SURFACE VEHICLE RECOMMENDED PRACTICE

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Model Description Documentation Recommended Practice for Ground Vehicle System and Subsystem Simulation

RATIONALE

Increased use of dynamical modeling and simulation for engineering development and testing of the functional performance of ground vehicles has resulted in a need for standardizing documentation of the dynamical models used. Multi-disciplinary global engineering teams spanning domains within organizations and collaborations between commercial businesses (OEMs and suppliers), government agencies, and research institutions often need to support usage of simulation models of entire ground vehicle systems and/or related subsystems. This requires a minimum level of model documentation to efficiently facilitate, integrate, and manage modeling and simulation work activities. Specifically, model documentation is essential to permit exchange and development of models as well as application and management of modeling and simulation processes.

The recommended practice for model description documentation presented in this technical report will help to: (1) create a common language, (2) increase productivity of processes, (3) promote uniform testing, and (4) reduce costs.

This version is an updated to include the changes in the dynamical modeling and simulation environment in the last 5 years.

SAE J2998 has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

Dynamical modeling as part of enterprise-wide and/or industry-wide engineering processes requires different types of documentation to support different engineering functions for model development, application, and management. These functions require both unique and common information about a model. In addition, to protect intellectual property and sensitive information, different levels of documentation are required for engineering collaboration functions internally within a company, externally between companies, and globally for internal and external work across national borders. Specifically, model description documentation (MDD) is needed for the following four categories of work functions:

1. Model users and simulation analysts from different disciplines apply models for various engineering tasks. For sharing and reusing existing models, they require a high-level overview description to select an appropriate model with the capabilities, features, and performance required for their specific analysis purposes.

2. Model developers or producers (simulation modelers/developers/providers/suppliers) create new models or maintain, integrate, and modify existing models. To develop new models, they need to receive documentation that specifies the requirements for the model to enable an intended analysis to be performed. They also need to provide documentation for users to understand and apply the models that they develop. In addition, they use model documentation to maintain models. To maintain, enhance, and continuously improve the existing models, they require more detailed information about the physical principles, equations, assumptions, and approximations used.

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3 Simulation model requestors are model users and simulation analysts, who require new or improved models to perform specific engineering analysis functions for which models do not exist or are inadequate. To request new models or improved models, they need to supply or provide documentation that specifies the requirements for the model to enable an intended analysis to be performed.

4. Modeling and simulation process management controllers require documentation to control the introduction, update, and removal of models from libraries of models available for standard engineering analysis. They ensure that the models are thoroughly tested, documented, and meet required performance measures before they are accepted for use in standard engineering analysis work activities. To guarantee quality of simulation results, they need information about model documentation, performance, verification, validation, change history, and theoretical basis.

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1. SCOPE

SAE J2998 defines the recommended information content to be included for documenting dynamical models used for simulation of ground vehicle systems. It describes the information that should be compiled to describe a model for the following user applications or use cases: (1) exchange, promotion, and selection; (2) creation requests; (3) development process management; (4) compatibility evaluation; (5) testing-in-the-loop simulations with hardware and/or software; (6) simulation applications; and (7) development and maintenance. For each use case, a model description documentation (MDD) template is provided in the appendices to facilitate model documentation. In addition, an example of a completed model documentation template is provided in the appendices.

1.1 Purpose

The purpose of producing standards for documentation of models is to:

1. Facilitate model sharing, reuse, acceptance, and marketing of existing models for collaboration between disciplines, throughout a company, and across the industry by providing a concise and consistent description of the features and capabilities of a model to reduce model development time, cost, and duplication of efforts.

2. Provide understanding of the methods, assumptions, limitations, and approximations used to mathematically describe a dynamical system in terms of physical phenomena or behavior and capabilities of a model to prevent or reduce model misuse.

3. Enable models to be judged for usability, reuse, and compatibility with other models or for other engineering analysis applications.

4. Standardize methods for communicating, understanding, requesting, or specifying the performance, capabilities, applicability, and requirements of a model.

5. Facilitate storage of technical information required for work continuity and incremental development (or continuous improvement) between different model developers to simplify the maintenance of models for modifications and updates.

6. Support modeling process quality, management, and standards such as ISO 26262, if using a model-based design/development process as part of a product development process.

7. Promote the development of more well-thought-out, appropriate, and better quality models.

2. REFERENCES

2.1 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

SAE Ground Vehicle Standards Committee Handbook, SAE International, March 2008.

SAE J2546 Model Specification Process Standard

SAE J3049 Model Architecture and Interfaces Recommended Practice for Ground Vehicle System and Subsystem Dynamical Simulation

TSB 003 Rules for SAE Use of SI (Metric) Units

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3. DEFINITIONS

3.1 ACAUSAL

A modeling approach where the system model is built using physical relations expressed in their natural form as a system of differential-algebraic equations, where X is the vector of unknowns that appear differentiated and Y is the vector of unknowns that do not appear differentiated.

3.2 BACKWARD SIMULATION MODEL

A model that progresses backward in time, using outputs to calculate the inputs required to achieve the output over a desired time interval.

3.3 CALIBRATION

The process of determining a set of model parameters required for a model to represent or characterize the behavior of a specific hardware, algorithm, or software. For a control algorithm, it is also the process of adjusting the parameters of an algorithm model achieve a specific performance objective.

3.4 CAUSAL

A modeling approach that assumes that a system of interest can be decomposed into block-diagram form with causal interactions between the sub-models expressed in explicit form, where U is the input vector, Y is the output vector, and X is the system state variable vector.

3.5 COMPONENT

One part of the collection of parts that are assembled or integrated together to form a system or subsystem.

3.6 CORRELATION

The state where a relation existing between phenomena or between mathematical or statistical variables which tend to vary, be associated, or occur together in a way not expected on the basis of chance alone.

3.7 DEGREE OF FREEDOM

The number of unrestricted and independent variables determining the result.

3.8 DYNAMICAL FUNCTIONAL MODEL (OR FUNCTIONAL MODEL)

A mathematical simulation model of a piece of hardware, algorithm or software that describes how the fundamental variables change with time. It describes the operation or behavior of the variables. The model may or may not represent the physical structure of the hardware and its connection to other components.

3.9 DYNAMICAL PHYSICAL MODEL (OR PHYSICAL MODEL)

A mathematical simulation model of a piece of hardware that describes how the fundamental physical variables change with time, while simultaneously capturing the physical structure of the hardware components and their interconnections in a schematic diagram that is similar to an electric circuit model. The model provides the functional behavior of the physical variables and a diagram that is a visual representation or schematic of the physical hardware, which is made from models of individual hardware components and their hardware connections to each other. Thus, the model diagram visually provides additional information about the construction and purpose of the physical hardware system represented by the model. Hence, dynamical physical models are a subset of dynamical functional models.

3.10 EMBEDDED BLACK-BOX MODEL

A model that is provided as an executable model with only a high-level description of functionality and capabilities defined to enable its usage. The details of the model are considered as proprietary intellectual property, so no details of model structure, equations or physical principles are provided. This model could be in the form of an executable file.

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3.11 FIDELITY[1]

The degree to which a representation, such as a model, captures the nature of the real object being represented.

3.12 FORWARD SIMULATION MODEL

A model that progresses forward in time using inputs to calculate outputs.

3.13 GROUND VEHICLE SYSTEM DYNAMICAL MODEL

A mathematical simulation model of the functional operation of a ground vehicle that describes how its fundamental physical variables change with time, including transients.

3.14 INTERCHANGEABILITY[2]

The “ability of a system or product to be compatible with or to be used in place of other systems or products without special effort by the user.”

3.15 INTEROPERABILITY

The “ability of a system or a product to work with other systems or products without special effort on the part of the customer. Interoperability is made possible by the implementation of standards.”[3] It should be noted the customer is the end user of a model. It is also a property of models that allows models developed with different tools to function together. It is enabled by compiler tools that can produce a different implementation of the model. It can also be enabled by co-simulation tools that integrate and control the simulation of models running in different simulation tools.

3.16 LEVEL-(N) SUBSYSTEM (OR NTH-LEVEL SUBSYSTEM)

A coordinated assembly of interconnected components operating together to perform a function or functions that provide part of the functionality of a level-(n-1) subsystem (i.e., the next level higher subsystem).

3.17 MODEL COMPATIBILITY

The property of a model to guarantee that it will work with other models. The compatibility of a model with another model means that the models were designed to work together and to connect with each other, such as an engine with special technologies requires models of special sensors and actuators, and a model of controller software that can read these special sensors and control the actuators to operate.

3.18 MODEL ICON

A picture or graphical representation of the function that the model describes. The icon can be used in addition or in place of the graphical block symbol used to represent a system, subsystem or component in a block diagram of the model. The icon provides a quick visual method for conveying the function that a modeling block describes. Inclusion of icons with modeling blocks can improve the high-level comprehension of a model without requiring a detailed review of the internal structure of the model.

3.19 MODEL MODULE

A self-contained subsection or part of a model that performs a specific standardized function, for easy assembly, flexible integration, and reuse with other model modules to form more complex models of whole components, subsystems, and systems. Some examples of model modules, which can be interconnected to form more complex models, are: (1) subsystems used to form a system, (2) subsystems used to form larger subsystems, (3) components used to form a subsystem, and (4) math functions used to form components. See the separate definition of subsystem given below.

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1 SAE J2546, Model Specification Process Standard.
2 Ground Vehicle Standards Committee Handbook, p. 40, SAE International, March 2008.
3 Ground Vehicle Standards Committee Handbook, p. 40, SAE International, March 2008.

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3.20 MODEL PLAYABILITY

The ability of a model to work or function correctly in any simulation tool environment without requiring any additional processing or modification to the model.

3.21 MODEL PLUGABILITY

A property of models that follow the same conventions or syntax; so, they can be connected together. Thus, they can exchange the interface variables required to function together. However, it does not guarantee that they will work seamlessly together.

3.22 MODEL PORTS

An element of a model which offers transfer of data into and/or out of the model during simulation.

3.23 MODULAR MODEL

A type of model that is composed of a collection of units, called model modules, which perform specific standardized functions for easy assembly, integration, and reuse.

3.24 PARAMETER

A quantity of a model that does not change explicitly with time. These quantities are functions, such as look-up tables, or model constants, whose values are set or fixed at the start of a simulation. They do not change explicitly with time over a simulation, but are only changed to configure a model to describe a different piece of hardware, algorithm or software that is governed by the same physical phenomena and equations described by the model or algorithm. The term parameter is not to be used interchangeably with the term variable. See the separate definition for variable given below.

3.25 PARAMETER FILE COMPATIBILITY

The property of parameter data files that guarantees that it contains only values for parameters of a model. The compatibility of a parameter data file with a model of a specific piece of hardware (system, subsystem or component) or algorithm means that the file contains only values for parameters that are required to configure the model to simulate a specific piece of hardware or algorithm.

3.26 PORTABILITY

This refers to a property of models that allows the models developed with one modeling and simulation tool to be seamlessly used in another modeling and simulation tool in the format of the tool in which it is simulated. One example of this capability would be a common model description method or language that would allow each tool to convert the model into the format required by the tool in which it is being used or simulated.

3.27 SIMULATION ENVIRONMENT

A software tool that enables a user to manage and control the simulation of models. Typically, it enables a user to configure a simulation by creating and connecting models, to execute (or run) a simulation, and to use simulation results for analysis and reporting. It may also provide other functions to manage a complete process of modeling and simulation.

3.28 SOFTWARE MODEL

A model that emulates either the behavior or the implementation of software code in the physical vehicle. It could be the actual in-vehicle software code generated by hand-coding or auto-coding.

3.29 SUBSYSTEM

A coordinated assembly of interconnected components operating together to perform a function or functions that provide part of the functionality of a larger system. It may also provide part of the functionality of a larger subsystem.

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3.30 SUBSYSTEM MODEL

A mathematical simulation model of a subsystem.

3.31 SYSTEM

A coordinated assembly of interconnected components or subsystems operating together to perform a common function or functions, which provides greater functionality than any individual component or subsystem provides alone.

3.32 SYSTEM MODEL

A mathematical simulation model of a system. It may be used as a system or subsystem model depending on how the model is used in a simulation. If a model module describes or models everything that is being simulated, it is the main subject of the simulation, and thus, called a system model. And, if it is one of the many interconnected supporting model modules that contribute to the functionality of the entire simulation under study, then it and the modules interconnecting with it are all called subsystem models.

3.33 TOP-LEVEL SYSTEM MODEL

The highest level mathematical simulation model of the entire system being simulated.

3.34 VALIDATION

The process of checking that the model adequately describes the functionality of the real physical system, algorithm, or software in sufficient detail to support the intended use. The fundamental questions being answered by this process are: were the right things modeled and are the model requirements sufficiently complete? These questions are answered through a process of physically testing the hardware, algorithm, or software over a set of test cases, and then simulating the model over the same set of test cases (which represent the intended use case) to confirm that the model was designed and calibrated correctly to reproduce the required behavior or functionality, sufficiently. For example, validation may reveal additional features, functions, or behaviors the model does not describe or requirements it does not meet, which causes unacceptable or inadequate performance. It should be noted that before validating the model, the model must be verified (see definition below) to ensure that the model is performing its calculations correctly as it was designed.

3.35 VARIABLE

A quantity of a model that changes as time progresses during a simulation. This is not to be used interchangeably with the term parameter. See the separate definition for parameter given above.

3.36 VERIFICATION

The process of determining that the model was implemented correctly as it was designed. Model verification is the process of simulating the model over a set of test cases to confirm that the design requirements have been achieved.

3.37 VIRTUAL ENVIRONMENT

A type of simulation environment used to simulate the environment a vehicle could be interacting with, including surrounding traffic, traffic lights/signs, pedestrians, and other relevant external interface conditions.

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4. MODEL DESCRIPTION DOCUMENTATION INFORMATION

4.1 Use Cases

The scope of the information to be included in the MDD is dependent upon the information requirements of the different use cases and the intended users. Hence, different collections of information will be required to meet the needs of different users. In order to maintain consistency and continuity between these user specific collections of information, a central or master model description documentation database (MMDDD) (e.g., central database or document file of model information) should be used. Thus, different users that require the same content will use exactly the same information from a single common source. The different MDDs required for the different uses will be linked to the central database or document to provide the different collections of information that are required by a specific user or for a specific use case. While this approach is highly recommended, implementation is not specified and is left to the user. The following is a list of the types of use cases or views and of the MMDDD elements that are typically needed.

1. Sales Brochure or Product Description Documentation View: Provides a high-level description of a model to enable an engineer to select the model required for their analysis application. It includes a description of model features, capabilities, interfaces, applications, performance, simulation environment tool requirements, and computer resources required.

2. Requirements Documentation View: Provides the detailed information required for a model user to request the development of a model by a model producer or component model supplier for a specific analysis task.

3. Compatibility Documentation View: Provides a simulation engineer with the information required to identify other models that are compatible with the model described in the documentation. The information provided by this view can be sorted by using compatibility rules to select appropriate models from a set of models to ensure that the model characteristics and interface information are compatible with a given model. It can also be used to identify what may need to be changed to make two models compatible, so they can work together.

4. Process Management Documentation View: Provides a modeling and simulation process manager with the information required to confirm the quality and maturity of models and simulations, and to control the introduction, update, and removal of models from libraries of models available for standard engineering analysis processes.

5. Testing-in-the-Loop Documentation View: This view includes hardware-in-the-loop (HIL), component-in-the-loop (CIL), software-in-the-loop (SIL), processor-in-the-loop (PIL), and vehicle-in-the-loop (VIL) applications. It provides a simulation engineer with the information required to select, configure, and apply the model to an HIL, CIL, SIL, PIL, or VIL test execution platform for the analysis of a specific component, subsystem, or system in an application where real-time execution cost and performance are critical. It includes information about data collection and calibration procedures for the model of a system, subsystem, component, or software algorithm.

6. Application Documentation View: Provides a simulation engineer with the information required to apply the model for the analysis of a specific component, subsystem or system. It also includes information about data collection and calibration procedures.

7. Technical Specification Documentation View: Provides the detailed information needed to enable a model developer to maintain, extend, modify, or update an existing model to provide the features, capabilities, and performance requested by model users for a specific analysis.

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4.2 Documenting a Model

4.2.1 Overview

The process of documenting a model is always an important part of the modeling and simulation process. Documentation is even more critical when the model is intended to be used by an engineering team to make vital engineering decisions. Modeling and simulation, when used as the basis of engineering processes, requires model documentation for supporting global team work (with colleagues, suppliers, and research institutions), personnel changes, quality control, and continuous improvement of work processes and products. Thus, the process of documenting models should be integrated into the standard work flow and not reserved as a job to be done after the model is completed. There are many value added benefits from distributing documentation work throughout the engineering design, development, and analysis processes. Specifically, some of the benefits of model documentation are as follows:

1. Supports the selection of model for a specific task to be performed.
2. Enables more thorough design reviews and decision making.
3. Improves understanding of the model by users.
4. Provides the foundation for technical memory.
5. Improves the quality of analysis and related work products.
6. Aids in debugging and problem solving.
7. Reduces design iterations caused by poor, incomplete, or misunderstood model requirements, approximations, or capabilities.

4.2.2 Process for Documenting a Model

The seven use cases defined in 4.1 are arranged in order of increasing number of content items. The first use case of a sales brochure or a product description requires the least amount of information to provide a high-level view of the model for the purpose of finding and selecting appropriate models to be used for specific engineering tasks, while the seventh use case of a technical specification requires the most information to support model maintenance, improvement, and expansion. Collecting all of this information can take significant effort, but does not need to be done all at one time. The information can be collected incrementally on an as needed basis as part of the standard work required for virtual engineering processes.

First, there needs to be a mechanism for using the model documentation as an integral part of standard engineering work. It is recommended that all existing modeling and simulation processes be reviewed to ensure that appropriate model documentation information is an integral part of the deliverables as a value-added contributor to efficiently producing quality work products and processes. Next, there needs to be a plan to develop documentation for two classes of models: (1) existing or legacy models, and (2) new models.

For legacy models, the easiest way to get started is to review all existing models to select the models currently used as a critical part of engineering analysis and decision making processes. These models should have a complete set of documentation to support all of their uses, because, they are integral to the quality of the work products delivered. Next, it is recommended that a plan should be developed to generate this documentation incrementally, when needed as deliverables to support both (1) on-going product development activities and (2) model reuse for future activities. The documentation should be developed to support immediate specific needs required by the virtual engineering process and not just for the purpose of producing documentation. So, once a plan has been developed and implemented for integrating documentation work of legacy models into standard work processes, then the same process can be used to facilitate documentation of new models, when they are required.

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A typical process for incrementally developing the required documentation for a new model could proceed as follows:

1. Start with developing a high-level sales brochure or product description (Use Case 1) that defines what is required for the model to enable the needed engineering design, development, and analysis tasks.

2. This product description should be reviewed by the engineering team to determine more specific details or additional requirements for the model to be used for specific tasks. These requirements would then be used to develop model request documentation (Use Case 2), which would serve the model developers or suppliers as the specification for the model they must develop, test, and deliver.

3. The model developers would use the model request documentation as the specification to develop and deliver the model to the users along with application documentation (Use Case 5 and/or 6, depending upon the intended use of the model) describing how to use the model. They would also provide compatibility documentation (Use Case 3) describing any requirements or constraints on the model that could affect compatibility with other models. This would also include a description of any model interfaces and characteristics that could be used to ensure compatibility between models.

4. Model users would then test, debug, and apply the model for the intended engineering task and would work with the developer to verify, validate, improve, and refine it. As a result of this work, the testing-in-the-loop documentation (Use Case 5) or application documentation (Use Case 6) would be updated with improved application guidelines, depending upon the intended use of the model.

5. Concurrently, during the model definition, development, and use processes the model would be periodically reviewed by the team and the status of development and release would be documented in the process management documentation (Use Case 4).

6. In addition, these reviews would also result in updates to the product description documentation, model requirements documentation, application documentation and testing-in-the-loop documentation. Concurrently, the developers and users would capture technical specifications documentation (Use Case 7) and update it with hints and details to capture any lessons learned, short cuts, and new requirements that would be required to maintain, expand, or modify the model by future developers or users.

5. RECOMMENDED INFORMATION FOR DOCUMENTING A MODEL

5.1 Overview

The information recommended for documenting a model is summarized in 5.2 as a list of content items arranged in a numbered outline format, where each item in the list is assigned a reference number to facilitate referencing and technical discussions. The list is broken into major categories that are labeled in bold text that is underlined. In addition, secondary information is categorized by subheadings that are underlined to aid in finding specific categories of information. After, each item is a description of what should be provided or described. Sometimes, this is followed by recommendations for even more details to include, and by examples.

To support the application and understanding of the model description documentation recommended practice, additional information, templates, and examples are provided in the appendices. An outline of all of the major section headings is presented in Appendix A (see Table A1) to provide a high-level understanding of the categories of information recommended for documenting a model. Next, Appendix B provides a matrix summarizing the content items that are recommended for inclusion in each use case (shown in Table B1). To facilitate model documentation, templates are presented in Appendix C (see Tables C1 to C7) for each of the seven use cases defined in 4.1. Finally, to clarify the application of the templates further, a specific example is provided in Appendix D, where a completed model description documentation template is presented in Table D1. This example is for technical specification documentation (Use Case 7), which requires supplying all of the information recommended for complete model documentation. It should be noted that most use cases require only a subset of the recommended information, which is presented as a number outline in 5.2.

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5.2 Definition and Description of Model Documentation Content Items

1. MODEL TITLE: PROVIDE A NAME FOR THE MODEL.

2. HIGH-LEVEL DESCRIPTION OF MODEL

2.1 High-Level Model Classification:

2.1.1 Provide a high-level type classification of the model. Choose any or all of the following items describing what is included in the model: hardware, controller algorithm, and/or controller software.

2.2 Model Complexity Classification:

2.2.1 Provide a model-complexity level classification. Choose one of the following model types best describing what the model represents: system, subsystem, component, function, or equation.

2.3 High-Level Model Description:

2.3.1 Provide a high-level description of the model. Describe the most salient features of the model.

2.3.1.1 Example: Turbocharged direct injection gasoline engine with variable valve timing and variable lift.

2.3.2 Include a part number, and/or component part numbers (if made from a collection of components with numbered parts), and model year, if applicable.

2.4 Model Classification:

2.4.1 Model Capability Type:

2.4.1.1 Describe the capability type of the model.

2.4.1.2 Choose the one that best describes the capabilities of the model: steady-state or dynamic.

2.4.1.3 Choose the one that best describes the capabilities of the model: 0-D, 1-D, 2-D, or 3-D.

2.4.2 Model Prediction Type:

2.4.2.1 Describe the prediction type of the model. Choose one of the following: forward or backward model.

2.4.3 Modeling Method Type:

2.4.3.1 Describe the modeling method type. Choose one of the following: causal or acausal model.

2.4.4 Model Keywords:

2.4.4.1 Define keywords for classifying the model to support searching for models with desired characteristics. Provide a list of words and terms that describe the model, which will help to locate or search for models with the desired characteristics or features, such as:

2.4.4.1.1 Physical Model, Empirical Model, Embedded Black-Box Model, Auto-Code Ready Model, Fixed Point Calculation, Floating Point Calculation, Environment Subsystem, Driver Subsystem, Vehicle Supervisory Controller Subsystem, Power Subsystem, Chassis Subsystem, etc.

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2.5 Model Standards Compliance:

2.5.1 Describe any standards to which the model complies.

2.5.2 List any standards or guidelines (including international standards) and their version number for each of the following items: model, documentation, architecture, variable and parameter naming conventions, variable and parameter units, and signal name list (i.e., a standard list of names and abbreviations).

3. PURPOSE/APPLICATIONS/USAGE

3.1 Purpose of the Model:

3.1.1 Explain why this model is needed and the problems it is designed to answer.

3.1.1.1 Specifically, describe the types of analysis applications and uses for which the model is recommended or designed to address.

3.1.1.1.1 Example: This model was developed to describe a turbocharger for performance, fuel economy, or component sizing analyses.

3.1.1.1.2 Note the types of applications also include auto-code generation, which would require providing the additional details of the compiler and target hardware used.

3.1.2 Describe any known types of analysis applications for which the model is not recommended. Whenever a model is used and discovered to be unsuitable for a task, it should be documented. It is recommended that there should be a process in place to capture any problems that occur and to update the model documentation accordingly in a timely manner.

3.1.2.1 Example: This engine model was not developed to study individual cylinder charging and torque production.

3.1.3 Provide examples of typical or generic applications along with some references to applications where the model has been previously used in projects, studies, and analyses.

3.2 Approved Applications:

3.2.1 Describe in detail the applications for which the model has been thoroughly tested and approved.

3.2.2 To make the approval more formal, include documentation of approval or authorization to use the model for these applications by appropriate engineer(s) and/or manager(s) signature(s) with approval date(s).

3.3 Model Compatibility Statement:

3.3.1 Define model files or libraries of model files that are compatible with the model described by this document.

4. FEATURES AND CAPABILITIES

4.1 Provide a high-level functional description of the model describing all of the features, capabilities, and phenomena that the model produces.

4.1.1 When used in a model request, this item describes the features, capabilities, and phenomena that the model should provide.

4.1.2 Also, mention whether tools are provided for calibration, initialization, or other functions.

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4.2 Provide a detailed description of the requirements for each feature, capability, or phenomenon of the real system that the model needs to emulate.

4.2.1 When used in a model request, this item describes the requirements for each feature, capability, and phenomenon the model should emulate.

4.2.1.1 Include any requirements on the fidelity of each required content item.

4.2.1.2 Also, describe the known features, capabilities, or phenomena of the real system that the model does not need to emulate and describe why it does not.

5. MODEL APPLICABILITY AND LIMITATIONS

5.1 Describe the range of environmental or other operating conditions for which the usage of the model has been approved.

5.2 Describe the limits of model applicability, such as limitations and constraints on model fidelity and feature content.

5.2.1 Example: Model fidelity is valid only below 50 Hz.

5.2.2 Example: Model feature content is valid only for handling, but not ride analysis.

5.3 Describe what other models this model is designed to be used with.

5.3.1 Example: This engine model was designed to be used in a passenger car vehicle system model with an automatic transmission model that includes a torque converter model.

6. EXTERNAL INTERFACE VARIABLES (OR INPUTS AND OUTPUTS)

6.1 Describe all external interface variables of the model.

6.1.1 For each variable, provide a variable name, a definition of the physical quantity (i.e., what does it measure, represent, control, or do in the physical system being modeled), units of measurement, data types, and range of typical values (including restrictions).

6.1.2 For causal models, these variables define the inputs and outputs of the model.

6.1.3 For acausal models, these variables define the model ports.

6.2 Describe all external models and associated Model Data Dictionaries that interface with the model.

7. INTERNAL VARIABLES

7.1 Describe all internal variables of the model (including any variables or signals needed for displaying or monitoring of the calculations).

7.1.1 For each variable, provide a variable name, a definition of the physical quantity (i.e., what does it measure, represent, control, or do in the physical system being modeled), units of measurement, data types, and range of typical values (including restrictions).

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8. PARAMETERS AND CALIBRATION PROCEDURES

8.1 Model Parameters:

8.1.1 Describe all parameters of the model.

8.1.2 For each parameter, provide a name, a definition of physical quantity (i.e., what does it represent, control, or do in the physical system being modeled), units of measurement, data types, and range of typical values (including restrictions).

8.1.3 Note initial conditions for internal variables are also model parameters, since they are used to calibrate a model to represent a specific piece of hardware or control algorithm functioning at an initial operating point.

8.1.4 Describe the parameters storage format; for example, MAT, MDF, CSV, JSON, etc.

8.2 Parameter Calibration Data Requirements:

8.2.1 Define data needed to calibrate model parameters to represent a specific hardware or control algorithm system, subsystem, or component.

8.2.2 Note the “calibration data” could come from real hardware tests, from virtual tests through simulation using higher fidelity models, from Computer-Aided Engineering (CAE) analysis, from other analytical means, or from a combination of all of these methods.

8.3 Calibration Data Collection Procedures:

8.3.1 Define procedures required to collect calibration data.

8.3.2 Note the procedures could require real hardware testing using instrumentation, virtual testing using simulation, other analytical means, or a combination of all of these methods.

8.4 Calibration Data Processing:

8.4.1 Define how the calibration data is processed to determine the values of the model parameters. This should also include descriptions of data entry methods, data types, and data formats required.

8.5 Model Calibration Tools:

8.5.1 Describe the details for using software tools to implement processes supporting model calibration.

8.5.1.1 Provide instructions to acquire any software tools or links to any graphical user interfaces (GUIs) available to facilitate calibration processes. This should include links to instructions describing how they are activated and to details of any available help information. Also, include descriptions of data entry methods, data types, and data formats required.

8.5.2 Provide references to any documented test procedures required to retune calibration parameters.

8.6 Model Configuration:

8.6.1 Model Configuration Tools:

8.6.1.1 Provide a list of any standard or custom-made software tools used for configuring model parameters and initial conditions. Also, this should include links to instructions describing how they are activated and to details of any available help information.

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8.6.2 Model Initialization Tools:

8.6.2.1 Initial conditions for internal variables may be determined by a separate initialization process. Provide a list of any standard or custom-made software tools used for configuring initial conditions. Also, this should include links to instructions describing how they are activated and to details of any available help information.

8.7 Method for Loading Parameters:

8.7.1 Describe the standards and methods for loading parameters into a model. This should also include descriptions of data entry methods, data types, and data formats required.

8.7.2 Provide a link to the simulation environment tool or GUIs, required by the model, where the method is described.

9. MODEL ARCHITECTURAL STRUCTURE

9.1 Provide a model architectural diagram and description outlining major model elements (i.e., subsystems and components), and how they are connected and function together.

9.1.1 The diagrammatic representation of the model architecture may be in the form of block diagrams, flow charts, schematics, etc.

9.1.2 A description of how these major model elements work together should accompany the diagram.

10. DETAILED FUNCTIONAL DESCRIPTION

10.1 Theoretical Basis:

10.1.1 Provide all equations, assumptions, approximations, and references (a list of all papers and reports) that were used to formulate and develop the model.

10.1.1.1 Nomenclature:

10.1.1.1.1 Provide a list of symbols, non-standard technical terms, and acronyms used in the model and model documentation.

10.1.1.2 Reference List:

10.1.1.2.1 Provide a list of all reference material cited in the document, which should adhere to the citation method used for SAE publications.

10.1.1.3 For models of algorithms, the functional description should also include the principles, strategies, logic details, calculation details (fixed or floating point), and history of development of the algorithm strategy. Also, the description should include whether the algorithm is new or an update on a proven algorithm.

10.1.2 For all parameter maps and tables (such as 2-D and 3-D look-up tables) employed in the model, provide diagrams or graphs, references to their sources, and sources of data for these functions.

10.1.3 Explicitly state which portions of the model are based on fundamental physical equations and which parts are based on empirical data.

10.2 Other Modeling Methods Considered and Rejected:

10.2.1 Describe other modeling techniques considered but not used. And, provide an explanation of the reasons why these techniques (methods, approaches, physical effects or features, approximations, etc.) were not used and why the current approach was selected. This should also include mention of other models of similar scope that were not chosen.

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10.3 Selectable, Configurable, and Potential Functional Capabilities:

10.3.1 Model Selectable Variants:

10.3.1.1 Provide details on how built-in model variants can be selected to provide different functions or capabilities.

10.3.2 Configurable Model Uses:

10.3.2.1 Provide details on how the model can be configured for other applications beyond its original intended usage.

10.3.2.2 Include a description of methods to configure the model for other applications, for example, by using existing internal hooks, scaling changes, calibration changes, or other methods. Also, provide details about any issues, notes, and hints to enable these uses.

10.3.3 Potential Model Extensions:

10.3.3.1 Provide details for any known potential model extensions. Describe how the model can be extended to provide other functions, features, or capabilities and to support additional related applications.

11. IMPLEMENTATION REQUIREMENTS AND DEPENDENCIES

11.1 Computational Resources:

11.1.1 Define the computational resources required, recommended, or used to execute this model (e.g., RAM memory, disk space, floating operations per second (FLOPS), etc.).

11.2 Operating System:

11.2.1 Define the operating system used or required to execute this model. Provide the operating system name, version, etc.

11.3 Simulation Environment:

11.3.1 Define the simulation environment used or required to execute this model. Provide the environment name, version, etc.

11.3.2 Describe the compatibility of the model or model elements with earlier or later versions of the simulation environment.

11.3.3 Describe the compatible solver options; for example, equation solver, integration method, step size, etc.

11.4 Model/Software Language:

11.4.1 Define the model/software language (or modeling tool) and the version that was used to create the model. Note the model/software language may be the same as the simulation environment.

11.4.2 Describe the compatibility of model elements with earlier or later versions of software.

11.4.3 Also, list any software versions that are known to work with the model. This information may be required to link the model to other existing user models or subroutines. (For example, linking optional user models (or subroutines) with some modeling tools requires a specific compiler release.)

11.5 Additional Files Required:

11.5.1 Define any common code base (such as libraries, templates, floating point math libraries, etc.) and the version that was used to develop the model. This includes details of any library options available to the user and instructions or links to instructions on how to access to them. Also, include any standards and guidelines to be followed related to the use of libraries.

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11.6 Model Execution Order Requirements:

11.6.1 Provide any requirements or relevant details for execution order of model features or functions. (This is usually used for algorithm models, but can also apply to plant models.)

11.7 Safety Requirements:

11.7.1 For an algorithm or software model, define the level of safety provided and the impact of the safety design on the design of the system.

11.7.1.1 Example: To achieve the required level of safety, the algorithm requires redundant sensors, dual-path independent calculations, dual store of variables and parameters, and processor integrity checks.

11.7.1.2 Also, provide references or links to documented results from safety analysis methods, such as failure modes and effects analysis, and fault tree analysis.

11.8 Model File Format:

11.8.1 Define the format of the file containing the model (e.g., XML, plain text, binary, etc.).

12. PERFORMANCE

12.1 Describe the emulation fidelity and accuracy both static and dynamic.

12.1.1 Also, include the sensitivity of accuracy to a list of key variables affecting accuracy. (Normally, this would just document the performance of the model, but for model requirements documentation, this would specify required or desired target values.)

12.2 Describe the computational execution time for the model in terms of maximum, minimum, and nominal time to execute once. (Normally, this would just document the performance of the model, but for model requests, this would define required or desired target values.)

12.2.1 Also, describe the sensitivity of the execution time to key variables or parameters. List all known key variables or parameters affecting execution time and define their effect on execution time in terms of minimum time, nominal time, maximum time, and sensitivity of execution time.

13. OPERATING INSTRUCTIONS

13.1 User Guide:

13.1.1 Provide directions to build and run the model, if necessary.

13.2 Troubleshooting:

13.2.1 Provide a list of typical problems and how to solve or avoid them. This should also include a short description of the problem and solutions, or should provide a link to a file or location where this information is stored. Whenever a model is used and discovered to be unsuitable for a task, it should be documented. It is recommended that there should be a process in place to capture any problems that occur and to update the model documentation accordingly in a timely manner.

13.3 Open Issues:

13.3.1 Provide a list or link to a list of all known issues, bugs, and incomplete documentation, including any planned resolution and completion dates.

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13.4 Installation Instructions:

13.4.1 Provide a description of the procedure for installing the model onto a local drive, if necessary, or a link to instructions for installing the model into a tool environment that includes database management.

14. VERIFICATION AND VALIDATION

14.1 Verification:

14.1.1 Note, for model development requests, this section would specify how the model should be verified.

14.1.2 Verification Summary: The process of verification confirms that the model performs as it was designed. It does not mean that the model emulates the physical system correctly. Has the model been verified? [Choose one: Model verified, or Model not verified] If verified, has it been verified on static performance, dynamic performance, or both? [Choose one: Static performance, Dynamic performance, or Both static and dynamic performance]

14.1.2.1 Provide a brief summary of the performance range for which the model has been verified, such as input operating range tested, parameter range tested, environmental conditions tested, the input voltage range tested (for HIL models), etc.

14.1.3 Describe how the model was verified. Define the verification requirements, the test data that was used, the tests that were performed, and the range of operation that was verified.

14.1.3.1 Describe the model verification requirements.

14.1.3.2 Describe the location of (or a link to) simulation test case data files that have been created to test the model in the simulation environment.

14.1.3.2.1 Note a test case is a data file, which consists of a set of independent variables (used in a calculation) along with their corresponding dependent variables that are produced by the calculation. Typically, this would be sets of input values or waveforms and parameter values along with their corresponding expected output values or waveforms.

14.1.4 Describe the verification process including results (or links to results) with references to relevant verification studies.

14.1.4.1 Describe how to use the files to verify that the model performs calculations correctly and how to compare the model outputs with expected results for the test cases in terms of model input waveforms or values and their corresponding output waveforms or values. For each variable used for verification, provide a variable name, a definition of the physical quantity (i.e., what does it measure, represent, control, or do in the physical system being modeled), units of measurement, data types, and range of typical values (including restrictions).

14.2 Validation:

14.2.1 Note, for model development requests, this section would specify how the model needs to be validated.

14.2.2 Validation Summary: The process of validation confirms that the model emulates the physical system to within an acceptable tolerance band, over a desired frequency band, etc. Has the model been validated? [Choose one: Model validated, or Model not validated] If validated, has it been validated on static performance, dynamic performance, or both? [Choose one: Static performance, Dynamic performance, or Both static and dynamic performance]

14.2.2.1 Provide a brief summary of the performance range for which the model has been validated, such as input operating range tested, parameter range tested, environmental conditions tested, the input voltage range tested (for HIL models), etc.

14.2.3 Describe how the model was validated. Define the validation requirements, the test data that was used, the tests that were performed, and the range of operation that was validated.

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14.2.3.1 Describe the model validation requirements.

14.2.3.2 Describe the location of (or a link to) simulation test case data files that have been created to test the model in the simulation environment.

14.2.3.2.1 Note a test case is a data file, which consists of a set of independent variables (used in a calculation) along with their corresponding dependent variables that are produced by the calculation. Typically, this would be sets of input values or waveforms and parameter values along with their corresponding expected output values or waveforms.

14.2.4 Describe the validation process including results (or links to results) with references to relevant validation studies.

14.2.4.1 Describe how to use the files to validate that the model performs correctly and how to compare the model outputs with expected results for the test cases in terms of model input waveforms or values and their corresponding output waveforms or values. For each variable used for validation, provide a variable name, a definition of the physical quantity (i.e., what does it measure, represent, control, or do in the physical system being modeled), units of measurement, data types, and range of typical values (including restrictions).

15. MODEL ADMINISTRATIVE INFORMATION

15.1 Model Version Control Information:

15.1.1 Provide the model version, date, model author/creator, date of latest revision and by whom, model release or completion date, model review date, and name and location of the change history log file.

15.2 Model Description Documentation Information:

15.2.1 Provide documentation version, creation date, author, date of latest revision, and by whom.

15.3 Model Source Information:

15.3.1 Provide the location of the file that contains the model.

15.3.2 Provide the location and description of parameter dataset files or libraries of files, which are compatible with this model (i.e., compatible parameter datasets are ones that contain all of the parameter values required to configure the model to simulate a specific piece of hardware or algorithm).

15.3.3 Define the location of all of the required related files (i.e., required .dlls, required .dat files, etc.).

15.3.4 Describe the location of the file of the graphical representation to be used as an icon to represent the model as part of a larger subsystem, or system model.

15.4 Technical Support Information:

15.4.1 Define who to contact for support and provide their contact information.

15.4.2 Provide the names of the model supplier(s), list of any company(ies) associated with the model including the address and personnel contact details, where appropriate.

15.5 Model Access, Availability, and Restrictions:

15.5.1 Describe who may have access to this model, the form of the model available for access (source code, object code, compiled function, etc.), the level of access (read, write, modify/update, etc.), and an expiration date for permission to access.

15.5.2 Describe whether or not the model is available for external use to other groups, or to other companies or organizations.

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15.5.3 Describe whether or not the model is available commercially and who to contact to acquire a copy.

15.5.4 Define confidentiality conditions for using the model by providing legal terms for use, and by defining who may use the model, limits on distribution, and time limits on use. For a model request, this section would define how the model supplier may or may not use this model.

15.6 Model Development Information:

15.6.1 Choose one of the following to define the status of the model development: proposed, under development, reviewed, or approved signed and released.

15.6.2 Choose one of the following to define the status of the model documentation: under development, reviewed, or approvals signed and released.

15.7 Model Update Procedure:

15.7.1 Provide details of the procedure required to modify the model (i.e., a model change request procedure), or a reference (or link) to separate documentation for change request procedures. Include reference to key contacts for submitting model change requests either within the company or externally.

15.7.2 Provide details of the model update history, including additions, deletions, or enhanced functionality, along with date and author.

6. NOTES

6.1 Revision Indicator

A change bar (l) located in the left margin is for the convenience of the user in locating areas where technical revisions, not editorial changes, have been made to the previous issue of this document. An (R) symbol to the left of the document title indicates a complete revision of the document, including technical revisions. Change bars and (R) are not used in original publications, nor in documents that contain editorial changes only.

PREPARED BY THE DYNAMICAL MODELING AND SIMULATION TECHNICAL COMMITTEE

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APPENDIX A - MODEL DESCRIPTION DOCUMENTATION LIST OF SECTION HEADINGS

Table A1 - Categories of information for model documentation

Model Description Documentation Section Headings	
Item No.	**Heading or Content Item**
1.	**Model Title:** Provide a name for the model.
2.	**High-Level Description of Model**
2.1	• High-Level Model Classification:
2.2	• Model Complexity Classification:
2.3	• High-Level Model Description:
2.4	• Model Classification
2.4.1	○ Model Capability Type:
2.4.2	○ Model Prediction Type:
2.4.3	○ Modeling Method Type:
2.4.4	○ Model Keywords:
2.5	• Model Standards Compliance:
3.	**Purpose/Applications/Usage**
3.1	• Purpose of the Model:
3.2	• Approved Applications:
3.3	• Model Compatibility Statement:
4.	**Features and Capabilities**
5.	**Model Applicability and Limitations**
6.	**External Interface Variables (or Inputs and Outputs)**
7.	**Internal Variables**
8.	**Parameters and Calibration Procedures**
8.1	• Model Parameters:
8.2	• Parameter Calibration Data Requirements:
8.3	• Calibration Data Collection Procedures:
8.4	• Calibration Data Processing:
8.5	• Model Calibration Tools:
8.6	• Model Configuration:
8.6.1	○ Model Configuration Tools:
8.6.2	○ Model Initialization Tools:
8.7	• Method for Loading Parameters:
9.	**Model Architectural Structure**

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Model Description Documentation Section Headings	
Item No.	**Heading or Content Item**
10.	**Detailed Functional Description**
10.1	• Theoretical Basis:
10.1.1.1	– Nomenclature:
10.1.1.2	– Reference List:
10.2	• Other Modeling Methods Considered and Rejected:
10.3	• Selectable, Configurable, and Potential Functional Capabilities:
10.3.1	○ Model Selectable Variants:
10.3.2	○ Configurable Model Uses:
10.3.3	○ Potential Model Extensions:
11.	**Implementation Requirements and Dependencies**
11.1	• Computational Resources:
11.2	• Operating System:
11.3	• Simulation Environment:
11.4	• Model/Software Language:
11.5	• Model Solvers Required:
11.6	• Additional Files Required:
11.7	• Model Execution Order Requirements:
11.8	• Safety Requirements:
11.9	• Model File Format:
12.	**Performance**
13.	**Operating Instructions**
13.1	• User Guide:
13.2	• Troubleshooting:
13.3	• Open Issues:
13.4	• Installation Instructions:
14.	**Verification and Validation**
14.1	• Verification:
14.2	• Validation:
15.	**Model Administrative Information**
15.1	• Model Version Control Information:
15.2	• Model Description Documentation Information:
15.3	• Model Source Information:
15.4	• Technical Support Information:
15.5	• Model Access, Availability, and Restrictions:
15.6	• Model Development Information:
15.7	• Model Update Procedure:

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APPENDIX B - SUMMARY MATRIX OF CONTENT ITEMS INCLUDED IN EACH USE CASE

This section provides a matrix that shows which content items are included in each use case template detailed in 4.1 and shown here for convience:

1. Sales Brochure or Product Description Documentation View: Provides a high-level description of a model to enable an engineer to select the model required for their analysis application. It includes a description of model features, capabilities, interfaces, applications, performance, simulation environment tool requirements, and computer resources required.

2. Requirements Documentation View: Provides the detailed information required for a model user to request the development of a model by a model producer or component model supplier for a specific analysis task.

3. Compatibility Documentation View: Provides a simulation engineer with the information required to identify other models that are compatible with the model described in the documentation. The information provided by this view can be sorted by using compatibility rules to select appropriate models from a set of models to ensure that the model characteristics and interface information are compatible with a given model. It can also be used to identify what may need to be changed to make two models compatible so they can work together.

4. Process Management Documentation View: Provides a modeling and simulation process manager with the information required to confirm the quality and maturity of models and simulations, and to control the introduction, update, and removal of models from libraries of models available for standard engineering analysis processes.

5. Testing-in-the-Loop Documentation View: This view includes hardware-in-the-loop (HIL), component-in-the-loop (CIL), software-in-the-loop (SIL), processor-in-the-loop (PIL), and vehicle-in-the-loop (VIL) applications. It provides a simulation engineer with the information required to select, configure, and apply the model to an HIL, CIL, SIL, PIL, or VIL test execution platform for the analysis of a specific component, subsystem, or system in an application where real-time execution cost and performance are critical. It includes information about data collection and calibration procedures for the model of a system, subsystem, component, or software algorithm.

6. Application Documentation View: Provides a simulation engineer with the information required to apply the model for the analysis of a specific component, subsystem, or system. It also includes information about data collection and calibration procedures.

7. Technical Specification Documentation View: Provides the detailed information needed to enable a model developer to maintain, extend, modify, or update an existing model to provide the features, capabilities, and performance requested by model users for a specific analysis.

The information is shown in Table B1, where each row lists a content item number followed by the content item description, which is followed by a column for each of the seven use cases. If the content item is included in a use case; then, an “X” appears in the column for that use case. The last column on the right shows the information type for each content item as an “S” for section headings or an “I” for instructions. Gray highlighted rows are inserted between the main sections. Also, for consistency between the use case templates (shown in Appendix C) and this matrix, a blue highlighted box with an arrow (➔) is shown in the first column on the left for the rows where the user would enter their responses into the use case templates for the requested content information. However, no information is to be entered in these rows of the summary matrix.

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Table B1 - Summary of content items for each use case

Summary Matrix of Content Items Included in Each Use Case									
Content Item Number	**Heading or Content Item**	**Use Case #1**	**Use Case #2**	**Use Case #3**	**Use Case #4**	**Use Case #5**	**Use Case #6**	**Use Case #7**	**Info. Type**
1.	**Model Title:** Provide a name for the model.	X	X	X	X	X	X	X	S
➔									
2.	**High-Level Description of Model**	X	X	X	X	X	X	X	S
2.1	• High-Level Model Classification:	X	X	X	X	X	X	X	S
2.1.1	Provide a high-level type classification of the model. Choose any or all of the following items describing what is included in the model: hardware, controller algorithm, and/or controller software.	X	X	X	X	X	X	X	I
➔									
2.2	• Model Complexity Classification:	X	X	X	X	X	X	X	S
2.2.1	Provide a model-complexity level classification. Choose one of the following model types best describing what the model represents: system, subsystem, component, function, or equation.	X	X	X	X	X	X	X	I
➔									
2.3	• High-Level Model Description:	X	X	X	X	X	X	X	S
2.3.1	Provide a high-level description of the model. Describe the most salient features of the model.	X	X	X	X	X	X	X	I
2.3.1.1	– Example: Turbocharged direct injection gasoline engine with variable valve timing and variable lift.	X	X	X	X	X	X	X	I
➔									
2.3.2	Include a part number, and/or component part numbers (if made from a collection of components with numbered parts), and model year if applicable.	X	X	X	X	X	X	X	I
➔									
2.4	• Model Classification:	X	X	X	X	X	X	X	S
2.4.1	○ Model Capability Type:	X	X	X	X	X	X	X	S
2.4.1.1	– Describe the capability type of the model.	X	X	X	X	X	X	X	I
2.4.1.1.1	– Choose the one that best describes the capabilities or the model: steady-state or dynamic.	X	X	X	X	X	X	X	I
➔									

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Summary Matrix of Content Items Included in Each Use Case									
Content Item Number	Heading or Content Item	Use Case #1	Use Case #2	Use Case #3	Use Case #4	Use Case #5	Use Case #6	Use Case #7	Info. Type
2.4.1.1.2	– Choose the one that best describes the capabilities of the model: 0-D, 1-D, 2-D, or 3-D.	X	X	X	X	X	X	X	I
➔									
2.4.2	○ Model Prediction Type:	X	X	X	X	X	X	X	S
2.4.2.1	– Describe the prediction type of the model. Choose one of the following: forward or backward model.	X	X	X	X	X	X	X	I
➔									
2.4.3	○ Modeling Method Type:	X	X	X	X	X	X	X	S
2.4.3.1	– Describe the modeling method type. Choose one of the following: causal or acausal model.	X	X	X	X	X	X	X	I
➔									
2.4.4	○ Model Keywords:	X	X	X	X	X	X	X	S
2.4.4.1	– Define keywords for classifying the model to support searching for models with desired characteristics. Provide a list of words and terms that describe the model, which will help to locate or search for models with the desired characteristics or features, such as:	X	X	X	X	X	X	X	I
2.4.4.1.1	▪ Physical Model, Empirical Model, Embedded Black-Box Model, Auto-Code Ready Model, Fixed Point Calculation, Floating Point Calculation, Environment Subsystem, Driver Subsystem, Vehicle Supervisory Controller Subsystem, Power Subsystem, Chassis Subsystem, etc.	X	X	X	X	X	X	X	I
➔									

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2.5	• Model Standards Compliance:	X	X	X	X	X	X	X	S
2.5.1	Describe any standards to which the model complies.	X	X	X	X	X	X	X	I
2.5.2	List any standards or guidelines (including international standards) and their version number for each of the following items: model, documentation, architecture, variable and parameter naming conventions, variable and parameter units, and signal name list (i.e., standard list of names and abbreviations).	X	X	X	X	X	X	X	I
➔									
3.	**Purpose/Applications/Usage**	X	X	X	X	X	X	X	S
3.1	• Purpose of the Model:	X	X	X	X	X	X	X	S
3.1.1	Explain why this model is needed and the problems it is designed to answer.	X	X	X	X	X	X	X	I
3.1.1.1	– Specifically, describe the types of analysis applications and uses for which the model is recommended or designed to address.	X	X	X	X	X	X	X	I
3.1.1.1.1	– Example: This model was developed to describe a turbocharger for performance, fuel economy, or component sizing analyses.	X	X	X	X	X	X	X	I
3.1.1.1.2	– Note the types of applications also include auto-code generation, which would require providing the additional details of the compiler and target hardware used.	X	X	X	X	X	X	X	I
➔									
3.1.2	Describe any known types of analysis applications for which the model is not recommended. Whenever a model is used and discovered to be unsuitable for a task, it should be documented. It is recommended that there should be a process in place to capture any problems that occur and to update the model documentation accordingly in a timely manner.		X		X	X	X	X	I

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3.1.2.1	– Example: This engine model was not developed to study individual cylinder charging and torque production.		X		X	X	X	X	I
➔									
3.1.3	Provide examples of typical or generic applications along with some references to applications where the model has been previously used in projects, studies, and analyses.	X	X	X	X	X	X	X	I
➔									
3.2	• Approved Applications:				X	X	X	X	S
3.2.1	Describe in detail the applications for which the model has been thoroughly tested and approved.				X	X	X	X	I
3.2.2	To make the approval more formal, include documentation of approval or authorization to use the model for these applications by appropriate engineer(s) and/or manager(s) signature(s) with approval date(s).				X		X	X	I
➔									
3.3	• Model Compatibility Statement:		X	X	X	X	X	X	S
3.3.1	Define model files or libraries of model files that are compatible with the model described by this document.		X	X	X	X	X	X	I
➔									
4.	**Features and Capabilities**	X	X	X	X	X	X	X	S
4.1	• Provide a high-level functional description of the model describing all of the features, capabilities, and phenomena that the model produces.	X	X	X	X	X	X	X	I
4.1.1	When used in a model request, this item describes the features, capabilities, and phenomena that the model should provide.	X	X	X	X	X	X	X	I
➔									
4.1.2	Also, mention whether tools are provided for calibration, initialization, or other functions.		X	X	X	X	X	X	I
➔									

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4.2	• Provide a detailed description of the requirements for each feature, capability, or phenomenon of the real system that the model needs to emulate.		X	X	X	X	X	X	I
4.2.1	When used in a model request, this item describes the requirements for each feature, capability, and phenomenon the model should emulate.	X	X	X	X	X	X	X	I
4.2.1.1	– Include any requirements on the fidelity of each required content item.		X	X	X	X	X	X	I
➔									
4.2.1.2	– Also, describe the known features, capabilities, or phenomena of the real system that the model does not need to emulate and describe why it does not.		X	X	X	X	X	X	I
➔									
5.	**Model Applicability and Limitations**		X	X	X	X	X	X	S
5.1	• Describe the range of environmental or other operating conditions for which the usage of the model has been approved.		X	X	X	X	X	X	I
➔									
5.2	• Describe the limits of model applicability, such as limitations and constraints on model fidelity and feature content.		X	X	X	X	X	X	I
5.2.1	Example: Model fidelity is valid only below 50 Hz.		X	X	X	X	X	X	I
5.2.2	Example: Model feature content is valid only for handling, but not ride analysis.		X	X	X	X	X	X	I
➔									
5.3	• Describe what other models this model is designed to be used with.			X			X	X	I
5.3.1	Example: This engine model was designed to be used in a passenger car vehicle system model with an automatic transmission model that includes a torque converter model.			X			X	X	I
➔									

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6.	**External Interface Variables (or Inputs and Outputs)**		X	X		X	X	X	S
6.1	• Describe all external interface variables of the model.		X	X		X	X	X	I
6.1.1	For each variable, provide a variable name, a definition of the physical quantity (i.e., what does it measure, represent, control, or do in the physical system being modeled), units of measurement, data types, range of typical values (including restrictions).		X	X		X	X	X	I
6.1.2	For causal models, these variables define the inputs and outputs of the model.		X	X		X	X	X	I
6.1.3	For acausal models, these variables define the model ports.		X	X		X	X	X	I
6.2	Describe all external models and associated Model Data Dictionaries that interface with the model.		X	X		X	X	X	I
➔									
7.	**Internal Variables**					X	X	X	S
7.1	• Describe all internal variables of the model (including any variables or signals needed for displaying or monitoring of the calculations).					X	X	X	I
7.1.1	For each variable, provide a variable name, a definition of the physical quantity (i.e., what does it measure, represent, control, or do in the physical system being modeled), units of measurement, data types, range of typical values (including restrictions).					X	X	X	I
➔									
8.	**Parameters and Calibration Procedures**					X	X	X	S
8.1	• Model Parameters:					X	X	X	S
8.1.1	Describe all parameters of the model.					X	X	X	I
8.1.2	For each parameter, provide a name, a definition of physical quantity (i.e., what does it represent, control, or do in the physical system being modeled), units of measurement, data types, range of typical values (including restrictions).					X	X	X	I

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8.1.3	Note initial conditions for internal variables are also model parameters, since they are used to calibrate a model to represent a specific piece of hardware or control algorithm functioning at an initial operating point.					X	X	X	I
8.1.4	Describe the parameters storage format; for example, MAT, MDF, CSV, JSON, etc.					X	X	X	I
➔									
8.2	• Parameter Calibration Data Requirements:					X	X	X	S
8.2.1	Define data needed to calibrate model parameters to represent a specific hardware or control algorithm system, subsystem or component.					X	X	X	I
8.2.2	Note the “calibration data” could come from real hardware tests, from virtual tests through simulation using higher fidelity models, from Computer-Aided Engineering (CAE) analysis, from other analytical means, or from a combination of all of these methods.					X	X	X	I
➔									
8.3	• Calibration Data Collection Procedures:					X	X	X	S
8.3.1	Define procedures required to collect calibration data.					X	X	X	I
8.3.2	Note the procedures could require real hardware testing using instrumentation, virtual testing using simulation, other analytical means, or a combination of all of these methods.					X	X	X	I
➔									
8.4	• Calibration Data Processing:					X	X	X	S
8.4.1	Define how the calibration data is processed to determine the values of the model parameters. This should also include descriptions of data entry methods, and the data types, and data formats required.					X	X	X	I
➔									
8.5	• Model Calibration Tools:					X	X	X	S
8.5.1	Describe the details for using software tools to implement processes supporting model calibration.					X	X	X	I

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8.5.1.1	– Provide instructions to acquire any software tools or links to any graphical user interfaces (GUIs) available to facilitate calibration processes. This should include links to instructions describing how they are activated and to details of any available help information. Also, include descriptions of data entry methods, and the data types, and data formats required.					X	X	X	I
➔									
8.5.2	Provide references to any documented test procedures required to retune calibration parameters.					X	X	X	I
➔									
8.6	• Model Configuration:					X	X	X	S
8.6.1	○ Model Configuration Tools:					X	X	X	S
8.6.1.1	– Provide a list of any standard or custom-made software tools used for configuring model parameters and initial conditions. Also, this should include links to instructions describing how they are activated and to details of any available help information.					X	X	X	I
➔									
8.6.2	○ Model Initialization Tools:					X	X	X	S
8.6.2.1	– Initial conditions for internal variables may be determined by a separate initialization process. Provide a list of any standard or custom-made software tools used for configuring initial conditions. Also, this should include links to instructions describing how they are activated and to details of any available help information.					X	X	X	I

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➔									
8.7	• Method for Loading Parameters:					X	X	X	S
8.7.1	Describe the standards and methods for loading parameters into a model. This should also include descriptions of data entry methods, and the data types, and data formats required.					X	X	X	I
➔									
8.7.2	Provide a link to the simulation environment tool or GUIs, required by the model, where the method is described.					X	X	X	I
➔									
9.	**Model Architectural Structure**					X	X	X	S
9.1	• Provide a model architectural diagram and description outlining major model elements (i.e., subsystems and components), and how they are connected and function together.					X	X	X	I
9.1.1	The diagrammatic representation of the model architecture may be in the form of block diagrams, flow charts, schematics, etc.					X	X	X	I
➔									
9.1.2	A description of how these major model elements work together should accompany the diagram.					X	X	X	I
➔									
10.	**Detailed Functional Description**				X	X	X	X	S
10.1	• Theoretical Basis:				X	X	X	X	S
10.1.1	Provide all equations, assumptions, approximations, and references (a list of all papers and reports) that were used to formulate and develop the model.				X	X	X	X	I
➔									
10.1.1.1	– Nomenclature:				X	X	X	X	S
10.1.1.1.1	– Provide a list of symbols, non-standard technical terms, and acronyms used in the model and model documentation.				X	X	X	X	I
➔									

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10.1.1.2	– Reference List:						X	X	S
10.1.1.2.1	– Provide a list of all reference material cited in the document, which should adhere to the method used for SAE publications.						X	X	I
➔									
10.1.1.3	– For models of algorithms, the functional description should also include the principles, strategies, logic details, calculation details (fixed or floating point), and history of development of the algorithm strategy. Also, the description should include whether the algorithm is new or an update on a proven algorithm.						X	X	I
➔									
10.1.2	For all parameter maps and tables (such as 2-D and 3-D look-up tables) employed in the model, provide diagrams or graphs, references to their sources, and sources of data for these functions.					X	X	X	I
➔									
10.1.3	Explicitly state which portions of the model are based on fundamental physical equations and which parts are based on empirical data.							X	I
➔									
10.2	• Other Modeling Methods Considered and Rejected:							X	S
10.2.1	Describe other modeling techniques considered but not used, and provide an explanation of the reasons why these techniques (methods, approaches, physical effects or features, approximations, etc.) were not used and why the current approach was selected. This should also include mention of other models of similar scope that were not chosen.							X	I
➔									
10.3	• Selectable, Configurable, and Potential Functional Capabilities:						X	X	S

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10.3.1	○ Model Selectable Variants:					X	X	X	S
10.3.1.1	– Provide details on how built-in model variants can be selected to provide different functions or capabilities.					X	X	X	I
➔									
10.3.2	○ Configurable Model Uses:					X	X	X	S
10.3.2.1	– Provide details on how the model can be configured for other applications beyond its original intended usage.					X	X	X	I
10.3.2.2	– Include a description of methods to configure the model for other applications, for example, by using existing internal hooks, scaling changes, calibration changes, or other methods. Also, provide details about any issues, notes, and hints to enable these uses.					X	X	X	I
➔									
10.3.3	○ Potential Model Extensions:							X	S
10.3.3.1	– Provide details for any known potential model extensions. Describe how the model can be extended to provide other functions, features, or capabilities and to support additional related applications.							X	I
➔									
11.	**Implementation Requirements and Dependencies**		X	X	X	X	X	X	S
11.1	• Computational Resources:		X	X	X	X	X	X	S
11.1.1	Define the computational resources required, recommended, or used to execute this model (e.g., RAM memory, disk space, floating operations per second (FLOPS), etc.).		X	X	X	X	X	X	I
➔									
11.2	• Operating System:		X	X	X	X	X	X	S

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11.2.1	Define the operating system used or required to execute this model. Provide the operating system name, version, etc.		X	X	X	X	X	X	I
➔									
11.3	• Simulation Environment:		X	X	X	X	X	X	S
11.3.1	Define the simulation environment used or required to execute this model. Provide the environment name, version, etc.		X	X	X	X	X	X	I
11.3.2	Describe the compatibility of the model or model elements with earlier or later versions of the simulation environment.		X	X	X	X	X	X	I
11.3.3	Describe the compatible solver options; for example, equation solver, integration method, step size, etc.		X	X	X	X	X	X	I
➔									
11.4	• Model/Software Language:		X	X	X	X	X	X	S
11.4.1	Define the model/software language (or modeling tool) and the version that was used to create the model. Note the model/software language may be the same as the simulation environment.		X	X	X	X	X	X	I
11.4.2	Describe the compatibility of model elements with earlier or later versions of software.			X	X	X	X	X	I
11.4.3	Also, list any software versions that are also known to work with the model. (This information may be required to link the model to other existing user models or subroutines. For example, linking optional user models (or subroutines) with some modeling tools requires a specific compiler release.)		X	X		X	X	X	I
➔									
11.6	• Additional Files Required:			X	X	X	X	X	S
11.6.1	Define any common code base (such as libraries, templates, floating point math libraries, etc.) and the version that was used to develop the model. This includes details of any library options available to the user and instructions or links to instructions on how to access to them. Also, include any standards and guidelines to be followed related to the use of libraries.			X	X	X	X	X	I

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➔									
11.7	• Model Execution Order Requirements:					X	X	X	S
11.7.1	Provide any requirements or relevant details for execution order of model features or functions. (This is usually used for algorithm models, but can also apply to plant models.)					X	X	X	I
➔									
11.8	• Safety Requirements:							X	S
11.8.1	For an algorithm or software model, define the level of safety provided and the impact of the safety design on the design of the system.							X	I
11.8.1.1	– Example: To achieve the required level of safety, the algorithm requires redundant sensors, dual-path independent calculations, dual store of variables and parameters, and processor integrity checks.							X	I
➔									
11.8.1.2	– Also, provide references or links to documented results from safety analysis methods, such as failure modes and effects analysis, and fault tree analysis.							X	I
➔									
11.9	• Model File Format:			X		X	X	X	S
11.9.1	Define the format of the file containing the model (e.g., XML, plain text, binary, etc.).			X		X	X	X	I
➔									
12.	**Performance**			X		X	X	X	S
12.1	• Describe the emulation fidelity and accuracy both static and dynamic.			X		X	X	X	I

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