GRID MODERNIZATION LABORATORY CONSORTIUM
U.S. Department of Energy

Interoperability Maturity Model

A Qualitative and Quantitative Approach for Measuring Interoperability

January 2020

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Final version from draft "A Qualitative and Quantitative Approach for Measuring Interoperability"

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Summary

As a component of the U.S. Department of Energy (DOE) Grid Modernization Laboratory Consortium (GMLC) Interoperability project, the interoperability maturity model (IMM) tool is used in conjunction with the other materials of the project, such as the Interoperability Roadmap Methodology document,[1] to promote a common understanding of the meaning and characteristics of interoperability and to improve the process of successfully integrating components and systems as business models and information technology evolve over time. The IMM tool can be used to measure the state of integrating the information and communications technology aspects of intelligent devices and systems to coordinate their operation with the rest of the electric power system. The use of the tool also reveals challenges and areas for improvement to more easily and reliably achieve interoperability.

The vision of a modern electricity grid is of a complex system overlaid with a hyper-connected network of cyber systems that integrates grid operations with end-use business processes and social objectives to achieve ever greater scales of performance efficiency under conditions that must adapt to short-term disturbances and long-term trends. A transformational aspect of this vision of the future electric system is the coordinated operation of distributed energy resources, which include generation, storage, and responsive load, with the electric delivery system infrastructure for greater efficiency, reliability, and resiliency.

The IMM tool can be used to articulate a baseline level of interoperability and to identify the gaps and priority aspects to consider for evolving toward higher levels of interoperability maturity. The IMM was created in parallel with the roadmap methodology because of their close relationship. The ultimate goal of a roadmap effort is to increase the interoperability maturity level to meet the ecosystem's objectives while being sensitive to the state of the art, the projected technology advances, and the cost/value of the effort. The IMM described in this document is a tool that is used as part of a broader strategy to develop roadmaps for advancing interoperability in technology integration domains. The roadmap process engages the communities (or ecosystems[2]) of organizations involved in smart technology deployment. A companion to the IMM in this strategy is a proposed roadmap development process, which is described in the Interoperability Roadmap Methodology document. The roadmaps developed using this methodology are intended help each ecosystem articulate a vision of interoperability as well as prioritized steps to move toward it. This document identifies a list of 33 interoperability criteria, which are grouped into 6 categories, for quantifying the state of interoperability in a technology integration domain. This document is written for stakeholders in technology integration domains who work on standards, guides, and supporting material that ease integration of devices and systems within a specific area, and for people interested in learning more about the dimensions of interoperability and associated details of the model.

[1] DOE (U.S. Department of Energy). 2020. Interoperability Roadmap Methodology, PNNL-2749 1.3. Accessed January 2020 at https://gridmod.labworks.org/projects/1.2.2

[2] ecosystem - A community of participating organizations collaborating to address one or more business or social objectives that concern interoperability and ease the deployment of specific technologies

Acknowledgments

This research was supported by the Grid Modernization Initiative of the U.S. Department of Energy (DOE) as part of its Grid Modernization Laboratory Consortium, a strategic partnership between DOE and the national laboratories to bring together leading experts, technologies, and resources to collaborate on the goal of modernizing the nation's grid.

This works rests on a foundation of smart grid interoperability-related work established by the GridWise® Architecture Council over the past dozen years[1,2] and the work done by the Smart Grid Interoperability Panel under the guidance of the U.S. National Institute of Standards and Technology. The vision for interoperability and plan for a strategic engagement with stakeholders follows from recent efforts funded by the DOE to advance interoperability for connected buildings[3].

The authors acknowledge the help and guidance received from the DOE managers, Marina Sofos and Christopher Irwin, in developing the plan for this document and encouraging outreach to relevant stakeholders. The authors' appreciation extends to their industry partners on this project, including Ron Bernstein, Dave Hardin, Austin Montgomery, and Matthew Butkovic. The final version of this guide was greatly influenced by the feedback received upon using the tool for an interoperability roadmap exercise focused on Institute of Electrical and Electronics Engineers Std 2030.5.[4] The authors thank the members of the 2030.5 Ecosystem Steering Committee for their practical and valuable comments. In addition, the authors recognize their Grid Modernization Laboratory Consortium liaisons to related grid modernization projects, including Jeffery Taft, Benjamin Kroposki, Robert Pratt, Liang Min, Ted Bohn, and Tom Rizy.

The model described in this document is an integral part of the interoperability roadmap methodology and the authors acknowledge the help and guidance received from members of that team, including Ron Melton and Keith Hardy.

Lastly, this work's value is determined by the participation of the broad grid modernization stakeholder community. Without stakeholder input and idea exchange at project review meetings and stakeholder engagement sessions, the ability of this material to influence the transformation of the electric system will vanish.

[1] GWAC (GridWise® Architecture Council). 2008. Interoperability Context-Setting Framework v1.1. Accessed January 2020 at http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf

[2] GWAC (GridWise® Architecture Council). 2011. Smart Grid Interoperability Maturity Model, Beta Version. Accessed January 2020 at http://www.gridwiseac.org/about/imm.aspx

[3] Hardin DB, EG Stephan, W Wang, CD Corbin, and SE Widergren. 2015. Buildings Interoperability Landscape. PNNL-25124, Pacific Northwest National Laboratory, Richland, Washington. Accessed February 2017January 2020 at https://energy.gov/eere/buildings/downloads/buildings-interoperability-landscape.

[4] IEEE (Institute of Electrical and Electronics Engineers). 2019. 2030.5 Ecosystem Steering Committee, "Interoperability Maturity Roadmap-IEEE Std 2030.5," October 2019. Accessible for free from IEEE-SA at https://www.techstreet.com/ieee/standards/ieee-white-paper?product_id=2090693

Acronyms and Abbreviations

CMMI	Capability Maturity Model Integration
DER	distributed energy resource
EV	electric vehicle
GMLC	Grid Modernization Laboratory Consortium
GWAC	GridWise® Architecture Council
IEA	International Energy Agency's
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
IMM	Interoperability Maturity Model
ISO	International Organization for Standardization
mph	mile(s) per hour
NIST	National Institute of Standards and Technology
ROI	return on investment
SGIP	Smart Grid Interoperability Panel
SEPA	Smart Electric Power Alliance
TOGAF	The Open Group Architecture Framework
V2G	Vehicle to Grid

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1.0 Introduction

The U.S. Department of Energy's Grid Modernization Initiative identified interoperability as an important quality for enabling new technology deployments. This resulted in the creation of a Grid Modernization Laboratory Consortium foundational project on interoperability. The mission of the project is to promote a common understanding of the meaning and characteristics of interoperability, in terms of the quality of integrating the information and communication technology aspects of automated devices and systems and the discipline to improve the process of successfully integrating these components as business models and information technology evolve over time. One element of the project is to articulate important characteristics of interoperability to measure the state of interoperability in specific technology deployment domains, such as substation automation, or the integration of "grid edge" technologies, such as electric vehicle charging, photovoltaic systems, and load flexibility from building automation. This document describes an interoperability maturity model (IMM) tool for measuring the state of integrating the information and communications technology aspects of intelligent devices and systems to coordinate their operation with the rest of the electric power system.

Stated succinctly, interoperability is "the ability of two or more systems or components to exchange information and to use the information that has been exchanged."[1] The electric power system continues the trend of embracing advancements in information and communication technology along with the rest of industry and our society. The vision of a modern energy grid is of a complex system of physical systems overlaid with a hyper-connected network of cyber systems that integrates grid operations with end-use business processes and social objectives to achieve ever greater scales of performance efficiency under conditions that must adapt to short-term disturbances and long-term trends. A transformational aspect of this vision of the future electric system is the coordinated operation of distributed energy resources, which include generation, storage, and responsive load, with the electric delivery system infrastructure for greater efficiency, reliability, and resiliency.

The IMM is a tool can be used to develop roadmaps for advancing interoperability in technology integration domains. The roadmap process engages the communities (or ecosystem[2]) of organizations involved in smart technology deployment. A companion to the IMM in this strategy is a proposed roadmap development process, which is described in the Interoperability Roadmap Methodology document.[3] The roadmaps developed using this methodology are intended to help each ecosystem articulate a vision of interoperability as well as prioritized steps to move toward it. This document identifies a list of 33 interoperability criteria, which are grouped into 6 categories, for quantifying the state of interoperability in a technology integration domain. This document is written for stakeholders in technology integration domains who work on standards, guides, and supporting material that ease integration of devices and systems within a specific area. Regulatory stakeholders that apply standards through policy action can also benefit from this document, as can people with interest in learning more about the dimensions of interoperability and associated details of the model.

This document first describes interoperability (Section 2.0), and then an IMM that can be used to measure interoperability for grid modernization beginning with background material on measuring interoperability and characteristics of interoperability (Section 3.0). Next, the criteria to be used for measuring

[1] ISO (International Organization for Standardization). 2010. ISO/IEC/IEEE standard 24765, Systems and software engineering – Vocabulary. Accessed January 2020 at https://www.iso.org/standard/71952.html

[2] Ecosystem - A community of participating organizations collaborating to address one or more business or social objectives that concern interoperability and ease the deployment of specific technologies

[3] DOE (U.S. Department of Energy). 2020. Interoperability Roadmap Methodology, PNNL-2749 1.3. Accessed January 2020 at https://gridmod.labworks.org/projects/1.2.2

interoperability are introduced (Section 3.2). Then, this document discusses domains or areas to which the model can be applied to measure interoperability (Section 3.3).

Building on the explanation of the structure of the IMM, the document provides a simplistic example of applying the IMM to a fictional case to show how it is used (Section 4.0). The remaining sections of the document are appendices that provide more detail about Interoperability Maturity Levels by Criterion (Appendix A) and how to score the results after the IMM has been applied (Appendix B)

2.0 Interoperability

To improve interoperability between automated devices and systems in the software engineering sense of communications and information processing, it is first necessary to converge on a common understanding about what interoperability is and who benefits from improved interoperability. This document addresses these challenges and introduces a method for measuring interoperability. This document uses the interoperability definitions and concepts introduced in the Interoperability Strategic Vision Whitepaper.[1] Another document, the Interoperability Roadmap Methodology,[2] describes the overall methodology including stakeholder engagement and roadmap development.

The objective of this work is to introduce and promote the use of interoperability criteria to aid in reducing the effort, and in turn the cost associated with the integration of a wide variety of devices and systems (both inside and outside the energy sector) that need to interoperate. This necessitates a definition of integration in this context. In this document, integration is a process that occurs after a decision to acquire systems and components has been made. The integration process includes planning for what changes need to be made to the devices, systems, and their interfaces; making those changes; and all other steps leading up to the successful operation of the system. Improved interoperability reduces the integration burden.

ISO/IEC/IEEE Standard 24765[3] states that interoperability is, "The ability of two or more systems or components to exchange information and to use the information that has been exchanged." For the purposes of this document, the scope of interoperability is concerned with the exchange of information at interfaces. A chain is only as strong as its weakest link, and the same is true of interoperability. If information cannot be exchanged, interoperability does not exist. If the information cannot be used, interoperability does not exist. If the information is not understood and actionable within an interaction process, interoperability does not exist.

It is not only the people who build and use interfaces that benefit from improved interoperability, it is also the people who use goods and services that are enabled by those interfaces who benefit. Thus, the stakeholders for interoperability are very wide-ranging. The concepts are general and can be applied anywhere, but the tools and approaches may vary with organizational scope and interdependencies: company, consortia, community, industry, government, technology domain, etc.

Many stakeholders may look at interoperability and ask, "how much will improvements to interoperability benefit me?" Improving interoperability requires an investment of time and effort. Thus, decisions about investment in interoperability need to be based on an understanding of alternative actions that can be taken for improvement and a quantification of the expected benefits. To do this, the present state of integration in the area of interest must be understood and the existing integration challenges must be articulated so that the gaps between the current state and improved interoperability can be identified.

This document presents the relevant concepts and organizing structures for specifying criteria that support a grid modernization strategic vision for interoperability. A key point to understand is that interoperability has many crucial elements, any of which may have areas for improvement. The document asserts that

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[1] DOE (U.S. Department of Energy). 2018. Interoperability Strategic Vision: A GMLC Whitepaper, March 2018, PNNL-27320. Accessed January 2020 at https://gmlc.doe.gov/sites/default/files/resources/InteropStrategicVisionPaper2018-03-29.pdf

[2] DOE (U.S. Department of Energy). 2020. Interoperability Roadmap Methodology, PNNL-2749 1.3. Accessed January 2020 at https://gridmod.labworks.org/projects/1.2.2

[3] ISO (International Organization for Standardization). 2010. ISO/IEC/IEEE standard 24765, Systems and software engineering – Vocabulary. Accessed January 2020 at https://www.iso.org/standard/71952.html

addressing interoperability concerns is a continually improving process, and as such, the measurement approach borrows heavily from quality improvement models. If those concerned with interoperability at an interface can assess the maturity levels of interoperability across its many dimensions, information can be gathered to help create a roadmap for how to improve interoperability.

To measure interoperability, it is helpful to focus on specific topics based on the objectives of the members of the ecosystem that are initiating interoperability advancement. The measurement tool is based on, and developed from, the GridWise® Architecture Council's (GWAC's) Beta release of its IMM.[4] As such, it represents an evolution of that IMM approach.

The IMM in a Nutshell

IMM is a tool that

- is designed to measure interoperability
- identifies gaps between current and desired levels of interoperability
- helps make integration easier and more cost-effective
- can be applied to
  - integration interests within the electricity delivery system, including transmission and distribution automation systems, energy management systems, and energy market systems
  - integration interests within distributed energy resource technology domains; for example: electric vehicles, photovoltaic systems, and buildings automation
  - integration between the electrical grid and distributed energy resource technology domains
- can be applied to the process of creating a roadmap for interoperability improvement
  - Before measuring interoperability, some high-level questions are asked.
  - After discussing/answering the high-level questions, several interoperability criteria are used to assess current interoperability maturity.
  - Interoperability criteria are grouped into six categories and each category (and each criterion) has five levels of maturity.
  - The category and criteria are the mechanisms by which different aspects of interoperability are assessed.
  - The criteria selected for review depend on one or more categories selected for measurement.
  - The gaps between current and desired levels of interoperability are used to develop a roadmap that aligns with the goals, drivers, and milestones identified by the stakeholders.

2.1 Target Domains

The IMM applies to the information and communications technology integration of smart devices and systems in various electric power system technology domains, such as interactions with bulk generation, transmission and distribution infrastructure, and distributed energy resources in customer systems. The

[4] GWAC (GridWise® Architecture Council). 2011. Smart Grid Interoperability Maturity Model, Beta Version. Accessed January 2020 at http://www.gridwiseac.org/about/imm.aspx

IMM is a companion to an interoperability roadmap development methodology that can be leveraged in ways such that strategic plans (roadmaps) can be developed for technology ecosystems to improve interoperability.

The first step in improving interoperability is to identify a target integration situation and the interfaces that support it. Once a target for applying the IMM has been selected, it is necessary to decide whether to apply the whole IMM or part of it. The choice of what parts (categories) to use may be driven by known interoperability deficiencies or specific drivers that cause the stakeholder(s) to prioritize one category over another. To facilitate this, the IMM has interoperability criteria that are used to determine interoperability maturity in specific areas and these criteria are organized into several categories.

2.2 Categories for Organizing Evaluation Criteria

The categories used in the IMM for grouping interoperability criteria are based on those used in GWAC's Beta IMM, which used technical, informational, and organizational categories of interoperability. These, together with three groups of cross-cutting issues, which are relevant to more than one category, provide a foundation for defining classification areas of interoperability criteria.

It is worth noting that the three interoperability categories (organizational, informational, and technical) are also used by The Open Group Architecture Framework (TOGAF) and others for grouping interoperability requirements.[5] Many efforts focus on the lower portion of the interoperability categories when trying to create interoperable applications, which makes the physical connection and exchange of data possible but ignores (or take for granted) the broader integration with business objectives and policies that are represented by the upper layers of Figure 2.1.

[5] The Open Group. The Open Group Architecture Framework, TOGAF®, an Open Group standard. Accessed February January 201720 at http://www.opengroup.org/subjectareas/enterprise/togaf

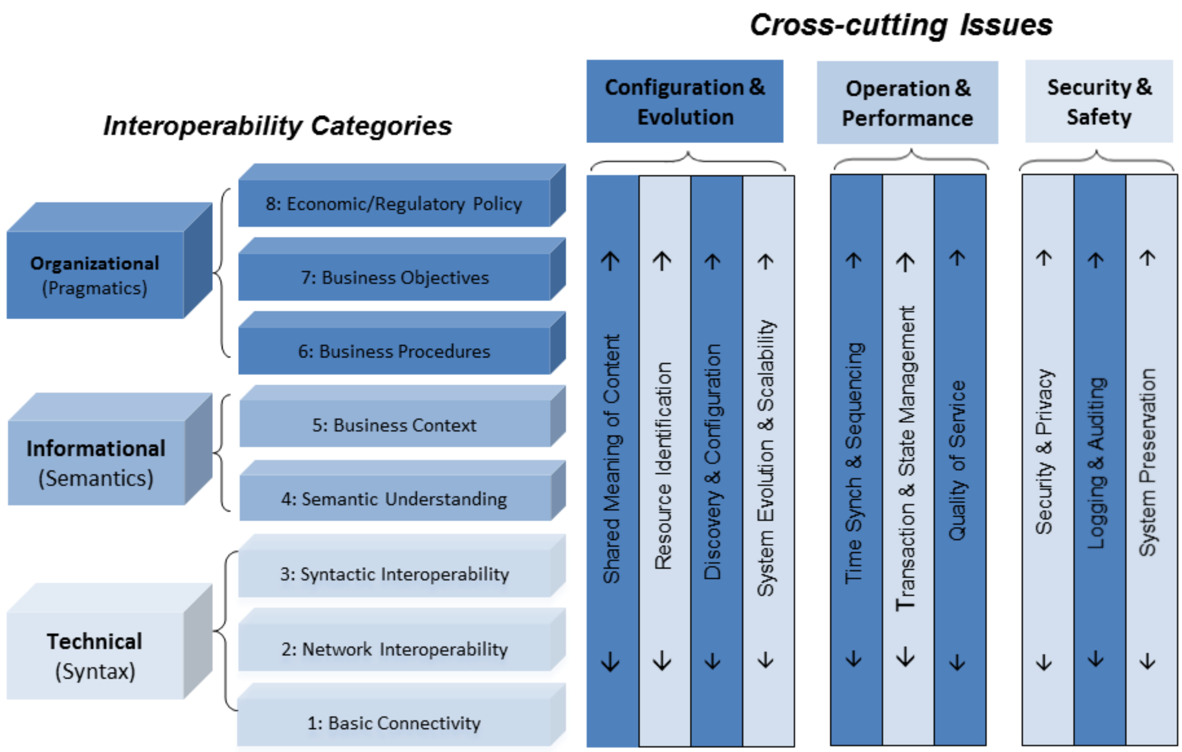

Figure 2.1. GWAC Interoperability Context-Setting Framework[6]

For the IMM, the evaluation criteria are categorized as follows:

- **Configuration and Evolution**

  These criteria address topics related to vocabularies, concepts, and definitions across multiple communities and companies. This means that all resources need to be unambiguously defined to avoid clashes between identification systems. This is important over time as new automation components enter and leave the system because resource identification is essential for discovery and configuration. This also provides the ability to upgrade (evolve) over time and to scale without affecting interoperability.

- **Security and Safety**

  These criteria are concerned with aligning security policies and maintaining a balance between minimizing exposure to threats and supporting performance and usability. This includes the capability to troubleshoot and debug problems that span disparate system boundaries, while placing the integrity and safe operation of the electric power system above the health of any single automation component.

- **Operation and Performance**

  These criteria focus on synchronicity and quality of service, as well as operational concerns. Operational concerns may include concerns such as maintaining integrity and consistency during fault conditions that disrupt normal operations and ensuring that distributed processes can meet expected interaction performance and reliability requirements.

- **Organizational**

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[6] GWAC (GridWise® Architecture Council). 2008. Interoperability Context-Setting Framework v1.1. Accessed January 2020 at http://www.gridwiseac.org/pdfs/interopframework_v1_1.pdf

These criteria represent the pragmatic aspects of interoperability. They represent the policy and business drivers for interactions. Interoperability is driven by the need for businesses (or business automation components) to share information and requires agreement on the business process integration that is expected to take place across an interface.

- **Informational**

These criteria emphasize the semantic aspects of interoperability. They focus on what information is being exchanged and its meaning and they focus on both human and device recognizable information. At this level, it is important to describe how entities are related to each other, including relationships to similar entities across domains and any constraints that may exist.

- **Technical**

These criteria address the syntax, format, delivery, confirmation/validation, and integrity of the information. They focus on how information is represented within a message exchange and on the communications medium. They focus on the digital exchange of data between systems, encoding, protocols, and ensuring that each interacting party is aligned.

In addition, several criteria focus more on the culture changes and collaboration activities required to help drive interoperability improvements in an ecosystem or community of stakeholders, and that reflect community maturity with respect to interoperability. Because these criteria may be relevant to one or more of the other six categories, an additional "Community" category was formed which has ties to the other categories, as depicted in Figure 2.2.

Figure 2.2. Categories for IMM Criteria

3.0 Measuring Interoperability

Well-formed evaluation criteria should identify the requirements for assessing achievement or gaps remaining. While the criteria describe attributes that support interoperable systems and components, it is the lack of desired interoperability traits that are often being measured. Some criteria, such as the existence of policies and testing and certification to standards, can be measured by providing evidence, but other criteria can be measured by lack of evidence. The roadmap methodology depends upon ways that these criteria have or have not been met, and therefore, they need to be measurable in pragmatic terms.

3.1 Characteristics

A criterion needs to exhibit several additional characteristics in addition to being measurable to be considered a “good” criterion. Good criteria[1] should have the following characteristics:

- **Traceable**: Criteria should be traceable back to a goal and be attributable to an authoritative source. This is most important for functional criteria, but the interoperability criteria specified in this document can, in many cases, be linked to a specific standard, report, paper, or another source.
- **Unambiguous**: The wording of each criterion should be considered from different stakeholder perspectives to determine whether it can be interpreted in multiple ways. Vague, general statements are to be avoided.
- **Measurable**: The implementation of criteria can be assessed quantitatively or qualitatively. Where the measurement is qualitative, guidelines should be provided to create consistency between assessments.
- **Testable**: Functional criteria must be testable to demonstrate that they have been met.
- **Consistent**: Criteria must be consistent with each other; no criterion should conflict with any other criterion. Criteria that have questionable feasibility should be analyzed and, if necessary, be eliminated.
- **Uniquely identified**: Uniquely identifying each criterion is essential if criteria are to be traceable and testable. Uniqueness also helps in referring to requirements in a clear and consistent fashion.
- **Design-free**: A criterion reflects "what" the system shall accomplish, while the design reflects "how" the criterion shall be implemented. Given the broad applicability of interoperability criteria to multiple domains, criteria should not be domain-specific; thus, it is important that no design-specific criteria are present.
- **Independent**: Criteria should be independent of each other so they can be assessed without being affected by other criteria.
- **Negotiable**: Understanding the business drivers and context mandates flexibility. For instance, it may be possible for a criterion to be met using different standards in different domains.

[1] There are many references for developing requirements, including IBM Rational RequisitePro, Carnegie Mellon University, MITRE Systems Engineering Guide, The Engineering Design of Systems Models and Methods (Wiley).

3.2 Interoperability Criteria

The interoperability criteria for use with the IMM are listed in Table 3.1.

Table 3.1. Interoperability Maturity Criteria

Ref	Statement	Category
01	The ability of the interface to accommodate the integration with legacy components and systems is described along with an upgrade migration path.	Configuration & Evolution
02	Interface capabilities can be revised over time (versioning), while accommodating connections to previous versions of the interface and without disrupting overall system operation (such as supporting a rolling upgrade process).	Configuration & Evolution
03	The way regional and jurisdictional differences are supported is described.	Configuration & Evolution
04	Configuration methods to negotiate options or modes of operation including the support for user overrides are described.	Configuration & Evolution
05	The capability to scale the integration of many components or systems over time without disrupting overall system operation is supported.	Configuration & Evolution
06	The ability of overall system operation and the quality of service to continue without disruption as interfacing actors (distributed energy resources [DERs], utilities, aggregators) enter or leave the system is supported.	Configuration & Evolution
07	Unambiguous resource identification and its management are described.	Configuration & Evolution
08	Resource discovery methods for assisting with identification and integration between actors (such as access to information like owner, DER type, location, etc.) are supported.	Configuration & Evolution
09	The requirements and mechanisms for auditing and logging the exchange of information is described.	Safety & Security
10	Privacy policies are defined, maintained, and aligned among the parties of interoperating systems.	Safety & Security
11	Security policies are defined, maintained, and aligned among the parties of interoperating system.	Safety & Security
12	Failure mode policies are described and aligned among the parties of the interoperating systems to support the safety and health of individuals and the overall system.	Safety & Security
13	Performance and reliability requirements are defined.	Operation & Performance
14	The interface definition specifies the handling of errors in exchanged data.	Operation & Performance
15	Time order dependency and sequencing (synchronization) for interactions are specified.	Operation & Performance
16	The interface definition specifies the mechanism for message transaction and state management.	Operation & Performance

Ref	Statement	Category
17	Compatible business processes and procedures exist across interface boundaries.	Organizational
18	Where an interface is used to conduct business within a jurisdiction or across different jurisdictions, it complies with all required technical, economic, and regulatory policies.	Organizational
19	Information models relevant for data exchanged across the interface are formally defined using standard information modeling languages.	Informational
20	Data exchange relevant to the business context is derived from the information model.	Informational
21	Where the data exchanged derive from multiple information models, the capability to link data from the different information models is supported.	Informational
22	The structure, format, and management of the communication protocol for all information exchanged are specified.	Technical
23	The information exchanged and business process interactions at the interface are cleanly layered (described separately) from the technical (communication networking) layers in the interface specification.	Technical
24	The ecosystem references openly available standards, specifications, or agreed-upon conventions in interface definitions.	Community
25	The ecosystem participates in development of interoperability standards efforts consistent with its businesses.	Community
26	The ecosystem supports interoperability test and certification efforts.	Community
27	The ecosystem identifies and shares lessons learned and best practices resulting from implementation experience and interoperability improvements.	Community
28	The ecosystem (standards development and implementation group contexts) periodically reviews refinements and extensions of interface definitions.	Community
29	Security and privacy requirements are specified in a manner to support integration and interoperation.	Community
30	Purchasers of technology that is expected to support the interface specify interoperability performance language in their procurement documents.	Community
31	Education and marketing initiatives about the ecosystem and its interoperability elements (including standards, implementation profiles, testing, and certification) are supported.	Community
32	The ecosystem adopts or aligns with existing mainstream, modern information-exchange approaches and standards that address the business objectives and maximize the longevity of the ecosystem's specifications.	Community
33	The ecosystem does not create new interface standards where suitable standards already exist.	Community

3.3 Domains

Domains define the integration ecosystems to which stakeholders choose to apply the IMM. Categories within the IMM reflect the specific aspects of interoperability that can be measured. High-level domains (as described in Section 2.1) can be summarized by the conceptual diagram developed by the National

Institute of Standards and Technology (NIST) and shown below in Figure 3.1. The word domain has also been applied to integration ecosystems for customer-owned buildings, electric vehicles, and local photovoltaic (PV) integration. These are all areas in which interoperability can be improved. These integration ecosystem examples can be considered "sub-domains" that fit into the Customer domain in Figure 3.1.

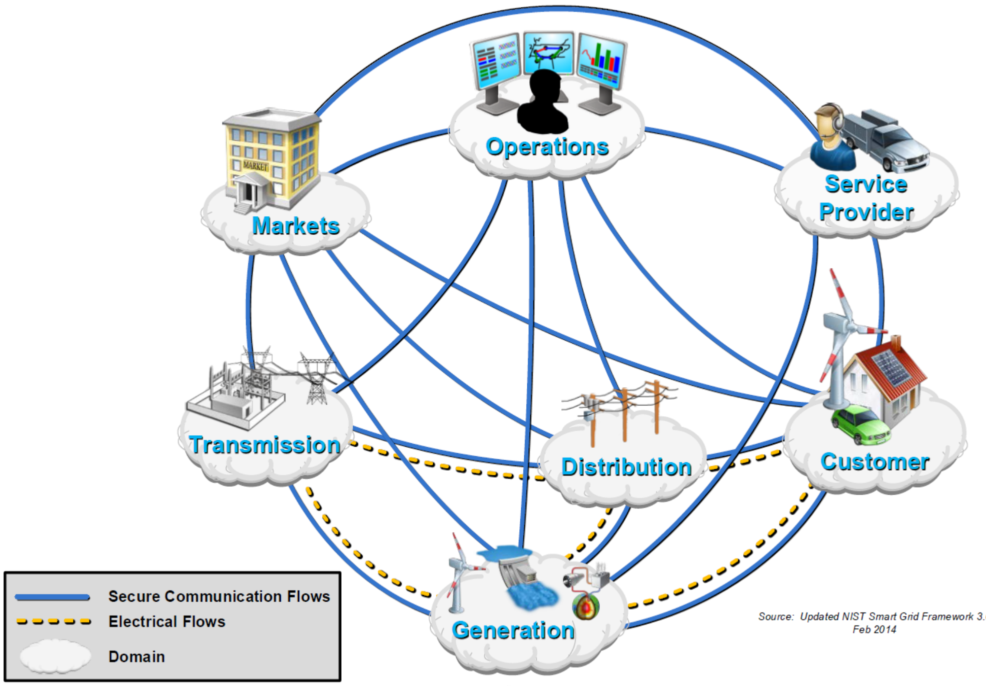

Figure 3.1. NIST Conceptual Domains[1]

One process for applying the IMM is described in the interoperability roadmap methodology and starts by selecting an integration ecosystem domain and integration interfaces of interest. To successfully apply the IMM tool, domains that have a sustainable congregation of stakeholders to support ecosystems of products and services need to be selected. These domains can form in technical societies, business consortia, or combinations of groups that give form to a community of people, businesses, and practices. To tackle the improvement of interoperability, an ecosystem should have a good understanding of the scope, context, and current level of interoperability maturity related to an integration interface, as well as the goal to put together a plan for how to make improvements.

3.4 Applying the IMM Tool

One use of the IMM is to facilitate the development of a roadmap to advance interoperability in a technology community. A methodology to create such an interoperability roadmap is described in a DOE companion roadmap document.[2] In applying the IMM tool, the roadmap evaluation team needs to understand the levels of maturity for each category and what each category covers.

[1] NIST (National Institute of Standards and Technology). 2014. NIST Framework and Roadmap for Smart Grid Interoperability Standards, Release 3.0. Accessed January 2020 at https://www.nist.gov/system/files/documents/smartgrid/NIST-SP-1108r3.pdf

[2] DOE (U.S. Department of Energy). 2020. Interoperability Roadmap Methodology, PNNL-2749 1.3. Accessed January 2020 at https://gridmod.labworks.org/projects/1.2.2.

The maturity levels in the IMM are based on the Capability Maturity Model Integration (CMMI).[3] This is the same system that was used by GWAC for the Beta[4] release of the IMM, which described the levels of maturity for different areas, as presented in Table 3.2.

Table 3.2. Interoperability Maturity Levels from the GWAC IMM[5]

GridWise Architecture Council Interoperability Maturity Model		Maturity Characteristics			
		Community / Governance	**Documentation**	**Integration**	**Test / Certification**
Maturity Level Statements	**Level 5** Optimizing	Managed by a community quality improvement process	Adopts and open community standard	Integration metrics used for improvement of the standard	Test processes are regularly reviewed and improved
Maturity Level Statements	**Level 4** Quantitatively Managed	Processes ensure currency and operation	References community standard w/o customization	Integration metrics are defined and measurements collected. Reference implementations exist	Community test processes demonstrate interoperability. Members claim interoperable performance
Maturity Level Statements	**Level 3** Defined	Managed by community agreement	References community standard w/ some customization	Integration repeatable w/ predictable effort	Tests exist for community w/ certification. Members claim compliance to standard
Maturity Level Statements	**Level 2** Managed	Managed by project agreement	Documented in a project specification	Integration is repeatable w/ customization expected	Testing to plan w/ results captured
Maturity Level Statements	**Level 1** Initial	Management is ad hoc	Documentation is ad hoc	Integration is a unique experience	Testing is ad hoc

By looking at the levels of maturity for each criterion, the evaluation team can make an informed decision about which categories of criteria are of most interest for interoperability improvement. Each individual criterion has five levels of descriptions that can be used to assess interoperability maturity on a more specific basis. A trial roadmap effort that applied a draft of the IMM found that there was some confusion about the meaning of the level labeled “Quantitatively Managed.” The term “Planned“ was found to more clearly communicate the intent of Level 4, which refers to processes that aid in achieving higher levels of interoperability by improving integration of current or future implementations. The scope of each category is described in Section 2.2 and is elaborated in Appendix A to include a brief description of interoperability for each of the interoperability levels for each category. The intent is to provide examples such that subjectivity can be reduced when making assessments about the level of interoperability maturity. However, future experience in using the IMM will likely reveal further refinements of the model.

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[3] The CMMI Institute. 2010. Capability Maturity Model Integration. Accessed January 2020 at http://cmmiinstitute.com/.

[4] For the Beta IMM developed by GWAC, the maturity characteristics (community/governance, documentation, integration, test/certification) were used to create a matrix of maturity characteristics and maturity level statements to provide guidance in assessing the maturity for each metric. This approach has been simplified for the current IMM.

[5] GWAC (GridWise® Architecture Council). 2011. Smart Grid Interoperability Maturity Model, Beta Version. Accessed January 2020 at http://www.gridwiseac.org/about/imm.aspx

The levels of maturity also refer to how a process of integration has evolved. For example, a system or device integration can be "ad hoc," which would indicate that interoperability issues are addressed as they appear. These systems require time and customization to achieve the goals of the integrator. A more mature situation may manage integration using project-specific processes. Such a managed integration process may even use standards, but there is an expectation that anything other than a previously integrated device or system will need some sort of customization. The lack of maturity in a "managed" system comes from being project-specific and not having an ecosystem of organizations aligned on standards and related integration processes. A "defined" level of maturity indicates coordinated effort and agreed-upon processes among ecosystem members. There is evidence of standards and specifications in place that have some level of compliance requirement. Interoperability is obtainable with a more predictable amount of effort and the results are also more predictable.

While a "defined" maturity level of interoperability may be acceptable in some cases, ecosystems may strive to achieve a higher level of maturity in order to quickly adapt to the evolution of processes, requirements, or technology. With appropriate planning and methods to approach changes and new implementation scenarios, interoperability can be achieved in a more fluid manner. This involves participation and communication with standards organizations, sharing of best practices, and planning a clear path for adapting or evolving the integration process as well as the components and systems which will be integrated.

Beyond this "planned" maturity level, an ecosystem may wish to advance interoperability at an "optimized" level. This means that the ecosystem members participate actively to improve the quality of integration and implementation processes. This includes addressing needed improvements of standards, specifications, or techniques, as well as the processes involved in planning and defining implementation of new and existing systems. Regular reviews will occur to evaluate system and integration metrics, standards and their development or evolution, and interoperability testing and certification efforts. These coordinated efforts not only improve the interoperability of the system and its components, but also the processes that will inevitably lead to higher quality, more dependable, and lower cost integration.

While a maturity scoring mechanism can be constructed for this type of assessment, the most important objective is to expose and articulate potential areas for improvement. One could think of the categories and their criteria as conversation topics that elicit opportunities for increased interoperability. Sometimes these conversations may expose gaps not necessarily related to the criterion being discussed.

4.0 Applying the IMM to Developing an Interoperability Roadmap

The following short, hypothetical example shows how the IMM might be applied to a technology scenario for electric vehicle (EV) charging integration. This involves evaluating the state of integration related to customer EV charging with distribution system operations.

Applying the IMM is only one step in the roadmap methodology depicted below in Figure 4.1. Before the IMM is used, there are many preceding steps that involve stakeholder tasks. Determining the current baseline level of interoperability maturity for the domain under consideration occurs during the Planning and Preparation phase. The development of the roadmap itself does not occur until Phase 4. Once the current level of maturity and future vision have both been determined, the information gathered can be compiled into a rational sequence of activities that demonstrate the steps to achieve the desired maturity outcomes.

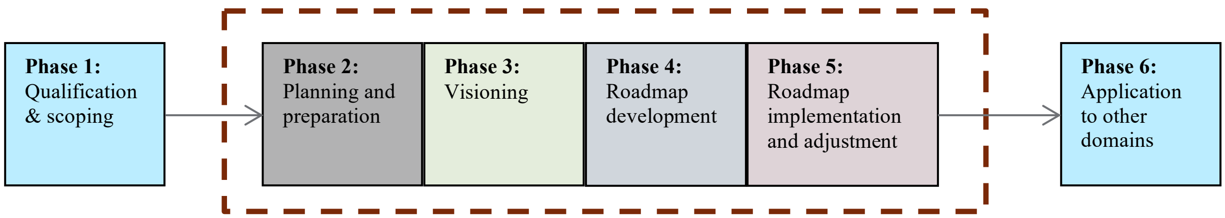

Figure 4.1. The Roadmap Methodology[1]

The questions in this section are intended to probe the problems and concerns of the interoperability areas of interest. The intent of probing is to help roadmap participants think about the current situations, the challenges being faced, and directions to be taken to improve the situation. It helps provide contextual information and clarifies issues that arise from discussing each specific IMM criterion.

Measuring interoperability maturity involves looking for evidence that practices are being performed and appropriate artifacts exist. Where there is a lack of evidence, a list of gaps is created so that the steps to reach a desired maturity level can be planned.

4.1 Measuring Current Interoperability Maturity

This example shows how the IMM and interoperability roadmap methodology work together to create a roadmap. The evaluation team is composed of stakeholders in an EV-charging integration ecosystem that are assessing how and where to apply incentives or performance targets to create a highly interoperable environment for integrating EVs within a state. Figure 4.2 shows the (fictional) overall interoperability maturity for EV integration within a state's jurisdiction; the levels shown are for illustration purposes only. The dots represent maturity levels for the different interoperability categories, determined by applying the IMM. In Figure 4.2, the interoperability categories are represented by the six columns, and the levels of interoperability maturity are represented by the rows. Level 1 at the bottom represents the lowest level of maturity and Level 5 at the top represents the highest level of maturity.

[1] DOE (U.S. Department of Energy). 2020. Interoperability Roadmap Methodology, PNNL-2749 1.3. Accessed January 2020 at https://gridmod.labworks.org/projects/1.2.2

		Interoperability Categories					
		Configuration & Evolution	Safety & Security	Operation & Performance	Organizational	Informational	Technical
Maturity Level	Level 5 Optimized						
	Level 4 Planned					●	●
	Level 3 Defined		●	●	●		
	Level 2 Managed	●					
	Level 1 Initial						

Figure 4.2. Example of Possible Current Interoperability Maturity for Electric Vehicle Integration

4.2 Articulating the Areas for Interoperability Improvement

While this example is fictitious, it illustrates a practical process for addressing gaps between current and target levels of interoperability for an emerging application and industry challenge: EV charging and the infrastructure needed to support expanding electrification of transportation. More generally this example illustrates how the IMM can be used to articulate focus areas for interoperability improvement using the engagement process described in the interoperability roadmap methodology. For the example below, the rationale for the goals could have been as follows:

- **Configuration and Evolution**

  Level 2 requires that vocabularies, concepts, and definitions be consistent in the interface specification at a project level. The evaluation team found that implementation approaches generally follow guidelines, but community agreed-upon specifications or standards are lacking. Interface specifications exist for definitions and identification of resources on a project basis but are not broadly adopted by the community.

- **Safety and Security**

  Safety and security are always important topics, especially where interaction with the electricity grid is involved. Level 3 requires that policies are defined for safety, auditing, security, and privacy. In this example, the evaluation team found that these policy guidelines exist for the community and there is evidence of adoption.

- **Operation and Performance**

  Level 3 requires that the interface specifications and integration practices be defined for the community and formalized in published standards. The evaluation team found that the specifications for quality of service, synchronization, and most operation and performance criteria are consistent and testable.

- **Organizational**

  The evaluation team found that while interoperability standards exist for operation and performance, the business process interactions were captured on a project deployment basis within a utility footprint. Similarly, there was no evidence of regulatory policy frameworks that were managed beyond jurisdictional boundary. This reflects Level 2 maturity.

- **Informational**

  Level 4 requires that the relevant information models be defined in standards along with processes and plans to maintain them in accordance with accepted semantic modeling techniques. The evaluation team found that semantic models are well-defined and the process to maintain them is organized. Relationships between related semantic models are well-described and there is a plan in place for incorporating any changes to the existing models or mapping to other, related information models.

- **Technical**

  The EV-charging community considers communications technology to be continually evolving, but the interface specifications are layered on Internet-based standards such that the message content and business process interactions can work with multiple communications technologies, such as WI-FI and Ethernet. The evaluation team found that the technology layer is defined independent of the informational layers so that different communication technologies can support the same message definitions.[2] Level 4 requires that the communications networking technology and protocols used be based on adopted standards that are well-defined, tested, and have plans and procedures in place for updates.

4.3 Comparing Current and Target Levels of Interoperability

The objective of comparing the defined goals from the roadmap methodology with the maturity assessment is to develop a plan to address the gaps. Figure 4.3 shows how the example EV-charging interoperability ecosystem may use the IMM to focus on the most important gaps to the community. For the categories of Operations and Performance, Informational, and Technical the target level has already been met. For the Configuration and Evolution, Safety and Security, and Organizational categories, the current maturity level is below the target level. The gaps between the current and target levels are revealed by reviewing the assessment of the status of the individual criteria in each interoperability category. Only by evaluating each criterion will gaps be able to be articulated and improvement actions developed.

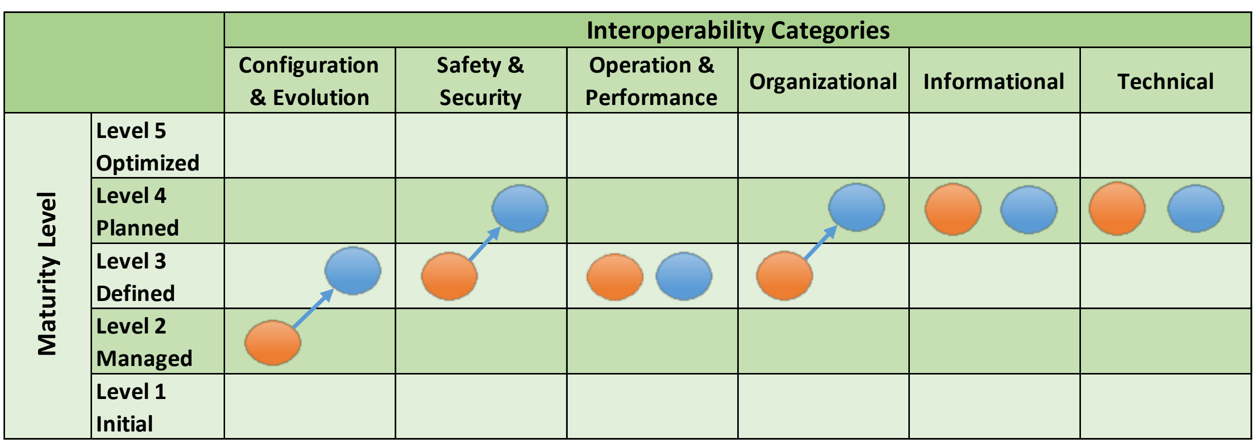

Figure 4.3. Example Gaps between Current and Target Interoperability Maturity

[2] Interoperability Maturity criterion 23 addresses this point.

4.4 Concluding Thoughts

The roadmap development methodology makes use of the IMM to help define a target maturity level and outlines steps to achieve it. The methodology for developing a roadmap is described separately.[3]

The IMM is one tool used in the interoperability roadmap methodology. It helps by measuring current interoperability maturity levels. The process by which current maturity is measured also creates discussion within the ecosystem. This can provide additional insights for the participating stakeholders when the measurement results are taken into consideration for building the roadmap.

Lastly, the IMM may also be applied for in other areas. For example, measures of interoperability can also be valuable for a purchaser of automation technology to evaluate technology supplier products and services. A related GMLC interoperability effort used the IMM to develop model language that could be used in smart technology procurement requests for information (RFI) and requests for proposal (RFP).[4]

[3] DOE (U.S. Department of Energy). 2020. Interoperability Roadmap Methodology, PNNL-2749 1.3. Accessed January 2020 at https://gridmod.labworks.org/projects/1.2.2

[4]DOE (U.S. Department of Energy). 2020. Reference Interoperability Procurement Language, PNNL-28666 Final. Accessed 2020 at https://gridmod.labworks.org/projects/1.2.2

Appendix A

Interoperability Maturity Levels by Criterion

In the main body of this document the individual criteria to be used for assessing interoperability maturity were laid out in Table 3.1 and an example of how the GridWise® Architecture Council's (GWAC's) Beta Interoperability Maturity Model (IMM) described maturity levels was presented in Table 3.2. Interoperability Maturity Levels from the GWAC IMM. The main body also provided an example of how the results of interoperability measurement and gap analysis can be applied to use gaps discovered by specific criteria to develop a roadmap and address areas where higher levels of interoperability maturity are desired or required.

This appendix describes the maturity levels for each interoperability criterion as grouped by category in **Error! Reference source not found.** through **Error! Reference source not found.**.

A factor in creating a maturity model is seeing that it will be applied consistently. If one reviewer has slightly different views from another reviewer who repeats the same assessment a year later to see what improvements have been achieved the result may be inconsistent assessments. Part of any continuous improvement program is assessing progress and evaluating it in a way that can be expressed quantitatively and consistently. The goal is to remove or reduce the element of subjectivity. For this to happen, some guidance is provided that describes the level of maturity for each criterion more specifically. The following tables elaborate on the descriptions in Table 3.1, Interoperability Maturity Criteria, and Table 3.2, Interoperability Maturity Levels from the GWAC IMM.

The requirements to meet levels of interoperability maturity have been described for each individual criterion. The titles of the 5 levels (Initial, Managed, Defined, Planned, and Optimized) are consistent with the Capability Maturity Model for Integration, except that Level 4, Quantitatively Managed, is called Planned, based on feedback received during a trial of the roadmap methodology and the IMM tool with an integration ecosystem. The descriptions are brief, and the wording has been updated to address the levels more consistently across the criteria based on the trial. Future versions of the IMM will continue to improve based on model use.

While the interoperability measurement category descriptions in Section 2.2 provide an overall description of the categories for organizing criteria, there is not enough detail to enable a stakeholder to make an informed decision by category. For each criterion, this appendix has a table that contains high-level descriptions. Table A.1 shows an example of the type of information that has been tabulated for each criterion.

Table A.1. Example Describing the Contents of Maturity Levels for Each Criterion in this Appendix

#	C&E	S&S	O&P	O	I	T
	Statement that describes a situational or capability criterion for interoperability maturity					
Level 5	Scenario/description that describes Level 5 maturity for this criterion.					
Level 4	Scenario/description that describes Level 4 maturity for this criterion.					
Level 3	Scenario/description that describes Level 3 maturity for this criterion.					
Level 2	Scenario/description that describes Level 2 maturity for this criterion.					
Level 1	Scenario/description that describes Level 1 maturity for this criterion					

Reference for the criterion

Interoperability maturity level

Description of what is required for the level of maturity for this criterion

The description of the criterion

These represent the six categories. Blue tabs indicate for which categories this criterion is used.

A.1 Configuration and Evolution

These criteria address topics related to vocabularies, concepts, and definitions across a community. This means that all resources need to be unambiguously identified in order to avoid clashes between identification systems. This is important over time as new automation components enter and leave the system because resource identification is essential for discovery and configuration. This category of concerns also facilitates (but does not guarantee) the ability to upgrade (evolve) over time and to scale.

1	C&E	S&S	O&P	O	I	T
	The ability of the interface to accommodate the integration with legacy components and systems is described along with an upgrade migration path.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of the process.					
Level 3	Defined – The ability of the interface to accommodate the integration with legacy components and systems is defined in standards and/or implementation profiles along with an upgrade migration path.					
Level 2	Managed – The ability of the interface to accommodate the integration with legacy components and systems is described on an implementation basis along with an upgrade migration path.					
Level 1	Initial – ad hoc and chaotic					

2	**C&E**	**S&S**	**O&P**	**O**	**I**	**T**
	Interface capabilities can be revised over time (versioning) while accommodating connections to previous versions of the interface and without disrupting overall system operation (such as supporting a rolling upgrade process).					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of the process.					
Level 3	Defined – The way interface revisions and upgrades are implemented without disruption to overall system operation is defined in the standards and/or implementation profile.					
Level 2	Managed – Interface revisions and upgrades are managed on a per implementation basis without disruption to overall system operation.					
Level 1	Initial – ad hoc and chaotic					

3	**C&E**	**S&S**	**O&P**	**O**	**I**	**T**
	The way regional and jurisdictional differences are supported is described.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of the process.					
Level 3	Defined – The process for addressing regional and jurisdictional differences are defined in the standards and/or implementation profile.					
Level 2	Managed – Regional and jurisdictional differences are managed on an implementation basis.					
Level 1	Initial – ad hoc and chaotic					

4	**C&E**	**S&S**	**O&P**	**O**	**I**	**T**
	Configuration methods to negotiate options or modes of operation including the support for user overrides are described.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of the process.					
Level 3	Defined – Configuration methods to negotiate options or modes of operation including the support for user overrides is defined in the standards and/or implementation profile.					
Level 2	Managed – Configuration methods to negotiate options or modes of operation including the support for user overrides are managed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

5	**C&E**	**S&S**	**O&P**	**O**	**I**	**T**
	The capability to scale the integration of many components or systems over time without disrupting overall system operation is supported.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements and extensions.					
Level 3	Defined – Scaling without disrupting overall system operation is defined in the standards and/or implementation profile.					
Level 2	Managed – Scaling without disrupting overall system operation is specified on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

6	C&E	S&S	O&P	O	I	T
	The ability of overall system operation and quality of service to continue without disruption as interfacing actors (DER, utilities, aggregators) enter or leave the system is supported.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The process for interfacing actors to enter or leave the system is defined in the standards and/or implementation profile.					
Level 2	Managed – Support for interfacing actors to enter or leave the system managed on an implementation basis.					
Level 1	Initial – ad hoc and chaotic					

7	C&E	S&S	O&P	O	I	T
	Unambiguous resource identification and its management is described.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The process for supporting unambiguous resource identification is defined in the standards and/or implementation profile.					
Level 2	Managed – Unambiguous resource identification is managed on an implementation basis.					
Level 1	Initial – ad hoc and chaotic					

8	C&E	S&S	O&P	O	I	T
	Resource discovery methods for assisting with identification and integration between actors (such as access to information like owner, DER type, location, etc.) are supported.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The process for resource discovery is defined in the standards and/or implementation profile.					
Level 2	Managed – Resource discovery is supported on an implementation basis.					
Level 1	Initial – ad hoc and chaotic					

A.2 Safety and Security

These criteria are concerned with aligning security policies and maintaining a balance in the tension between minimizing exposure to threats and supporting performance and usability. This includes the capability to troubleshoot and debug problems that span disparate system boundaries, while placing the integrity and safe operation of the electric power system above the health of any single automation component.

9	C&E	S&S	O&P	O	I	T
	The requirements and mechanisms for auditing and for logging exchange of information are described.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The requirements and mechanisms for auditing and logging the exchange of information are defined in the standards and/or implementation profile.					
Level 2	Managed – The requirements and mechanisms for auditing and logging the exchange of information are managed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

10	C&E	S&S	O&P	O	I	T
	Privacy policies[1] are defined, maintained, and aligned among the parties of interoperating systems.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements and extensions of the privacy policies and their management.					
Level 3	Defined – Privacy policies and their management are defined in the standards and/or implementation profile.					
Level 2	Managed – Privacy policies and their management are specified on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

11	C&E	S&S	O&P	O	I	T
	Security policies[2] are defined, maintained, and aligned among the parties of interoperating systems.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements and extensions of the security policies and their management.					
Level 3	Defined – Security policies and their management are defined in the standards and/or implementation profile.					
Level 2	Managed – Security policies and their management are specified on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

[1] A statement or a legal document that discloses some or all the ways a party gathers, uses, discloses, and manages a customer or client's data (http://www.businessdictionary.com/definition/security-policy.html).
[2] A set of rules defining who is authorized to access what and under which conditions, and the criteria under which such authorization is given or cancelled (http://www.businessdictionary.com/definition/security-policy.html).

12	C&E	**S&S**	O&P	O	I	T
	Failure mode policies are described and aligned[1] among the parties of the interoperating systems to support the safety and health of individuals and the overall system.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – Failure mode policies are defined, maintained, and aligned among the parties of the interoperating systems.					
Level 2	Managed – Failure mode policies are specified on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

13	C&E	**S&S**	O&P	O	I	T
	Performance and reliability requirements of the interface are defined.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of the performance and reliability requirements.					
Level 3	Defined – The performance and reliability requirements are defined in the standards and/or implementation profile.					
Level 2	Managed – Performance and requirements are specified on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

A.3 Operation and Performance

These criteria focus on synchronicity and quality of service, as well as operational concerns such as maintaining integrity and consistency during fault conditions that disrupt normal operations such that distributed processes can meet expected interaction performance and reliability requirements.

14	C&E	S&S	**O&P**	O	I	T
	The interface definition specifies the handling of errors in exchanged data.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The handling of errors in exchanged data is defined in the standards and/or implementation profile.					
Level 2	Managed – Error handling is managed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

[1] Defined, maintained, and aligned creates three sub-criteria. Compliance with all pieces is required to meet this criterion.

15	C&E	S&S	O&P	O	I	T
	Time order dependency and sequencing (synchronization) for interactions is specified.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – Time order dependency and sequencing requirements for interactions are defined in the standards and/or implementation profile.					
Level 2	Managed – Time order dependency and sequencing for interactions is managed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

16	C&E	S&S	O&P	O	I	T
	The interface definition specifies the mechanism for message transaction and state management.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The mechanism for message transaction and state management is defined in the standards and/or implementation profile.					
Level 2	Managed – The mechanism for message transaction and state management is handled on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

A.4 Organizational

These criteria represent the pragmatic aspects of interoperability. They represent the policy and business drivers and process for interactions. Interoperability is driven by the need for businesses (or business automation components) to exchange information and it requires agreement on the business process integration that is expected to take place across an interface.

17	C&E	S&S	O&P	O	I	T
	Compatible business processes and procedures exist across interface boundaries.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The process for defining compatible interface messages assure that business processes and procedures on either side of the interface are compatible.					
Level 2	Managed – Incompatibilities in the business processes and procedures across the interface boundaries are managed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

18	C&E	S&S	O&P	O	I	T
	Where an interface is used to conduct business within a jurisdiction or across different jurisdictions, it complies with all required technical, economic, and regulatory policies.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of the process.					
Level 3	Defined – The process for specifying compliance with technical, economic, and regulatory policy within or across jurisdictions is defined.					
Level 2	Managed – Noncompliance within or across jurisdictions is managed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

A.5 Informational

These criteria emphasize the semantic aspects of interoperability. They focus on what information is being exchanged and its meaning. At this level it is important to describe how information classes are related to each other, including the relationships to similar entities across domains and any constraints that may exist.

19	C&E	S&S	O&P	O	I	T
	Information models relevant for data exchanged across the interface are formally defined using standard information modeling languages.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future information model improvements.					
Level 3	Defined – The process for updating information models using standard modeling language is defined.					
Level 2	Managed – Information models are defined using a standard information modeling language.					
Level 1	Initial – ad hoc and chaotic					

20	C&E	S&S	O&P	O	I	T
	Data exchange relevant to the business context is derived from the information model.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future data exchange extensions mapped to the information model.					
Level 3	Defined – The process for defining data exchanged assures mapping to the information model.					
Level 2	Managed – The data exchanged for each business context maps to the information model.					
Level 1	Initial – ad hoc and chaotic					

21	C&E	S&S	O&P	O	I	T
	Where the data exchanged derive from multiple information models, the capability to link data from different information models is supported.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has guidelines in place for future data exchange extensions to maintain consistency among the various information models.					
Level 3	Defined – The process for defining data exchanged is consistent among the various information models.					
Level 2	Managed – The data exchanged is consistent among the various information models.					
Level 1	Initial – ad hoc and chaotic					

A.6 Technical

These criteria emphasize the syntax or format of the information. They focus on how information is represented within a message exchange and on the communications medium. They focus on the digital exchange of data between systems, encoding, protocols, and assuring that each interacting party is aligned with one another.

22	C&E	S&S	O&P	O	I	T
	The structure, format, and management of the communication protocol for all information exchanged is specified.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The structure, format, and management of the communication protocol for all information exchange is defined in the standards and/or implementation profile.					
Level 2	Managed – The structure, format, and management of the communication protocol for all information exchange is managed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

23	C&E	S&S	O&P	O	I	T
	The information exchanged and business process interactions at the interface are cleanly layered (described separately) from the technical (communication networking) layers in the interface specification.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements.					
Level 3	Defined – The information and business process are defined and clearly layered separate from the technical layers in the standards and/or implementation profile.					
Level 2	Managed – The information and business process are clearly layered separate from the technical layers on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

A.7 Community (Multi-category Criteria)

The category of community is associated with the motivation and participation of ecosystem stakeholders to promote interoperability. This category includes the activities involving interoperability standards and their improvement, openly sharing best practices and lessons learned to improve interoperability, and increasing adoption of equipment and methods that will increase interoperability.

24	C&E	S&S	**O&P**	O	**I**	T
	The ecosystem references openly available standards, specifications, or agreed-upon conventions used in interface definitions.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of the interface definitions based upon improved standards, specifications, and agreed-upon conventions.					
Level 3	Defined – Interface definitions are defined based upon openly available standards, specifications, or agreed-upon conventions.					
Level 2	Managed – Interface definitions are specified on a per implementation basis, based upon openly available standards, specifications, or agreed-upon conventions.					
Level 1	Initial – ad hoc and chaotic					

25	**C&E**	S&S	O&P	**O**	I	T
	The ecosystem participates in development of interoperability standards efforts consistent with its businesses.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place to increase stakeholder participation and improve the standards engagement process.					
Level 3	Defined – The process for ecosystem stakeholders to participate in the development of interoperability standards is defined.					
Level 2	Managed – Ecosystem stakeholders participate in the development of interoperability standards efforts on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

26	C&E	S&S	**O&P**	**O**	I	**T**
	The ecosystem supports interoperability test and certification efforts.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements and extensions of testing and certification.					
Level 3	Defined – Interoperability testing and certification procedures are defined in the standards and/or implementation profile.					
Level 2	Managed – Interoperability testing and certification is specified on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

27	C&E	S&S	O&P	O	I	T
	The ecosystem identifies and shares lessons learned and best practices resulting from implementation experience and interoperability improvements.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements to identifying and sharing lessons learned and best practices.					
Level 3	Defined – Avenues for identifying and sharing lessons learned and best practices are defined.					
Level 2	Managed –The ecosystem identifies and shares lessons learned and best practices on an implementation basis.					
Level 1	Initial – ad hoc and chaotic					

28	C&E	S&S	O&P	O	I	T
	The ecosystem (standards development and implementation group contexts) periodically reviews refinements and extensions of interface definitions.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements and extensions.					
Level 3	Defined – The process for review and refinements for extensions is defined.					
Level 2	Managed – The review of refinements and extensions is managed on an implementation basis.					
Level 1	Initial – ad hoc and chaotic					

29	C&E	S&S	O&P	O	I	T
	Security and privacy requirements are specified in a manner that supports integration and interoperation.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements and extensions of the process.					
Level 3	Defined – Security/privacy policies are defined a way that promotes interoperability.					
Level 2	Managed – Conflicts in interoperability caused by security/privacy policies are managed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

30	C&E	S&S	O&P	O	I	T
	Purchasers of technology that is expected to support the interface specify interoperability performance language in their procurement documents.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of the interoperability performance language to be used in connected technology procurement contracts.					
Level 3	Defined – The ecosystem has defined the interoperability performance language to be used in connected technology procurement contracts.					
Level 2	Managed – Procurement contracts include interoperability performance language as needed on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

31	C&E	S&S	O&P	O	I	T
	Education and marketing initiatives about the ecosystem and its interoperability elements (including standards, implementation profiles, testing, and certification) are supported.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans in place for future refinements of education and marketing initiatives.					
Level 3	Defined – The ecosystem structures and processes for promoting education and marketing initiatives are defined and supported.					
Level 2	Managed – The ecosystem promotes education and marketing initiatives on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

32	C&E	S&S	O&P	O	I	T
	The ecosystem adopts or aligns with existing, mainstream, modern information-exchange approaches and standards that address the business objectives and maximize the longevity of its specifications.					
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.					
Level 4	Planned – The ecosystem has plans and criteria in place for future refinements and extensions for alignment to mainstream, modern information-exchange approaches.					
Level 3	Defined – The ecosystem addresses adoption and alignment to mainstream, modern information-exchange approaches using a defined process.					
Level 2	Managed – The ecosystem addresses adoption and alignment to mainstream, modern information-exchange approaches on a per implementation basis.					
Level 1	Initial – ad hoc and chaotic					

33	C&E S&S O&P O I T
	The ecosystem does not create new interface standards where suitable standards already exist.
Level 5	Optimized – The ecosystem engages in continuous improvement of the process itself.
Level 4	Planned – The ecosystem has plans and criteria in place to determine if existing interface standards are suitable for adoption to address future refinements.
Level 3	Defined – The ecosystem determines if existing interface standards are suitable for adoption prior to considering the creation of any new standards using a defined process.
Level 2	Managed – The ecosystem determines if existing interface standards are suitable for adoption before considering the creation of any new standards on an implementation basis.
Level 1	Initial – ad hoc and chaotic

Appendix B

Scoring Using the Interoperability Maturity Model

Table B.1 shows where scores are required for each category of interoperability criteria.

Table B.1. Criteria Selection for Applying the IMM

	Configuration & Evolution	Safety & Security	Operation & Performance	Organizational	Informational	Technical
1	✓					
2	✓					
3	✓					
4	✓					
5	✓					
6	✓					
7	✓					
8	✓					
9		✓				
10		✓				
11		✓				
12		✓				
13		✓				
14			✓			
15			✓			
16			✓			
17				✓		
18				✓		
19					✓	
20					✓	
21					✓	
22						✓
23						✓
24			✓		✓	
25	✓			✓		
26			✓	✓		✓
27	✓	✓	✓	✓		
28	✓				✓	
29		✓	✓			✓
30				✓	✓	✓
31	✓		✓	✓		
32	✓				✓	✓

	Configuration & Evolution	Safety & Security	Operation & Performance	Organizational	Informational	Technical
33	✓	✓	✓	✓	✓	✓

To use the Interoperability Maturity Model (IMM), it is first necessary to determine which categories are going to be evaluated. Table B.1 shows which criteria need to be selected. If a criterion is included in multiple categories that are selected for evaluation, then its score is included for each category.

It is not necessary to have received a successful evaluation at any level n of the IMM before being evaluated for level n+1; however, an incremental improvement program is probably a wise approach. This might be accomplished by setting a time frame for meeting a certain level of maturity. For example, what the maturity should be in five years.

Determining whether a criterion has been met is a function of determining whether the basic intent of the level is observable and verifiable. The basic intent for each criterion by level is described in Appendix A.

B.1 Guidelines

In determining whether the basic intent of the level is observable and verifiable, asking and answering the following questions may provide helpful guidance:

- Is there evidence that the practice described in the criterion is being performed?
- Is there evidence that the capability described in the criterion is being practiced?
- Is there evidence that implementations meet the described criterion?
- Are the expected outputs observable and available for inspection?
- Is the practice described in the criterion documented and shared with all who need to know?
- Have the standards and guidelines that support the practice/criterion been identified and implemented?
- Is the practice/criterion supported by policy, and is there appropriate oversight over the performance of the practice?
- Are practice/criterion improvements documented and shared across internal constituencies so that the organization reaps the benefits of these improvements?
- Is there a community-sponsored definition of the practice/criterion from which organizations can derive practices that fit their unique operating circumstances, while still achieving the shared goals of the community?

B.2 Performing the Scoring

The scoring rubric is as follows:

- **Step 1.** Score the criteria in each category. Each criterion in a category is scored by answering whether there is documented evidence to support whether the criterion is being met as defined by the required level description, and scored as follows:
  - ***performed*** when the question is answered with a “Yes.”
  - ***not performed*** when a question is answered with

    - Incomplete evidence
    - No
    - Not Answered.
  - If the result for a criterion is "Not Answered" the criterion shall be scored the same as a "No."
- **Step 2.** Create the score for each category. The score (rating) for the category is then determined as follows:
  - ***achieved*** when all practices are performed
  - ***partially achieved*** when some practices are performed
  - ***not achieved*** when no practices are performed.

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