end of every term. Hence, for example, the first term should be read as "across variable."

Table 9. Types of Variables

Across, Action, Activation, Algebraic, Allocated, Antithetic, Arbitrary, Argument, Artificial, Attached, Auxiliary, Behavior, Binary, Boolean, Bounded, Class, Constrained, Continuous, Continuous-change,

input, Controlled, Coordination, Correlated, Decision, Declared, Declared Random, Dependent, Descriptive, Deterministic, Discrete, Discrete-change, Discrete-time, Discriminant, Dual, Dummy, Endogenous, Essential, Exogenous, Experimental, Experimentation, External, Externally generated, Flow, Formal, Free, Fuzzy, Gaussian, Global, Goal, Holistic, Independent, Initialized, Input, Instance, Instantiated, Instrumentable, Instrumental, Instrumented, Internal, Internally generated, Interpolated, Irrelevant, Key, Lag, Lagged, Latent, Lead, Level, Linguistic, Local, Logical, Monitored, Nonnumerical, Nonobservable, Numerical, Observable, Output, Qualified, Qualitative, Quantified, Quantitative, Random, Rate, Relevant, Run control, Simple, Slack, Stabilized, State, Statistical, Stochastic, Subscripted, Temporal, Temporary, Through, Time, Transition, Typed, Uncontrollable, Uninitialized, Yoked.

As a testimony of the richness of concepts in M&S, a special type of variable, i.e., "input variable" is elaborated and a taxonomy of input variables in conventional as well as artificial intelligence-directed and agent-directed simulation. is provided in Tables 10 and 11 (Ören 2001).

Table 10. Types of Externally Generated Inputs

Mode of input	Type of Input
Passive acceptance of externally generated (exogenous) input (imposed or forced input)	**Type of access to input**: coupling, argument passing, knowledge in a common area, message passing. **Nature of input**: - ***Data*** *(facts)* - *Forced* ***Events*** - ***Sensation*** (converted sensory data: from analog to digital; single or multi sensor: sensor fusion). Sensory inputs include haptic inputs and visual, auditory, and chemical sensation inputs). - ***External goals*** *(imposed goals)*
Active perception of externally generated (exogenous) input (perceived input)	- ***Perception*** (interpreted, sensory data and detected events) -- includes: decoding, selection (filtering), recognition, regulation - ***Perceived goals*** - ***Evaluated inputs*** -- evaluation of inputs (acceptability) -- evaluation of source of inputs (reliability, credibility)

Table 11. Types of Internally Generated Inputs

Mode of input	Type of Input
Active perception of internally generated input	- ***Introspection*** (perceived internal facts, events; or realization of lack of them)
Internal generation of :	- ***Anticipated facts*** *and/or* ***events*** (anticipatory systems) - ***Questions*** - ***Hypotheses*** by: -- Data-driven reasoning (Expectation-driven reasoning) (Forward reasoning) (Bottom-up reasoning) -- Model-driven reasoning - **Goals**

Table 12 outlines topics to be coverd under models and modeling. They will be elaborated on in future versions of the M&SBOK.

Table 12. Models and Modeling

Conceptual modeling Basis for modeling and model processing: system theories, modeling formalisms, modeling methodologies, model specification languages and environments

M&SBOK – Model processing

Model processing includes building and using model bases and model repositories, model analysis, and model transformation (Ören 1983).

Model analysis consists of model characterization (Descriptive model analysis) (see Table 13) and model evaluation (Evaluative model analysis) (see Table 14).

Table 13. Model Characterization

Model characterization (Descriptive model analysis)
Model comprehensibility • *Model documentation* - Static model documentation - Dynamic model documentation • *Model ventilation* (to examine its assumptions, deficiencies, limitations, etc.)
Model usability • *Model referability* - Model integrity • *Model modifiability*

- Model composability

Table 14. Model evaluation

Model evaluation (Evaluative model analysis)
with respect to a **Modeling formalism** *Consistency of representation* of the • component model • coupled model • federated model *Model robustness*
with respect to **Another model** **(Model comparison)** *Structural model comparison* • model verification (comparison of a computerized model with its specification) • model homomorphism • model isomorphism • model equivalencing - for any two models - for a simplified and original model - for an elaborated and original model *Behavioral model comparison* (Comparison of several models within a given scenario)
with respect to **Real system** *Model qualification* • *Model realism* (veracity, verisimilitude) - Adequacy of model structure - Adequacy of model constants and parameters -- Model identification -- Model fitting -- Model calibration • *Model correctness analysis* - Dimensional analysis *Model validity* • Structural validity • Replicative validity • Predictive validity
Goal of the study Model relevance (For single models as well as federated models) • Domain of intended applications - Appropriate use of a model • Range of applicability of a model Acceptability od a model with respect to its technical system specification

Classes of model transformations are highlighted in Table 15.

Table 15. Model Transformation

Isomorphism Homomorphism Endomorphism Simplification Elaboration

M&SBOK – Experimentation

Table 16 highlights main topics concerning experimentation.

Table 16. M&SBOK – Experimentation

Simulation run Length of the run Number of runs Warm-up period Steady-state period Antithetic run
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
Analysis of simulation results Post simulation analysis and report Post live/virtual/constructive simulations reports
Multisimulation (to experiment with several aspects of reality simultaneously

M&SBOK – Model Behavior, Behavior Generation, and Behavior Processing

For an early taxonomy refer to Ören (1987b). Tables 17 and 18 show classifications of simulation based on the nature and generation characteristics of model behavior (Ören 1987a, 1987b).

Table 17. A Classification of Simulation Based on the Nature of Model Behavior

Criteria	Type of simulation
Behavior is trajectory Behavior is structure	- Trajectory simulation - Structural simulation

Table 18. A Classification of Simulation Based on the Generation Characteristics of Model Behavior

Criteria	Type of simulation
Hardware use Hardware is: - used - not used	 - Simulator ((hu)man-in-the-loop simulation) - Simulation - Virtual simulation
Time: Real-time Compressed time Expanded time	 - Real-time simulation - Compressed time simulation - Expanded-time simulation
Procedure: ***Continuous generation*** of model behavior	Simulation run (single-run simulation study)
Intermittent generation of model behavior	
- Multiple runs	- [Multiple-run] simulation study - Antithetic run - Regenerative simulation - Sensitivity simulation
- Nested simulation	- Optimizing simulation -- sim. within optimization -- optimization within sim.
	- Expert system (ES) & Simulation -- simulation within ES -- ES within simulation
- Interaction among decision makers	- Gaming simulation (game-theoretic simulation) -- competition (zero-sum games) wargaming (netcentric wargaming) business gaming -- cooperation Peace game -- coopetition conflict management simulation
Interaction between model behavior generation and the real system	- Stand-alone simulation - Integrated simulation

Some additional topics for model behavior are highlighted in Table 19.

Table 19. Additional Topics for Model Behavior Generation and Processing

Behavior generation techniques - for each modeling formalism
Behavior generation
Behavior analysis: - compression (statistical, numerical, qualitative) - confidence intervals, - variance reduction
Visualization (display, graphics, virtual environments)

M&SBOK – M&S Infrastructure

Table 20 highlights issues of M&S infrastructure.

Table 20. M&SBOK – M&S Infrastructure

Standards	Metadata Documentation of M&S studies Common services Interoperability
Reposito-ries	Specifications of (models, physical environments, scenarios, studies) Data, constants, parameters, auxiliary parameters Simulation components (reusable, extensible, composable)
M&S capability	Rapid, reconfigurable, and adaptive capability HLA, RTI, and beyond Composable frameworks

M&SBOK – M&S Computerization

Table 21 highlights major categories of issues in M&S computerization.

Table 21. M&SBOK – Computerization

Software	Packages, languages, tools, environments
	Large-scale simulation environments
	Problem solving environments with (several level of) simulation abilities
Execution	
Desirable features	Reusability of software with ties to reusability of specifications
	Interoperability: HLA necessary but not

	sufficient (Numrich 2004)
	Integrated composable M&S ability (Numrich 2004)
Special computers	Simulation on high-performance computers
Platform	Web-centric (Web-based, Web-enabled, network-centric) simulation
	Grid computing Simulation on GIG (Global Information Grid)

M&SBOK – User/System Interfaces

Table 22 highlights User/System Interface issues.

For AI support in U/Sis, see Ören (1994). For quality principles in U/Sis, see (Ören and Yilmaz 2005).

Table 22. M&SBOK – User/System Interfaces

Front end interfaces
Back-end interfaces
Sound, color, multimedia, motion, vibration, touch, gesture

M&SBOK – Reliability and Ethics

Table 23 highlights reliability and ethics issues.

Table 23. M&SBOK – Reliability and Ethics

M&S attributes (What? How much?)	• Fidelity
	• Resolution
	• Scalability
Ethics	(for individuals and organizations)
Types of errors in:	• Instrumentation • Data collection • Experimentation • Scenarios (consistency of joint scenarios in federations and federations of federations) • Computation - Numerical computation - Soft computing • AI: Rule-based (expert) systems • Software agents (trustworthy agents, moral agents) • Types of fallacies in logic - paralogisms, sophisms • M&S infrastructure
Built-in quality assurance	• Algorithmic checks of completeness and consistency • Rules for built-in quality assurance
V&V	Validation, verification, and testing (VV&T) techniques (aims, applicability, scope, limitation)
Accredita-tion and Certification	• Authority • Validity conditions and period • Computer-aided VV&A • Documentation of VV&T certification - Procedures - Scope/limitation
Implementa-tion	• Monitoring, Evaluation
Lessons learned	• Do's and Don'ts in M&S

M&SBOK – M&S History

Table 24 highlights issues related to M&S history.

Table 24. M&SBOK – M&S history

Analog simulation: Differential analyzer
Hybrid simulation
Simulators: First pilot trainer of Link (1929)
M&S languages: Early languages and their critique
Early applications: Space flight simulations …
Visualization for simulators, synthetic environments: The beginnings

CORE ELEMENTS OF SUPPORTING DOMAINS

Core elements of the supporting domains and needed competency requirements are outlined in Table 25.

Table 25. Core Elements of Supporting Domains

Area	Competency Requirement
Simuland	Application domain knowledge is essential
Systems Engineering	For large and complex simulation studies
Mathematics – differential equations	For engineering or scientific applications
Mathematics – numerical analysis	For engineering or scientific applications
Queuing theory	In discrete systems
Probability and Statistics	For discrete systems
Physics	For engineering or scientific systems

Software engineering	For developers of M&S tools/environments
Artificial intelligence	
Software agents	
Project management	If will become manager or supervisor, otherwise to appreciate the needs
Interpersonal skills	For team work
Oral and written reporting and documenting	

Simuland

Simulation is applicable in all cases where experimentation with dynamic models is beneficial. Hence, it has a very large application area for existing or engineered systems. Table 26 highlights some application domains.

Table 26. M&SBOK – Simuland

Existing or designed system of interest (real system)
Application domain knowledge: Defense, Education, Engineering (aerospace, electrical, mechanical, chemical, civil); Science (Physics, nuclear physics), Human behavior (personality, emotions, cultural background), Social science, Political science, Meteorology, Astronomy, Transportation, logistics, Energy, Health care (medicine, pharmaceutical), Process control, Manufacturing, Business, …

Systems Engineering

The systems engineering paradigm (see Table 27) needs to be combined with simulation life cycle paradigm to be complete.

CONCLUSION

A BOK for M&S can be very useful to provide a comprehensive and integrative view of the discipline, for self-assessment and for assessment of professionals and organizations, as well as for curriculum development for academic or professional development courses and degree programs.

The way we perceive reality affects (directs/limits) our actions. Since the realization of simulation as a model-based activity (Ören, Zeigler 1979), simulation discipline realized quantum advancement. Now that simulation is applied to many complex and large scale projects, it may be beneficial to perceive the field from the perspective of simulation systems engineering to assure needed reliability. An M&SBOK from this perspective may be very useful for the discipline and the stakeholders.

Table 27. M&SBOK – Systems Engineering Paradigm for M&S

State the problem   *Assure consensus* of the customer on the life cycle of the project, needs, goal, and several performance metrics: • Fitness to purpose, Usefulness, Usability, Cost effectiveness, Timeliness, Efficiency, Maintainability at specification level / code level   • Scope of usability/applicability   • Document at every level: of the study, system, assumptions (explicit, implicit), … (Documentation standards)
Investigate alternatives
Model the system
Integrate   Systems of systems   Federations of federations
Simulate the system
Launch the system
Assess performance   • Consider the success of M&S from satisfying the original goal of the system and not just a limited point of view such as efficiency of M&S study.   • For military applications, for example, as expressed by Darkin (2004): "What impact have we had on how soldiers, sailors, and marines prepare for and execute their missions?"   • Similarly, use a goal-directed performance assessment, in all application areas.
Re-evaluate

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M&SBOK and I look forward receiving views for this purpose.

QUESTIONS

- Cite the possible benefits of having an M&SBOK.
- Give at least four reasons why time is ripe to have an M&SBOK.
- What is stand-alone use of simulation?
- Cite four stakeholders of M&S and enumerate for each one, two benefits of having an M&SBOK
- Enumerate five core areas in M&S.
- Cite five application categories of M&S
- Explain the difference between simulators and virtual simulators
- Explain two types of constructive simulation
- Cite five types of simulation used for decision support
- Enumerate five core areas in supporting domains of M&S.
- Enumerate ten types of variables.
- What types of simulation we can discern by taking into account interaction among decision makers (players)? Give three examples.

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