What Is
Predictive Capability Maturity Model (PCMM)

V&V/UQ and Credibility Processes Team

This "What Is" will:

- Provide you with a high level understanding of the PCMM framework
- Provide you with an introduction to the PCMM assessment process and the tool
- Provide you with understanding of how PCMM aids in supporting & communicating CompSim credibility

Prerequisite reading: What Is CompSim Credibility; What Is Verification and Validation (V&V); What Is PIRT

The Predictive Capability Maturity Model is an expert elicitation process designed to characterize and communicate the completeness and rigor of the approaches used in computational model definition, code and solution verification, validation, and uncertainty quantification for an application prediction. The PCMM is based on six evaluation elements that are fundamentally important to the quality of a Computation Simulation (CompSim) analysis for a particular application scenario.

Verification, Validation and Uncertainty Quantification analyses provide part of the evidence that is assessed using the PCMM framework.

Why should you perform a PCMM assessment?

With the increasing dependence on CompSim in engineering analyses, the importance of characterizing and communicating the completeness of the modeling and simulation approaches used in an application analysis has also increased.

The PCMM process provides additional structure and formality in evaluating the completeness and quality of a CompSim analysis for a target application. The PCMM tool helps to organize assessment evidence for the purpose of reporting in a consistent and transparent way and to identify major gaps in the CompSim analysis.

What are the PCMM Elements?

1. Code Verification (CVER): evaluates the degree to which the computational simulation code has been shown to accurately represent the underlying mathematical model and its solution. The evaluation identifies the important code capabilities that have not been sufficiently verified for the intended use.

2. Physics and Material Model Fidelity (PMMF): evaluates the fidelity in representing the physics of the application, including the material models. The evaluation identifies the important physics and material models that may not be adequate for the intended use.

3. Representation and Geometric Fidelity (RGF): evaluates the geometric fidelity in representing the system or subsystem(s) being modeled. The evaluation identifies the elements of the application geometry model that have been de-featured and the potential sensitivity to these approximations.

4. Solution Verification (SVER): evaluates whether the numerical error and associated uncertainties of the computational simulation have been quantified, and if the simulation and post-processing input decks have been verified. The evaluation identifies spatial, temporal, and/or stochastic resolution limitations in the application simulation.

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5. Validation (VAL): evaluates the assessment of computational simulation results against experimental data throughout the validation hierarchy, and the proximity of the experimental conditions to the application conditions. The evaluation identifies issues with the validation comparisons, validation hierarchy coverage, and/or degree of extrapolation from the validation conditions to the application conditions.

6. Uncertainty Quantification (UQ): evaluates the uncertainty in the CompSim results. The evaluation identifies issues with the characterization of input uncertainties, the characterization of output uncertainties, and/or the aggregation and extrapolation of the validation uncertainties to the application.

Each element is broken down further into sub-elements, providing the assessment of each element with more detail. The sub-elements are assessed on a scale from 0 to 3 where Level 0 roughly equates to little or no attention being given to the particular sub-element to Level 3 indicating that the most rigorous treatment/methodology was used.

Using a scoring system to evaluate each sub-element provides a quantitative characterization for reporting; however, the primary goal of the PCMM assessment is to ultimately identify and communicate major gaps in the six elements of a CompSim analysis, not to provide a CompSim "grade."

What is the PCMM process?

The overall goal of performing a PCMM assessment is to increase clarity and content of communication within the analysis team and with the customer, about the necessary completeness and rigor of the computational simulation analysis for the application.

A PCMM process includes organizing an appropriate team and communicating the assessment process, team roles and responsibilities. Participants include customers, analysts, physics modelers, code developers, experimentalists, and a V&V/PCMM specialist. The breadth of experience and knowledge of participants should be adequate to provide subject matter expertise to address the major features of CompSim that are relevant to the engineering application. The team lead is responsible for selecting team members, communicating impact, and delivering final PCMM product of the team to the customers as necessary. The V&V facilitator is responsible for conducting and managing the overall process, including working with the team lead to ensure that momentum is maintained and leading discussion during the team meetings. Facilitators act as a resource on the use of and interpretation of the items in the PCMM spreadsheet tool. Team members are responsible for providing individual scores and participating in the deliberations for the group evaluation scores.

The following subject matter expert elicitation process was designed to help ensure that both individual opinions and group consensus are characterized in the resulting PCMM product. The resulting product is a completed PCMM spreadsheet by team consensus, including completion of the lessons learned and impact fields.

Step 1: The team meets to discuss the PCMM tool, the elicitation process, and the expectations and use of the resulting PCMM product. Copies of the PIRT should be provided to the team before this meeting.

Step 2: After the meeting, the team members individually develop an initial evaluation of the elements in the PCMM that they feel they can adequately address.

Step 3: The team meets to discuss the individual assessments, to share knowledge that affects the assessments, and to reach a team consensus.

Step 4: After the meeting, the individual team members reflect on the deliberations and update their own scores if appropriate. Note that individual scores do not have to reflect the team scores. These individual scores are used to document diversity of opinion after the deliberation process is completed.

The tight inter-relationship between PIRT, PCMM, validation hierarchy, and the V&V plan needs to be preserved and clearly established. These documents are not independent of one another.

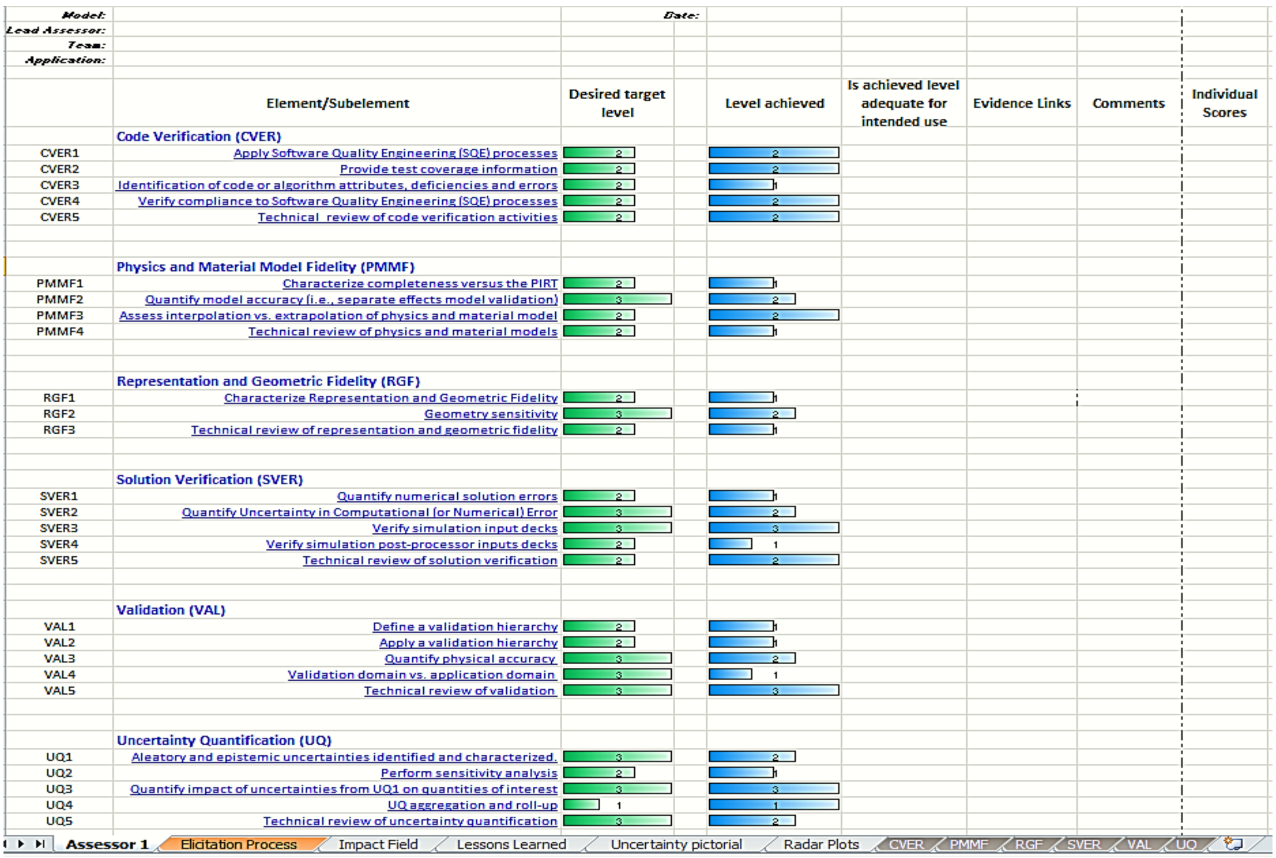
The availability of a PIRT for the application is a necessary condition to start PCMM evaluations. The PIRT identifies physical phenomena and assesses the adequacy of computational simulation capabilities, which are relevant to the PCMM evaluations.

The availability and use of a validation hierarchy for the application is evaluated in the PCMM. A validation hierarchy provides a comprehensive view of physics and hardware that have been evaluated relative to the application analysis.

Step 5: Final meeting of the team to discuss the actual or potential impact of the evaluation. The team lead is responsible for providing a summary of the impact in the PCMM tool. Impacts can be as specific as planned or recommended programmatic adjustments, or more generally as an increased understanding of the ability (or lack thereof) of the CompSim to provide the customers with actionable results.

What is the PCMM assessment tool?

The PCMM tool is Excel-based and is used to facilitate the evaluation of the elements and sub-elements of a CompSim analysis and identify major gaps. The current implementation of the PCMM assessment tool is shown in Figure 1. The tool has the following features:



Model:
Lead Assessor:
Team:
Application:
Date:

	Element/Subelement	Desired target level	Level achieved	Is achieved level adequate for intended use	Evidence Links	Comments	Individual Scores
	Code Verification (CVER)						
CVER1	Apply Software Quality Engineering (SQE) processes	2	2				
CVER2	Provide test coverage information	2	2				
CVER3	Identification of code or algorithm attributes, deficiencies and errors	2	1				
CVER4	Verify compliance to Software Quality Engineering (SQE) processes	2	2				
CVER5	Technical review of code verification activities	2	2				
	Physics and Material Model Fidelity (PMMF)						
PMMF1	Characterize completeness versus the PIRT	2	1				
PMMF2	Quantify model accuracy (i.e., separate effects model validation)	3	2				
PMMF3	Assess interpolation vs. extrapolation of physics and material model	2	2				
PMMF4	Technical review of physics and material models	2	1				
	Representation and Geometric Fidelity (RGF)						
RGF1	Characterize Representation and Geometric Fidelity	2	1				
RGF2	Geometry sensitivity	3	2				
RGF3	Technical review of representation and geometric fidelity	2	1				
	Solution Verification (SVER)						
SVER1	Quantify numerical solution errors	2	1				
SVER2	Quantify Uncertainty in Computational (or Numerical) Error	3	2				
SVER3	Verify simulation input decks	3	3				
SVER4	Verify simulation post-processor inputs decks	2	1				
SVER5	Technical review of solution verification	2	2				
	Validation (VAL)						
VAL1	Define a validation hierarchy	2	1				
VAL2	Apply a validation hierarchy	2	1				
VAL3	Quantify physical accuracy	3	2				
VAL4	Validation domain vs. application domain	3	1				
VAL5	Technical review of validation	3	3				
	Uncertainty Quantification (UQ)						
UQ1	Aleatory and epistemic uncertainties identified and characterized.	3	2				
UQ2	Perform sensitivity analysis	2	1				
UQ3	Quantify impact of uncertainties from UQ1 on quantities of interest	3	3				
UQ4	UQ aggregation and roll-up	1	1				
UQ5	Technical review of uncertainty quantification	3	2				

Figure 1. Main Assessment Tab of the PCMM tool

1. The main page of the assessment tool (Figure 1) displays:
   a. An area to capture the header information for the CompSim analysis that is being assessed.
   b. Six columns representing the Elements/Sub-elements, Desired Target Level, Achieved Level, Is Achieved Level Adequate for the Intended Use, Evidence Link, and Comments. These columns capture the team's assessment of the CompSim effort relative to each of the sub-elements' descriptor for each level:

      i. The "Desired Target Level" column sets the **target** level for the CompSim effort. This is as a result of negotiations between all the stakeholders.
      ii. The "Achieved Level" column reflects the **actual** level that the CompSim effort achieved. This column acknowledges that constraints (time/funding) sometimes prevent the achievement of the target level.
      iii. The "Is Achieved Level Adequate for the Intended Use" column provides an indication as to whether or not the difference between the achieved level and the target level is significant to impact the use the CompSim for the intended use.

iv. The "Evidence Link" and "Comments" columns serve as a place to capture relevant supporting evidence and explanatory comments to clarify the assessment process.
v. An additional column is also included in the spreadsheet to record the individual scores from the team members.

2. Other tabs (listed at the bottom of Figure 1):
   a. The Elicitation Process tab outlines the suggested process to perform a PCMM assessment.
   b. The Impact Field and Lessons Learned tabs capture relevant issues during an assessment.
   c. The Uncertainty pictorial tab provides uncertainty quantification definitions and images.
   d. The Radar Plots tab displays the PCMM element scores in a graphical manner.
   e. The Elements tabs have a complete description of each sub-element related to a particular element. This includes, Additional Info, Changes from previous level, Brief description of evidence relevant to this level, Additional evidence from previous level, and Key Words/Phrases. An example of this is shown in Figure 2.

Descriptor	Additional Info	Change(s) from previous level	Brief description of evidence relevant to this level	Additional evidence from previous level	Key Words/ Phrases
Model has no major or minor features present. Model is mainly "blobs" or point masses or stick-figure models or a curve fit of data.	The current writing is centric to meshed geometries. The words are not applicable to more general representation resolution issues. This is a TBD issue. RGF1 speaks to the level of meshed geometric detail in the problem. Level 0 means that there is essentially no discernible level of meshed detail in the presented predictive capability. Conceptual representation of the simulated geometry may be interpreted as detailed cadcam representation of the physical geometry exists, even though this is neglected in the computational simulation capability. The word "model" means "predictive computational simulation capability for the intended application."	n/a	Evidence of "blobs" etc. is presented.	n/a	Model = finite element model

Figure 2. Example of Representation of Geometric Fidelity sub-element: Characterize Representation and Geometric Fidelity (RGF1 – Level 0)

How does PCMM help assess credibility?

The primary goal of a PCMM assessment is to provide supporting information or evidence about claims of computational predictive capability. The evidence speaks to the *completeness* and *quality* of the work (both CompSim and V&V/UQ) that has led to delivered CompSim results. This evidence forms the basis of reported CompSim credibility claims.

Where do you get more information?

The PCMM elements are described in detail in guidance documents on the V&V Portal: What Is V&V, What Is Code Verification, What Is Solution Verification, What Is Validation, What Is Uncertainty Quantification, What Is PIRT, and How To PIRT, https://rails-rn-prod.sandia.gov/vvuq/.

Oberkampf, W.L., Pilch, M., and Trucano, T.G., "Predictive Capability Maturity Model for Computational Modeling and Simulation," Sandia National Laboratories Report, SAND2007-5948, October 2007.

PCMM Tool (Excel spreadsheet), V&V/UQ Portal, https://rails-rn-prod.sandia.gov/vvuq/pcmm

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