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CONTENT CONSIDERATIONS FOR SIMULATION CONCEPTUAL MODEL DOCUMENTATION

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ABSTRACT

A simulation conceptual model (SCM) has many uses such as supporting clarification of the model design across stakeholders, guiding the computer model development, and supporting verification and validation efforts; however, proper documentation of the SCM is critical. SCM literature covers approaches and methods for developing SCMs, and for documenting SCMs, but literature directly addressing content considerations for SCM documentation is sparse. In this paper we address the determination of what content should be include in SCM documentation to maximize its utility. We first synthesize information across the literature, creating a superset of types of SCM content, and also discuss different audiences and their purposes for SCM documentation. We then provide a first-pass analysis of what types of content are most important to include in SCM documentation for different audiences and purposes, offering insights for determining which types of content to include in any given model's documentation.

1 INTRODUCTION

A common theme in literature pertaining to simulation conceptual models (SCMs) is that conceptual modeling is an important part of the process of developing a computer simulation model, and that conceptual modeling activities should be explicitly undertaken prior to implementing a model in code. An SCM is beneficial for supporting clarification of the model design across stakeholders, guiding the development of the computer model, and supporting verification and validation efforts, among other things. However, without proper documentation, the usefulness of the SCM for these purposes is significantly hampered.

Much of the SCM literature covers approaches for developing SCMs, standard formats and languages for representing SCMs, and approaches and tools for documenting SCMs (e.g., Alves et al. 2024; Gabriel et al. 2022). Balci and Ormsby (2007) also mentions that SCM documentation can be specified "in a variety of communicative forms such as animation, audio, chart, diagram, drawing, equation, graph, image, text, and video". However, literature explicitly addressing what content should be included in SCM documentation is sparse. The majority of SCM papers that do mention types of content to be included in SCM documentation do so in passing, many merely providing a brief list of a few types of content; they also differ significantly on what is seen as important content to be included in the documentation. When considering which types of information to include in the documentation for an SCM, a primary consideration should be the needs of those who will be using the documentation, i.e. the audience. We found few papers that specifically discuss the different audiences for SCM documentation, or their differing needs. Therefore, this paper focuses specifically on the documentation of SCMs, notably the determination of what content should be included in the SCM documentation to maximize its utility, considering each documentation audience and their needs.

An inherent difficulty when discussing topics pertaining to SCMs is the lack of consistent use of terminology; therefore, we first provide some important clarifications. We then review relevant literature, synthesizing information pertaining to SCM documentation content, resulting in a list of different content types. We next specify a variety of audiences for SCM documentation. The specification of the audience,

coupled with an understanding of the purpose for which each audience might require the SCM documentation, then forms the basis for determining the types of content that should be included in the SCM documentation. We then provide a first-pass analysis of the content types, audiences, and purposes, identifying what types of content would be most important to include in SCM documentation for the different audiences and purposes.

2 DEFINITIONS AND CLARIFICATIONS

When studying the literature pertaining to SCMs, it quickly became apparent that there are differences in definitions and uses of fundamental terminology. In fact, in his 2020 paper on grand challenges for simulation conceptual modeling, Robinson points out that, "A key problem is a lack of agreement on the definition of a conceptual model." The primary difference in definitions of an SCM can be summarized as: some think of the SCM as describing the "real world problem domain" or key information about the "system under investigation", while many think of the SCM as describing the conceptualized simulation model that is an "abstraction from the real world" (Robinson 2020). In this paper we subscribe to the second interpretation of SCM and instead use the term *simuland* to refer to the information about the real-world system being simulated (DoD 1998).

When reviewing the SCM literature, it also became evident that the term *conceptual model* (CM) was being used to describe both the SCM and the documentation of the SCM. Even in the papers where model documentation was explicitly discussed, very few made a distinction between the model and the documentation, referring to both as the CM. This distinction is not completely overlooked in literature though. Balci and Ormsby (2007) state, "A simulation *Conceptual Model* (CM) is the model formulated in the mind of the simulation modeller and specified in a variety of communicative forms". Robinson et al. (2015) state, "My perspective is that the model exists within the mind of the modeler and that the documentation (should it exist) and the computer model are simply explicit representations of that model." Robinson et al. 2015 state this distinction even more explicitly, saying "Even if the conceptual model is never documented, or indeed, the model code written, the conceptual model still exists." However, even these authors that do recognize a distinction between the SCM and the documentation of the SCM still use the term CM to refer to both the model as conceived and the model documentation.

This distinction between the SCM and the documentation of the SCM matters. Much of the decision-making involved in the process of developing an SCM is, and should be, different than the decision-making for the development of the SCM documentation. For example, development of an SCM involves designing the model, notably making decisions pertaining to the abstraction of reality required during model design, e.g., what aspects of the referent to represent accurately, what to approximate, and what to leave out of the model. On the other hand, development of SCM documentation requires decisions pertaining to what documents to create, using which methods, and what information to include in these documents. While the SCM design and development process and the SCM documentation process are often, and should be, undertaken in parallel and closely intertwined, they are still distinct processes. This lack of distinction between the model and the documentation of the model when using the term CM in much of the SCM literature, is a likely contributor to there being so little in the literature pertaining to the important content decisions when developing SCM documentation.

The second clarification that is important to make here is the distinction between an SCM and the implementation of that SCM in computer code. Documentation of a coded simulation model will include additional code-implementation-specific documentation content that is not part of the implementation-independent SCM documentation. And, while the SCM documentation for a simulation under development may include some overview information that pertains to how the conceptual model might be implemented, the details of the implementation should be documented separately in the simulation software documentation.

3 OVERVIEW OF LITERATURE REVIEW

This review of the literature on information pertaining to SCM documentation content is intended to provide a representative overview of what is in the literature; therefore, it was neither systematic nor exhaustive. We looked through over 40 documents gathered as part of a larger SCM project. Most of these documents were from the last 5 years, with some from earlier years. The majority were journal articles but some were reports and presentations from various groups, providing a broader diversity of perspectives. Of the documents reviewed, many did not specifically mention anything about the kinds of content that SCM documentation should contain. Seventeen of the documents did have relevant information and are included in the discussions below.

In reviewing the literature, we noted any mention of content to be included in SCM documentation, and also any mention of audiences for that documentation. In light of the fact that much of the literature uses the term SCM to also refer to SCM documentation, we interpreted discussion of SCM content or audience in a reference as a discussion of SCM documentation content or audience wherever that interpretation appeared to be what was intended by the authors.

4 SCM DOCUMENTATION CONTENT TYPES

The most comprehensive considerations of SCM documentation content were found in NATO (2012), Grimm et al. (2020a; 2020b), Morse and Drake (2022), and SISO (2024). The final report of the NATO Modeling and Simulation Group 058 (NATO 2012) provides an in-depth discussion of the SCM development process and the documentation that should be produced during that process. Grimm et al. (2020a; 2020b) focus on thoroughly documenting the design of SCMs, primarily for agent-based simulation models. (For the purposes of this paper, the two Grimm et al. papers, 2020a and 2020b, had essentially identical content since the 2020b paper is a supplement to the 2020a paper, providing additional detail on ODD documentation content. Therefore, for brevity, we will treat these as one source, citing the more detailed paper (2020b) in the discussions and tables below.) Morse and Drake (2022), in a paper discussing Multi-Viewpoint Conceptual Modeling, mentions quite a few types of content for SCM documentation. SISO (2024) presents the Simulation Interoperability Readiness Level (SIRL) standard, which is a tool that provides an evaluation method and scoring regarding how easy it may be to assess the potential interoperability of specific training simulations "on the basis of engineering evidence in form of documentation". While the SIRL standard uses documentation of an implemented simulation, it also explicitly considers the availability of conceptual model documentation and describes types of information the SCM should contain.

In looking through these very different types of sources and perspectives for information on what content should be included in SCM documentation, it became clear that some content types pertain more to the design of the SCM while others pertain more to the overall simulation development project. We therefore found it useful to categorize content types as more design-related or more project-related. This categorization decision was made based on whether documentation audiences would likely need the information in the SCM documentation (other than for record-keeping purposes) once the final computer simulation had been developed and any necessary Verification, Validation, and Accreditation (VV&A) steps were completed. We recognize that these categories are not entirely mutually exclusive but may be helpful in organizing the potentially large amounts of documentation that could be written for an SCM. Further refinement of categorizations of SCM documentation content types, while needed, is beyond the scope of this paper, particularly since there are still many differences in definitions and uses of key terms in the conceptual modeling literature, most notably as to the definition of a simulation CM itself (Robinson 2020; Wilsdorf et al. 2020).

In Table 1, we provide the information for the content types that pertain more to the SCM design. The first column gives a concise name for the type of content; the second column provides a description of the content type; and the third column provides a listing of the references we reviewed that made at least a mention of including that type of content in SCM documentation. Note that the reference only had to make

mention of the content type to be included here; only some of the papers that mention content types provide any explanation or discussion of it. Recognizing that different simulation modeling approaches, such as ABS, DES, and Systems Dynamics, use divergent language and partition information about a simulation differently, so an attempt was made to represent this diversity of language in the content type descriptions.

Table 1: Design-related SCM documentation content types.

Content Type	Content Description	References
Purpose	The need, or purpose the SCM addresses, as well as the objectives and intended use	Abdelmegid et al. 2022; Borah 2003; Grimm et al. 2020b; Morse and Drake 2022; NATO 2012; Quade 2023; Robinson 2013; Robinson 2015; Wilsdorf et al. 2020
Assumptions	Assumptions made in the development of the SCM and its limitations	Abdelmegid et al. 2022; Borah 2003; Çilden et al. 2023; Grimm et al. 2020b; Jones et al. 2022; Morse and Drake 2022; Quade 2023; Robinson 2013; SISO 2024; Wilsdorf et al. 2020
Design Overview	Overview of the model design, the overall design concepts and/or the design framework or architecture, and the modeling domain	Grimm et al. 2020b; Jones et al. 2022; NATO 2012; Quade 2023; SISO 2024; Wilsdorf et al. 2020
Capabilities	What the simulation specified by the SCM will be designed to do, what it is capable of	Borah 2003; Morse and Drake 2022
State Variables	Information the simulation's operating characteristics, and variables that may change as the simulation advances, includes information on advancement of simulation as it runs (typically, but not always, over simulated time)	Borah 2003; Çilden et al. 2023; Grimm et al. 2020b; Morse and Drake 2022
Environment/ System	Description of the modeling of the environment or system in which actions or events will take place; also includes environment/system characteristics, attributes, and variables	Aros et al. 2023; Abdelmegid et al. 2022; Grimm et al. 2020b; Morse and Drake 2022

Actors	Entities, agents, or resources in model (i.e. things in the model that will do something, exhibit some type of behavior or activity; also includes actors' descriptions, attributes, and variables	Abdelmegid et al. 2022; Aros et al. 2023; Borah 2003; DoD 1998; Grimm et al. 2020b; Morse and Drake 2022; NATO 2012; Robinson 2015; SISO 2024; Wilsdorf et al. 2020
Behaviors	Activities or behaviors and associated rules or logic, i.e. description of the ways in which the entities, agents, actors or resources may behave, the actions/activities they may undertake, and conditions under which they undertake these actions/activities	Abdelmegid et al. 2022; Aros et al. 2023; Borah 2003; DoD 1998; Grimm et al. 2020b; Morse and Drake 2022; NATO 2012; Robinson 2015; SISO 2024
Relationships	Relationships and dependencies among entities, agents and actors, and between them and the environment/system; also, relationships and dependencies between attributes and variables throughout SCM	Borah 2003; NATO 2012; Quade 2023; SISO 2024
Effects	Effects that occur across relationships; how the entities, agents, actors, and environment/system effect changes on the others	Aros et al. 2023; Morse and Drake 2022; SISO 2024
Algorithms	Detailed decision logic, math functions, state transition logic, etc. that governs behaviors, effects, and environmental/system changes as the simulation proceeds	DoD 1998; Çilden et al. 2023; Morse and Drake 2022; Quade 2023
Stochasticity	Description of where, and how, randomness is used in the model	Grimm et al. 2020a
Inputs/Outputs	Simulation inputs and initialization criteria, as well as outputs, and their formats; may include information about simulation interfaces	Abdelmegid et al. 2022; Borah 2003; Grimm et al. 2020b; Jones et al. 2022; Robinson 2013;
Data	Information about the model's data requirements, structures, and sources	Abdelmegid et al. 2022; Borah 2003; Morse and Drake 2022; Quade 2023; Wilsdorf et al. 2020

An interesting thing to notice about Table 1 is that many content types are mentioned in a quite a few reviewed sources while some content types were only mentioned in one or two sources. It is possible that some of these differences could result from different papers being written from a different modeling paradigm lens, the fact that the stochasticity content type was only mentioned in one of the reviewed papers (Grimm 2020b) proves that's not a complete explanation. Some of the differences may also be explained by differing uses of terminology.

An overall take-away from this compilation of content types in Table 1 is that none of the reviewed papers explicitly mentioned all of the design-related content types. In addition, none of the content types were mentioned in more than the 9 of 13 references that appear in at least one place in this table.

In Table 2 we provide our compiled list of SCM documentation content types that are more related to a simulation development project. The columns in Table 2 are the same as in Table 1. Note that not all of authors that mention these project-related content types shown in Table 2 necessarily assert that they are part of the set of SCM documentation, but they at least mention that they are important in the development of an SCM; others (e.g., NATO 2012) do explicitly include these content types as part of the SCM documentation.

Table 2: Project-related SCM documentation content types.

Content Type	Content Description	References
Stakeholders	All of the agencies and people involved with the simulation development project; may include a mapping of stakeholders to roles and responsibilities	Abdelmegid et al. 2022; NATO 2012
Requirements	Information about what the simulation should be capable of, as well as any specific attributes, characteristics or qualities that are required	NATO 2012; Borah 2003; Wilsdorf et al. 2020
Meta-Data	Records about model development, such as: who was involved, when was it developed, what tools or development standards were used, etc.	NATO 2012
Referent	All the information that is known about the real, or imagined, simuland (i.e. what is being simulated)	Borah 2003; NATO 2012; Pace 2000; Quade 2023; Robinson 2013
Constraints	Constraints and policies, often found in operational guidance that pertain to "organizational regulations; technical standards; enterprise conventions; stakeholder preferences; or contingency conditions relating to availability of information, staff or materiel resources" (NATO 2012, p.6-6)	NATO 2012
Verification/ Validation	Set of information pertaining to the VV&A process, e.g., process requirements, acceptability criteria, etc.	Borah 2003; NATO 2012
Acceptability/ Suitability	Statement of how the completed model aligns with the original Requirements, i.e. how suitable is the model, does it meet the Requirements acceptably well	Quade 2023

As can be seen in Table 2, much fewer of the reviewed sources consider content pertaining more to a simulation project as being part of the SCM documentation. In fact, only seven of the sources reviewed appear in Table 2, whereas thirteen of them appeared in Table 1. Another interesting observation about these tables is that the NATO (2012) source appears in the majority of rows for the project-related content types, but only in a few rows for the design-related content types. On the other hand, both Morse and Drake (2022) and Grimm et al. (2020b) appear in the rows of almost all of the design-related content types, and none of the rows for the project-related content types. This makes it even more apparent that there are very different perspectives regarding what content should be included in SCM documentation or included with SCM documentation.

5 SCM DOCUMENTATION AUDIENCES AND PURPOSES

In order to gain the most benefit from documenting an SCM, it is important to determine the purpose, or purposes, for which the documentation is being developed. Different audiences of SCM documentation can have quite different purposes for, and therefore needs pertaining to, the documentation. This section describes typical audiences for SCM documentation. Recall that SCM documentation pertains to the implementation-independent SCM only; during the process of implementing an SCM in code, an additional set of software documentation should be developed that pertains to the implementation and software.

Little of the SCM literature specifically addressed audiences of SCM documentation, but a few papers make some mention of them, such as NATO (2012) and Balci and Ormsby (2007). We have distilled the information about audiences and purposes in this section from the few references that mention audience or purpose, as well as from experience being a member of several different audience categories at one time or another. The compiled list, shown in Table 3, is by no means thorough; rather, it is an initial pass at specifying SCM documentation audiences and purposes.

Table 3: Audiences and purposes for SCM documentation.

Audience Category	Audience	General Purpose
Simulation End User / Consumer	End User - Trainer	Understand the overview, concept & purpose of simulation and how to use it to facilitate training
	End User - Trainee	Understand the overview and concept of simulation and how to interact with it during training
	End User - Analyst	Understand simulation scope, functionality and assumptions of simulation, how to use it for analysis, and enough of the design to make inferences from results
Simulation and Engineering Professionals	Developer / Maintainer	Understand details of SCM design, structure, purpose, and functionality in order to implement, maintain, improve, or reuse portions of a simulation
	Systems Engineer	Understand SCM assumptions, design concepts, scope and functionality, inputs & outputs, limitations in order to determine effectiveness of simulation systems or integrate multiple simulations
Evaluator / V&V Analyst	Evaluator / V&V Analyst	Understand simulation design and specifications to determine whether the simulation provides an acceptable or valid representation of what was simulated, verify SCM design was implemented correctly, support accreditation process
Sponsor / Acquisition Personnel	Program sponsor, acquisition leads & analysts	Understand SCM purpose, scope, design, and capabilities in order to evaluate a proposed or completed SCM to determine if it meets requirements
SCM project team	Project team members	Communicate across all involved in development of an SCM providing common understanding of SCM requirements and design

Not all SCMs will necessarily require documentation for all of the audiences listed in Table 3. For example, when a simulation modeler develops a small simulation model for their own use, they should be sure to provide documentation for the developer and the appropriate end user audience. This documentation is not only useful if another person begins to use, improve, or reuse the simulation, but can also be useful to the original developer if they find that they need assistance in recalling aspects of the SCM use or design

after some time has passed. For simulation development projects that will be handed over to a sponsor or considered as part of an acquisition process, SCM documentation should be written to provide all the necessary information for that kind of audience. And simulation projects involving teams of any size will want to develop and disseminate SCM documentation to the project team members to ensure a common understanding and compatibility of work, particularly as the SCM development work progresses.

6 INSIGHTS FOR SCM DOCUMENTATION CONTENT

Decisions regarding what information to include in SCM documentation should be made in light of the intended audience's purposes and needs. In this section, we assess the needs of the different audiences for information about each of the design-related SCM content types. In addition to which audiences need information on each content type, it is useful to give some consideration to what level of detail is needed.

Throughout the literature we reviewed there are varying opinions on how much detail should be provided when documenting an SCM, and some authors advocate for having documentation that provides information at different levels of detail (e.g., Morse and Drake 2022). For our assessment, we will just delineate two levels: basic and detailed. This delineation is somewhat in line with the informal vs. formal distinction made in the literature regarding SCM documentation (see, for example, Borah 2003). This delineation is, of course, not a strict dichotomy; rather, it is somewhat of a continuum. As Borah (2003) points out, during the simulation development process, the documentation is 'living' in that it "grows from an informal description to a formal description". However, as will be seen in our assessment, not all audiences need the final, formal documentation; for some, more informal documentation may be more useful. We leave further exploration of the topic of informal vs. formal documentation, and the spectrum between the extremes, for future work since the papers we found that mention level of detail do not include any significant discussion on the topic.

Table 4 provides our assessment of what types of SCM documentation content are needed by different audiences, and at what level of detail may be best. The rows in the table are the audiences from the second column of Table 3, and the columns are the design-related content types from the first column of Table 1. Each cell is filled in with a circle if the content type for that column should be included in SCM documentation for the audience shown in that row, with the size and fill of the circle indicating the level of detail that may be best. A smaller open circle indicates a basic/informal level of documentation detail, which would provide more of an overview of the relevant information in order to provide an understanding of what is modeled without unnecessary complexity. A larger solid circle indicates a detailed/formal level of documentation detail, which would provide all the complexity necessary to fully describe that aspect of the SCM.

Table 4: Suggested SCM documentation content types, and levels of detail for various documentation audiences.

	Purpose	Assumptions	Design Overview	Capabilities	State Variables	Environment/System	Actors	Behaviors	Relationships	Effects	Algorithms	Stochasticity	Inputs/Outputs	Data
End User - Trainer	●	○	○	●		○	○	○		○		○	●	○
End User - Trainee	○			○			○	○		○			○	
End User - Analyst	●	●	●	●	○	○	○	○	○	○	○	○	●	●
Developer / Maintainer	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Systems Engineer	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Evaluator / V&V Analyst	●	●	●	●	●	●	●	●	●	●	●	●	●	●
Program sponsor, acquisition leads & analysts	●	●	○	●	○	○	○	○	○	○	○	○	○	○
Project team members	●	●	●	●	○	○	○	○	○	○	○	○	○	○

Key: ○ basic/informal documentation ● detailed/formal documentation

The assessment of content needs provided in Table 4 were determined based on the experience of the author; and for audiences the author was less familiar with, such as the acquisition "Program sponsor, acquisition leads & analysts" and "System Engineer", they were reviewed by experts in those areas. This assessment is by no means authoritative. A more formal study of the needs of various SCM documentation audiences, particularly gathering more input from the different audiences, is recommended as future work. In addition, it is possible that the documentation content needs of different audiences may differ somewhat in one organization as compared to another.

7 CONCLUSIONS

It is widely understood that simulation conceptual modeling is an important part of the simulation development process, and that an SCM is of minimal usefulness when it has not been documented. The purpose of this paper is to explicitly address an SCM modeling issue that has mostly received tangential coverage in the literature, i.e. discussing considerations regarding what content the SCM documentation should include to be of maximal usefulness. Documentation that is too detailed or contains unnecessary information is less likely to be read and understood, while documentation that is missing important content or does not contain enough detail may not be sufficient to satisfy the purpose for which it is needed. This paper offers a first-pass analysis of SCM documentation content considerations, including audience, purpose, and level of detail. It also provides a listing of SCM documentation content types compiled from a variety of literature sources, resulting in a more comprehensive set of content types than in any of the papers we reviewed.

Much work remains to be done. This paper represents initial work in this area, providing a non-systematic, nor exhaustive, review of the literature. A more thorough literature review should be undertaken to ensure that important content types have not been overlooked. In addition, the needs of various audiences

of SCM documentation should be formerly assessed to provide well-grounded guidance regarding SCM documentation content requirements. Too often SCM documentation has proven to be insufficient, and much work has been published to address this issue, advancing a wealth of SCM documentation approaches, tools, and methods; however, without a solid understanding of the needs of the audience, the benefits of that important research are unnecessarily limited.

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