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TOWARDS AN ENCYCLOPEDIA OF MODELING AND SIMULATION METHODOLOGY

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ABSTRACT

Modeling and Simulation is both multidisciplinary and interdisciplinary. While this provides great benefits to the discipline, it poses great challenges in that 1) the body of knowledge is often dispersed in application areas and 2) each application area develops and uses methods that are seemingly unconnected with one another and are difficult to relate into a cohesive body of knowledge. In this paper, we propose the creation of an encyclopedia of Modeling and Simulation methodologies in order to address these challenges. We survey the structure of several encyclopedias and propose a taxonomical structure and tentative content for the book. We present the characteristics that such a book should have and discuss the potential benefits and areas of growth.

1 INTRODUCTION

The idea of an *Encyclopedia of Modeling & Simulation (M&S)* is inspired by the authors' participation in the development of the *Modeling and Simulation Knowledge Repository* (MSKR 2014) and the teaching of introductory M&S courses at the graduate and undergraduate level. One of the observations in trying to convey the breadth of M&S is the difficulty in relating topics in a coherent narrative. As the discipline of M&S continues to emerge, it is essential to collect and organize the Body of Knowledge (BoK) so as to provide a nuanced and contextualized view of past and present work. Diallo et al. (2015) have shown that while M&S is strongly related to computing and systems science, it is conceptually its own discipline. Past and current efforts have focused on creating thesauri of M&S terms in general (IEEE 1989) or in a particular domain; e.g., military glossary of terms (DOD MSCO 2011). Beyond the establishment of dictionaries, Birta (2003) and Oren (2005), among others, have recognized the need for the establishment of a BoK in M&S and proposed frameworks to organize the discipline. More recently, scientometric studies that aim at identifying key concepts, authors, methods and publications have shown that the discipline is self-organizing into meaningful clusters (Mustafee et al. 2012; Mustafee et al. 2014). However, several challenges remain towards the pursuit of realizing a universally recognized M&S BoK:

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- *Independently Developed Theories, Frameworks and Tools:* Mustafee et al (2012) identified over one-hundred M&S theories, technologies, approaches and techniques. The challenge is that M&S theory and practice is still not united in a commonly accepted coherent framework where theories are instantiated into frameworks and frameworks are implemented in tools. As a result, it is difficult to classify tools and frameworks and compare theories to identify complementarity and divergence. In addition, it is difficult to evaluate whether a tool that is applied in one domain is applicable in another or whether a framework that works well in one domain is transferable to
- another. For instance, the Discrete-EVent system Specification (DEVS) was formulated as a theory but is now instantiated into different frameworks (Cell-DEVS, Parallel-DEVS, etc.) that are each implemented in tools. As a result it is fairly simple to understand the use of tools and to compare the frameworks. However, this is a rare exception;
- *Multitude of Application Areas:* Oren (2005) states that M&S is applicable in all engineering areas, in most of the scientific domains and the entertainment business. Consequently, it is a challenge for scientists in one domain to understand and use methods that are frequently used in another application area. As a result, it is arguable that advancements in M&S brought about through scientific enquiry taking place within the confines of a particular domain do not necessarily percolate through towards the overall development of the M&S discipline. This lack of transparency is exacerbated by the academic publication and evaluation systems; e.g., international journal rankings like the UK Association of Business Schools' (ABS) *Academic Journal Quality Guide* (ABS 2015), that puts more value on publications arising from scientists' immediate work domains. For instance, even though structural equation modeling is prevalent in managerial science, it is seldom used in system science, even though the idea of understanding and explaining the variance in an outcome in of interest in both domains.

While these challenges will not be solved overnight, it is important to continue the work of pioneers by cataloging M&S such that it is relatively easy to identify similarities in theories, frameworks, methods and tools. This paper contributes by providing a first step towards a comprehensive encyclopedia of M&S. The remainder of the paper is structured as follows: Section 2 reviews the field of *Operations Research and Management Science* (ORMS) to identify existing work in this sphere. Section 3 reviews books in the M&S field to identify the main topics within M&S as theory, application, and tools. Section 4 describes the structure of the proposed encyclopedia. Section 5 describes the method for acquiring data and building content. Section 6 proposes a timeline and schedule and discusses how the encyclopedia will be maintained and extended before we conclude in Section 7.

2 REVIEW OF KNOWLEDGE REPOSITORIES IN ORMS

ORMS offers analysts a wide plethora of predominantly quantitative tools to help model the system of enquiry. In ORMS literature, M&S tools and techniques, when used in the context of business and management, are considered to be a subset of this wider discipline. The *Institute for Operations Research and Management Sciences (INFORMS)* in the US has, for example, the *INFORMS Simulation Society*; among the premier publications of INFORMS is the *Operations Research* journal which includes an area editor specially for Simulation. Similarly, the *UK Operational Research Society (UKORS)* has a special interest group in Simulation. Further, UKORS publishes a journal that specially focuses on M&S – the *Journal of Simulation*. The authors therefore consider it pertinent to look wider than the specific area of M&S and try to identify existing efforts in the ORMS discipline which may have led to the development of indexable reference material, compendium of knowledge, and encyclopedia, among others. Our search has identified ORMS keyword lists that are maintained through organizational effort and academic endeavor. Furthermore there exists reference materials that provide an intellectual scaffolding for this discipline through in-depth discussion on individual ORMS techniques, tools and application domains. These initiatives are much wider than review papers or indeed textbooks. In the remainder of this section we discuss the most important artefacts that we have identified in relation to keyword lists and encyclopedias.

The keyword list maintained by the INFORMS uses keywords from the *American Annual Comprehensive Index (ACI)*. The keywords in this list are accompanied by a three-digit code and the list includes 442 entries. However, this scheme has not been updated since 2001 as it was superseded by the *International Abstracts in Operational Research (IAOR)*. Yet, there are remarkable differences between the two schemes both in terms of the keywords used as well as to the categories adopted for classification. IAOR is maintained by the *International Federation of Operational Research Societies (IFORS)* and is quoted to be the "definitive database of the world's OR/MS literature; it consists of 68,000 abstracts from over 1200 individual journal titles, going back more than 25 years" (IFORS/IAOR 2013). In the IAOR database all entries are classified and indexed by keywords. Presently this consists of 184 words and expressions, which have four-digit codes. It is also accompanied by a second list which is much longer and contains 1600-plus words and phrases which have been used to further classify abstracts but are not structured in a scheme. Over the years the IAOR editors have modified the classification scheme from the original list that was created over 50 years ago (Rand 2001). Why is a keyword list important when considering the development of an encyclopedia? It is arguable that keywords from extant literature will help in the identification of the intellectual core of the discipline, since the keywords and their frequency (retrieved subsequent to parsing meta-data relating to papers published over the decades) would offer insights on specific discipline-related topics. Furthermore, a hierarchical and multi-level keyword structure would go a long way in establishing a classification scheme for a discipline. This has already been done in Information Systems (Barki et al. 1988; Barki et al. 1993; Dwivedi et al. 2009).

Our search has identified one important ORMS compendium of knowledge. The "Wiley Encyclopedia of Operations Research and Management Science" (Cochran et al. 2011) is marketed as an "unparallel undertaking" that is devoted towards the advancement of ORMS. It is a multi-volume authoritative reference (8 volumes; over 6000 pages) which has won the Reference and User Services Association's (RUSA) *2011 Award for Outstanding Business Reference Source*. The encyclopedia is an archive of research papers classified into more than 30 categories, which may refer to OR methods (e.g., Linear Programming, Qualitative OR, Game Theory, Simulation Modeling and Analysis), OR application areas (e.g., Industrial Applications, Retail and Service Applications, Transportation and Warehouse), or indeed OR application contexts (e.g., Reliability and Maintenance, Supply Chain Management). If the authors are allowed to offer a critique, the organization by topic (as it currently stands) is perhaps not ideal since OR techniques, application areas and application contexts are all included and there is no hierarchical ordering of articles under sub-topics. A multi-level keyword classification list would have arguably led to better structure and would serve to facilitate better recognition of both the breadth and the depth of this field. Furthermore, some topics are not covered in sufficient detail; to an extent this is understandable as the scholarly body of ORMS is humongous and the encyclopedia tried to cover all relevant research that it represents. Taking the example of the coverage of M&S in the Wiley encyclopedia, it has a total of only 16 articles and includes topics on random numbers, conceptual Modeling, discrete-event simulation, rare-event simulation, distributed simulation (Taylor and Mustafee, 2010), and sensitivity analysis, among others. There is obviously a gap in the encyclopedia's representation of the M&S BoK, and it is our hope that this work will go a long way in addressing this gap.

3 REVIEW OF M&S BOOKS: THEORY, APPLICATION, AND TOOLS

Books within M&S focus on three topics: the theory of M&S that contributes to the discipline as a whole (Fishwick 1995; Law 2007; Sokolowski and Banks 2010), specific application areas for M&S (Sokolowski and Banks 2009; Sokolowski and Banks 2011; Sokolowski and Banks 2012; Tolk 2012), and M&S tools (Borshchev 2013; Kelton, Sadowski, and Swets 2010). The books that cover the discipline of M&S as a whole focus on the paradigms and the theories that build the foundation of the field and allow for the creation of models and simulations. The books that discuss specific application areas within M&S focus on how the paradigms and theory within the discipline are applicable to solving real questions. The books that discuss tools focus on how specific tools are designed and used to build models and simulations. These three categories are elaborated upon within this section.

The work of Sokolowski and Banks (2010) provides an overview of the M&S domain spanning from the theoretical bases to the practical domains that benefit from M&S. This work provides an introduction to M&S covering individual paradigms, methodologies, examples, and visualization with describe the fundamentals, characteristics, and categories comprising M&S. Paradigms within M&S are presented in order to provide the theoretical basis of how to conduct modeling exercises. These theoretical bases are connected to methodologies which apply M&S to real scenarios within the social sciences and behavioral modeling domains. The work of Fishwick (1995) provides an overview of model designs, types, and algorithms as well as types of simulations. This work outlines the role of simulation, the foundations of model design, and the construction of conceptual models. Additionally, this work covers the topics of declarative modeling, functional modeling, constraint modeling, spatial modeling, multimodeling, and parallel and distributed simulation. The work of Law (2007) covers the basics of simulation modeling from the nature of simulation to specific modeling paradigms to the advantages and disadvantages of simulation. This work discusses types of software packages and how they support M&S processes. The theory of selecting input distributions, random-number generators, output data analysis, experimental design and optimization is also discussed in this work.

The work of Sokolowski and Banks (2009) provides an application of M&S to the social sciences by representing real world events and human behavior. This work covers advantages and disadvantages of M&S for problem solving and presents system dynamics, agent-based modeling, social network modeling, and game theory paradigms for modeling global behavior. The application of each of these paradigms to the social sciences is provided by applying each paradigm to different case studies at the global level. Tolk (2012) presents the application of M&S to the military domain. This work discusses the challenges of modeling combat and in using distributed simulation and presents the history of combat modeling. Specific attention is given to modeling movement, sensing, effects, the environment, communication, command, and control as these are integral components of combat. This work also discusses distributed simulation and the challenges, standards, and verification and validation aspects of distributed simulation.

Sokolowski and Banks (2011) displays the application of M&S within the medical and health sciences and discusses on the terms, paradigms, ethics, and research and development components of M&S. Sokolowski and Banks (2012) presents real world applications for M&S and provides examples pertaining to modeling human behavior in the context of the military and public transportation among others. Kelton, Sadowski, and Swets (2010) presents the simulation concepts surrounding discrete event simulation and progresses through an in-depth tour of the Arena software. Borshchev (2013) provides an overview of the AnyLogic simulation tool that allows for the construction of models using discrete event simulation, agent-based modeling, system dynamic, and combinations of these paradigms. This work examines the perspectives that accompany these three paradigms and focuses on how to construct simulations using these paradigms individually and collectively. As this work deals with the implementation of simulations, the effects of virtual and real time units are examined along with user interfaces and animation.

While these works cover a wide range of topics of M&S, there is not a single source that covers the entire range of topics comprising the discipline, application, and tools. Our hope is to incorporate the three categories of M&S theory, M&S application, and M&S tools into the encyclopedia of M&S.

4 STRUCTURE

Existing encyclopedias provide insights into what is needed to create an effective encyclopedia of a discipline. The “Wiley Encyclopedia of Electrical and Electronics Engineering” provides engineers access to topics within electrical and electronics engineering (Webster and Wiley Interscience 1999). Additionally, it provides information pertaining to education, historical background on fields within this discipline, patents, societies, technologies, and related topics within computer and software engineering. The "Encyclopedia of Medical Devices and Instrumentation" focuses on the practice of medicine using medical devices (Webster and Wiley 2006). The topics within this encyclopedia include current developments and expected future advances in medical devices which are written by experts within their respective fields, such as fiber optics and signal processing. The "Encyclopedia of Software Engineering" covers the topics of ethics, licensing, certification, education, training, and terms and standards for software engineering (Marciniak and Wiley 2002). These topics help us formulate a set of requirements to help guide our vision.

The *first* requirement is that the encyclopedia provides an overview of the field of M&S and complements the in-depth coverage of topics in books rather than replace it. This requirement means that we need to provide the reader with an understanding of a topic and how it relates to other topics in M&S. For instance, we can describe discrete-event simulation in a way that conveys to the reader what the topic is without going into the details of a specific engine or tool.

The *second requirement* is that encyclopedia be extensible to accommodate the incorporation of emerging topics. We anticipate that the reach and diversity of M&S will expand with the emergence of new technology and we need a way to quickly incorporate these topics in the encyclopedia.

The *third requirement* is that the encyclopedia is comprehensive in its reach. This requirement means that we are interested in modeling and simulation in all of its aspects without any limitations (conceptual, geographic, application domain, etc.).

The *fourth requirement* is that we focus on the worldview espoused by a topic. We believe that by doing so, we are able to capture the essence of the topic and thus we can relate it to other topics. For instance, if we are discussing simulation methods, Discrete Event Simulation forces one to view the world (or *referent* to be more specific) into a set of discrete states where transitions are caused by events, whereas Discrete Time is similar but the change in step happens at specific times. Monte Carlo simulation on the other hand forces us to see to see the world as a series of stochastic processes made of independent events. All three can be implemented in the same simulation engine but this requirement forces the authors to provide the reader with a mind map of how to approach the world when using a particular method. In short, our goal is to be as inclusive and exhaustive as possible.

In order to satisfy these requirements, we propose the structure shown in Table 1 and have numbered the topics and sub-topics. Although we do not currently plan to develop a keyword classification scheme for M&S (arguments for which were presented in Section 2), this can be considered as future work; such a classification scheme will enable us to better define the table structure by applying academic rigor in the generation of the topics and sub-topics. At the time of writing, we consider the top level topics to be, *Modeling*, *Simulation*, *Application Areas*, *Grand Challenges* and *Key Figures*. We distinguish between modeling and simulation to accommodate the fact that they are two distinct and complementary activities. In the field of M&S, it is possible to consider them as being part of a continuum that starts with a model, goes through a simulation (computer experimentation) and ends with analysis. However, we have to recognize the existence of models that are not meant to be executed on a digital computer (cognitive models, business process models, data models, etc.) as we understand it in M&S. We thus believe that the encyclopedia should not be restrictive; therefore, we want to impose as few rules as possible so as not to bias the view of M&S. Consequently, we distinguish between *Modeling Theories* and *Modeling Methods* that aim to explain modeling (what is modeling?, how to model?) and simulation theories and methods that aim to explain simulation (what is simulation?, how to simulate?). It is important to note that we include *Verification and Validation* and *Accreditation* as sub-topics for both the parent topics *Modeling* and *Simulation*. For instance a mathematical model can be verified and validated (i.e. it is a fair representation of a natural process then implemented in a simulation engine that has been verified and validated separately (i.e. the engine is a fair representation of a computational process through approximations and discretization). Once implemented in the engine, the equation has to be verified again but not validated. These three processes while sharing the same objective are different in practice and therefore should be captured separately.

Similarly, we distinguish between *Modeling Languages* and *Simulation Languages* with the distinction that a modeling language captures the description of a model in an non-executable form while a simulation language is one that is executable by a digital computer. For instance calculus (differential equation) is a modeling language while C++ or Java is a programming language which can be used for developing simulations. *Modeling Languages* can be formatted or formal but it is to be noted that formal languages such as ALLOY or OWL are modeling languages even though they allow one to reason over them through an engine.

The *Engineering Process* that guides the life cycle path from *Model Language* to *Simulation Language* should also be considered as an important knowledge key for M&S. This process is frequently based on Model Driven Engineering (MDE), it can be standardized or not. A particular variant of the MDE is the Model Driven Architecture (MDA) that is a software implementation approach, proposed and supported by the OMG, it has been investigated early by Tolk (2002) to evaluate its contribution to simulation engineering. Others variations have been developed, e.g. Model Driven Interoperability (MDI), (MDSEA) or, in the software domain, Microsoft DSL Tools. The DSEEP is, among others, a methodological guide of best practices for engineering and execution of distributed simulations (IEEE 2010). It describes an engineering process dedicated to the distributed simulation structured under 7 stages, covering the entire life cycle of a distributed simulation, from the definition of requirements and objectives for the operation of the simulation results, through simulation design. The DSEEP replaces and extends FEDEP to other than distributed simulations using HLA. Several initiatives exist to implement these concepts, eventually combining many of them (Tu et al. 2013). It is essential to use a management methodology to support a M&S project, in particular to rationalize the development for complex M&S applications. To implement the model driven approach the model transformation can be used (Bocciarelli et al. 2014) (Bazoun et al. 2014). In that case the use of semantic approach can be an issue to match the different categories of models (Song et al. 2012).

Finally, we distinguish between *Academic* applications which cover the use of M&S for scientific discovery and *Industry* applications which cover the use of M&S in professional business settings. We use the *North American Industry Classification System (NAICS)* code classification for industry as the basis to list M&S applications because it has a large list of professional categories. In addition, this list can be extended to accommodate emerging areas and allows the encyclopedia to be exhaustive and grow with the emergence of new industries. For the same reasons, we propose the use of the *Digital Commons* list of academic disciplines as the potential list of academic areas where M&S can be applied (Bepress 2015).

Grand challenges capture open problems that need to be tackled as a community in M&S. These problems can be domain specific or general and can range from technical to methodological and theoretical. For instance, Tolk (2009) discusses the challenges with modeling human behavior while Taylor et al. (2013) examines grand challenges on the theory of modeling and simulation and Taylor et al. (2012) presents a series of grand challenges for M&S in general. The encyclopedia needs to capture and organize these challenges so that when they are solved or proven to be unsolvable, we can make the community as a whole aware of that outcome.

Table 1: An overview of the topics and sub-topics of the proposed encyclopedia of M&S.

Topic	**Sub-topic-1**	**Sub-topic-2**
A. Modeling	**A.1** Theories	
	A.2 Methods	
	A.3 Tools	
	A.4 Frameworks	

	A.5 Languages	
	A.6 Verification and Validation	
		A.6.a Methods and Frameworks
		A.6.b Tools
	A.7 Accreditation	
		A.7.a Organization
B. Simulation	**B.1** Methods	
	B.2 Tools	
	B.3 Environments	
	B.4 Languages	
	B.5 Verification and Validation	
		B.5.a Methods and Frameworks
		B.5.b Tools
	B.6 Accreditation	
		B.6.a Organizations
C. Engineering Process	**C.1** General Methodology	
	C.2 Dedicated Methodology	
D. Application Area	**D.1** Academia	
		D.1.a Digital Commons
	D.2 Industry	
		D.2.a North American Industry Classification System (NAICS) code
E. Grand Challenges	**E.1** General	
	E.2 Domain-specific	
F. Pioneers and Key Figures		

The final topic of the encyclopedia recognizes the importance of the *Pioneers and Key Figures* of M&S, and its purpose is to capture information for the same. Persons are considered key if they are recognized as having contributed significantly to topics in M&S. Our intention is not to create a Who's Who of M&S, rather we wish to make readers aware of important figures that have advanced the field theoretically, methodologically or have contributed to the practice. For instance J.W. Forrester can be considered a pioneer because of his formulation of System Dynamics, while Edgar Cobb and Peter Chen are key contributors because of their impact in Data Modeling Theory. Usually key figures are recognized by societies and professional organizations as such. This year has also seen the release of a book recognizing the contribution of Tuncer Ören works (Yilmaz 2015), and it is our expectation that our encyclopedia will extend tribute volumes to these works.

Having specified the topics and sub-topics, we now focus on the structure of each topic (Table 2). For every method, theory, framework, language, and grand challenge, we propose the following structure:

- *Overview:* The overview captures the essential components of the topic. It presents its main tenets, and principles. The goal is to give the reader a quick introduction of the topic
- *History:* The historical perspective allows the reader to understand the state of the art at the time the topic was brought to the forefront. This historical perspective allows the reader to understand the most prevalent way of thinking and allows her to appreciate the contribution of the topic.
- *Worldview:* The worldview presents the axiomatic structure that the topic requires in order to function. This axiomatic structure usually requires a certain way to look at the world in order to model it. We ask that authors describe how objects and relationships are viewed within the topic

but most importantly we require them to describe how time is conceptualized and to capture what causes change to occur according to the topic. Our goal is to allow readers to see the world according to the topic and by doing so help them compare, contrast and select topics.

- *Problem Space:* The problem space captures a description of the type of problem that the topic is considered to apply to. We also ask authors to describe what has to be known and assumed about the problem in order to apply the topic. The goal here is to go beyond a listing of application domains and help the reader relate a topic to a family of problems characterized by certain properties.
- *Application Area:* Since we have two large lists of application areas, we ask authors to relate the topics to the relevant areas. This approach is more in line with what is traditionally found in textbooks.
- *Overview, History and Contribution:* For Pioneers and Key figures, we provide a biographical overview, the historical context at the time of their work and a summary of their contribution. We hope to provide the readers a sense of perspective of the relative importance of the work of each pioneer and key contributor.

While this structure is subject to change, it represents the basic philosophy behind the concept of an encyclopedia of M&S. Next, we present our data collection and content building strategy.

Table 2: An overview of the topic and sub-topic structure for the proposed encyclopedia of M&S.

Topic	**Structure**	**Sub level**
Modeling **(A)** - Theory **(A.1)**, - Methods **(A.2)**, - Frameworks **(A.4)**, - Languages **(A.5)**, - V&V **(A.6)** Simulation **(B)** - Methods **(B.1)** - Tools **(B.2)**, - Environments **(B.3)**, - Languages **(B.4)**, - V&V **(B.5)** Engineering Process (D) Grand Challenges **(E)**	Overview	
	History	
	Worldview	Objects
		Relationships
		Time
		Dominant source of change
	Problem Space	Overview
		Type
		Knowns
		Assumptions
	Application Area	
Pioneers and Key Figures **(F)**	Overview	
	History	
	Contribution	

5 DATA COLLECTION AND CONTENT BUILDING

The scope of this project requires the participation of a large number of experts engaged in M&S. We recognize that this effort will never be truly finished and the encyclopedia is merely a report that reflects the time of its publication (however, the M&S knowledge repository can be kept updated through the publication of subsequent editions). As a result, we need to formulate a strategy for collecting, vetting and managing data. First, it is important to distinguish between sources, and contributors. Sources comprise of data that is publicly or privately available. As editors, we will strive to identify, organize and mine sources to retrieve information on what topics should be included. Contributors are individuals that will take ownership of a topic and organize it as described in this paper. We intend to solicit contributors in two areas:

- *Professional Organizations and Experts:* This is an obvious source of contributors and we plan on inviting contributors for input based on their level of expertise and area of work;
- *Social Media:* Through this channel (Research Gate, LinkedIn groups, etc.) we will identify experts that have practical experience in a topic and ask for their contribution in domains where they excel. The topics covered by experts include but are not limited to tools and frameworks;

Each contributor will be listed as the main point of contact for the topic (subject area experts) and will be responsible for collecting and accepting updates for the assigned topic. By doing so, we empower them to manage their topic but we also ask them to link their topic to the rest of the M&S BoK. Furthermore, we encourage people to volunteer topics for potential inclusion. The editors will review the topic and work with the person proposing it to ensure that it is not already covered as part of another topic. Table 3 shows an example list of topics organized according to the structure proposed in Section 2.

Table 3: An sample of topics and their prospective content. Each content is assigned to a contributor who will provide the content based on the proposed structure.

Topic	**Content**
Modeling Methods	Finite Element Modeling; Structural Equation Modeling; Mathematical Modeling; Bond Graph Modeling; Petri Nets; Markov-chain Modeling; Statistical and Monte Carlo Modeling; Stochastic Modeling; Visual Interactive Modeling; Bayesian Networks; Discrete-Time Modeling; GERT -Graphical Evaluation and Review Technique; Meta-Modeling; Semi-Markov Model
Modeling Theories	Composable Cellular Automata Formalism; Devs – Devs/soa; Devs – DsDevs; Devs – eUDevs; Devs – GDevs; Devs – RDevs; Devs - Cell space approach (note: this is different from Cell-Devs); Formal Specification and Analysis (Maude); Heterogeneous Flow System Specification Formalism
Modeling Languages	UML, SysML, ALLOY, PVS, BPMN, BPEL, IDEF, Z, B
Simulation Methods	Discrete Event Simulation; Monte Carlo Simulation; Numerical Simulation; Real Time Simulation Discrete-Event Simulation and Visualization; System Dynamics; Trace-based Simulation Continuous Simulation/Flow Simulation; Statistical Simulation (including Regression and Poisson Simulation) Rare Events Simulation; Software-In-The-Loop Simulation; Stochastic Simulation; Virtual Reality Simulation; Web-based Simulation Chaos-based Simulation; Interval-based Microscopic Simulation; Qualitative Simulation and Prediction; Simulation Visualization; Spreadsheet Simulation
Engineering Process	MDE, MDA, FEDEP, DSEEP, MDI, MDSEA

In order to accommodate the social aspect of building the repository, we will host a site where any interested reader can follow the progress of the encyclopedia and potential contributors can submit topics. Technically a solution to facilitate hosting and concurrent participation can reside in a collaborative content management system based on a Wiki-like approach.

6 TIMELINE AND SCHEDULE

We envision the development of an initial version of the encyclopedia to take one year starting from the date of the official agreement with the publisher. Our proposed timeline is divided into four quarters:

- *First quarter:* Our goal is to finalize the topics and contributors to be included in the first release of the encyclopedia. To that effect, the editorial team will first finalize the content, then identify contacts and obtain agreement from contributors;
- *Second Quarter:* The focus of this quarter is to build and setup the encyclopedia corpus and conduct a data collection effort. Our goal is to 1) identify and consolidate M&S related work in a single place, 2) organize the information in the structure defined here and 3) provide mechanisms for adding topics and volunteering to contribute. In addition, we will identify a team of reviewers to ensure that the contributions are accurate and representative.
- *Third Quarter:* We will collect contributions and begin the review process. We intend to finish the setup of the site and start populating it with the data that we have collected. The reviewers and contributors will start communicating and exchanging different versions of their work
- *Fourth Quarter:* We plan to conclude the reviews, and begin assembling the encyclopedia. At the end of this quarter, the initial version of the work will be turned over to the publishing office for final review. We intend to ask the reviewers to have a final look at the work before it is finalized and shared with the community.

We expect this process to be iterative and fluid. The priority of topics might change depending on the commitment and availability of contributors.

7 CONCLUSION

As a contribution to the growth of M&S, we propose the development of an encyclopedia of M&S. The goal of this encyclopedia is to organize and link the body of knowledge of M&S such that students, professionals and academics can easily select, compare and contrast M&S topics. In addition, our goal is to provide historical and philosophical mindsets embedded within M&S theories, methods and practices. In this paper, we propose a structure that we believe could achieve those goals and invite the M&S community to contribute to the realization of this work.

It is important to note that we are not limiting our vision to engineering and computer science M&S. Our aim to provide as comprehensive a view as possible and to capture the evolution of M&S over time. The challenge is getting the M&S community to work together to achieve this goal and we believe that this is possible in the near future in light of the work that has already been done by pioneers in the field.

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