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Model Portfolio Management Guide

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Albert C. Hoheb[1], Alexander K. Chang[2], Misak Zetilyan[3], and Jordan Howie[4]
[1]Architecture and Design Subdivision; Systems Engineering Division
[2]Space Architecture Department; Architecture and Design Subdivision
[3]Applied Software Technologies Department; Software Engineering Subdivision
[4]Agile Systems Engineering, Planning and Analysis Department; Acquisition Analysis and Planning Subdivision

Prepared for:

The National Reconnaissance Office
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Abstract

The Model Portfolio Management (MPM) Guide defines the tasks and products for the Model Portfolio Manager to ensure that the collection of models meets organizational needs, has a planned evolution, meets integration targets, has known risks and quality, and can be used to set and apply modeling best practices/standards. The MPM role works in conjunction with program managers, project managers, and their modelers responsible for their models through a governance process.

The intent of this guide is to provide an organization that is managing a portfolio of models with the terms, tasks, and approaches that can be adopted to create a comprehensive MPM approach. The organizational response to this guide depends on their organizational and modeling objectives as well as available resources. Implementation of this guide could start with an MPM plan and may entail institutionalizing registries, repositories, and reports.

This guide may be useful as a reference document for the pre-award acquisition process (market research through source selection), be placed in the bidder's reference library, be a reference in the proposal preparation instructions, and used as a reference in the model contract.

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Preface

This document is prepared as an Aerospace Technical Operation Report (TOR) prepared for the corporation through the sponsorship of several program offices.

Authors

The principal authors of this Guide are:

Albert "Al" Hoheb (project lead)
Alexander Chang
Jordan Howie
Misak Zetilyan

Reviewers

In addition to the authors and contributors, this document was coordinated through a sequence of Aerospace subject matter expert (SME) reviewers in addition to the sponsors. With all TORs, this report was approved by line management.

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Website: https://aerospace.org/

1. INTRODUCTION

Organizations need guidance and standards on how to manage their collection of symbolic models to meet their organizational goals. Symbolic models include analytical and descriptive models, not physical models. When asked how organizations currently manage their portfolio of models, organizations generally have incomplete and inadequate approaches adding to the risks that the models are not planned or managed effectively. When organizations cooperate or contractually collaborate on modeling efforts, it is beneficial or required to have understood and synchronized model management approaches. If organizations apply the INCOSE Model-Based Capabilities Matrix [1] and User's Guide to assess their modeling capabilities, they usually rate Model-Management as ad-hoc; with the model manager having an unassigned role that has no reference guidance or standard and, hence, an inability to define or apply model management consistently across their organization. This guide is provided to address the needs to manage an organization's portfolio of models so that the models meet needs.

1.1 DOCUMENT PURPOSE

The purpose of this Model Portfolio Management (MPM) guide is to identify goals and tasks necessary to manage an organization's collection of models, henceforth called a portfolio, so that they contribute to the business and technical objectives of that organization. This document is intended for any organization to improve their management of their collection of models and modeling resources. For an acquirer, like the government, the MPM Guide would be helpful to manage their own model libraries, to enhance reuse, and to provide contractors a reference for potential further model development. The government acquirer may also want to use this document as a reference document through the pre-award process to assist with performing market research, qualifying sources, and as a reference document to the Request for Proposal (RFP) so that the MPM concepts are understood by bidders. Potential suppliers may use this guide to organize their work and communicate their plans for managing their modeling efforts to assure the government that model efforts are well-managed, trusted, and are designed to meet acquisition modeling objectives.

The MPM tasks are performed by the role of Model Portfolio Manager. The need for MPM has been documented in literature and in presentations to International Council on Systems Engineering (INCOSE) and the National Defense Industrial Associations (NDIA). The notion of model curation and the model curator role has been incorporated into the overall scope of MPM.

The role of the Model Portfolio Manager can be assigned to anyone in the organization. For the MPM role to be most effective, it may be to assign that role to a key leader within systems engineering, which has a unique relationship between Acquisition and Engineering and its interdisciplinary integration of cost, schedule, risk and project management.

This guide may apply to any/all organizational levels when an organization has a collection of models to manage. Large organizations may have organizational hierarchies, such as Division/Center that are decomposed into Business Unit/Enterprise, Product line/Program, and/or product organizations. There could be an MPM role at each level of the organizational hierarchy.

This guide is written to manage the portfolio of models and is written at the goal and task level; identifying the tasks or "what" needs to be done. It is not intended to be written to provide the "how" to perform the tasks, nor is it written to tackle the topics related to single models, such as model development, model configuration management, model quality assessment, etc.

Implementation against this guide can take many forms; it may start by writing and conducting tasks against a written organizational MPM Plan (see Appendix C for a suggested outline). It may establish the MPM management tools, such as stakeholder agreements, governing bodies, model repositories, MPM reports, etc. Organizations and the MPM are encouraged to conduct the tasks that are most valuable due to resource limitations. Unless directed otherwise, the implementation is organization specific and is a balance of MPM concepts and the organizational resources and constraints.

1.2 BENEFITS OF USING THIS GUIDE

There are many benefits to implementing MPM using this guide. The more the organization recognizes the benefit, the more guide features it may want to institutionalize. This guide has been written to provide these benefits:

- *To define and communicate terms and principles related to managing a portfolio of models.*
- *To ensure the portfolio of models meet the business needs of the organization and to identify gaps and risks to the business objectives relative to models.*
    - To characterize needed modeling investment of dollars, time, people to ensure the portfolio of models continues to meet organizational business needs.
- *To establish model portfolio governance across the roles of organizational Model Portfolio Manager, individual model Principal Investigators (PIs), governance boards, and outside organizational stakeholders.*
- *To characterize models for acquisition, development, verification, reuse, extensibility, and integration, with the goal of providing a more capable portfolio of models.*
- *To maintain the model repository to ensure that the latest models, associated scripts and data components are available to users.*
- *To ensure that only authorized users get access to models and model elements.*
- *To enhance model integration and model assurance, as well as applying risk management with the goal of enhancing trust in model utility.*
- *To adopt/establish standards and conventions (extensions, plug-ins and scripts) across the portfolio to enhance model interoperability, model development, model quality assessment, and model configuration.*

    - To define and reduce training needed, converge on modeling tools, and enhance model reuse.

- *To ensure that the information technology (IT) underpinning the models evolves in a way that allows the portfolio of models to continue to be supported.*

- *To establish organizational agreements (e.g., memoranda of agreement, memoranda of understanding, contracts) when linking models outside of an organization (data flow in or out).*

- *To establish a reference document for contracting.*

    - *To ensure the contractor understands the scope of the model management effort*.

    - *To consider inclusion of this document in a contract and as a reference in the bidder's library.*

    - *To use as a reference to create an MPM Plan.*

1.3 HOW TO USE THIS DOCUMENT

This guide is useful in defining the organization's MPM Plan, establishing roles and governance, establishing model repositories, characterizing model registries, developing model artifact accession lists, and providing other useful management information to coordinate modeling efforts across the organization.

The MPM governance role is coordinated with the overarching organizational executive, the program and project managers, and the model managers. Figure 1 shows the notional roles of the Organizational Executive, Model Portfolio Manager, Program Manager, and Project Model Manager. The Organizational Executive is the person responsible for the organization. The Program Manager is responsible for several projects; each project may have any number of models. The Project Manager is responsible for their project and any project models. At the direction of the Organizational Executive, the Model Portfolio Manager is responsible for managing all the models within the organization and shares that model management responsibility with both the program manager(s) and project manager(s). To coordinate the MPM efforts, a Portfolio Steering group may be used to perform model governance.

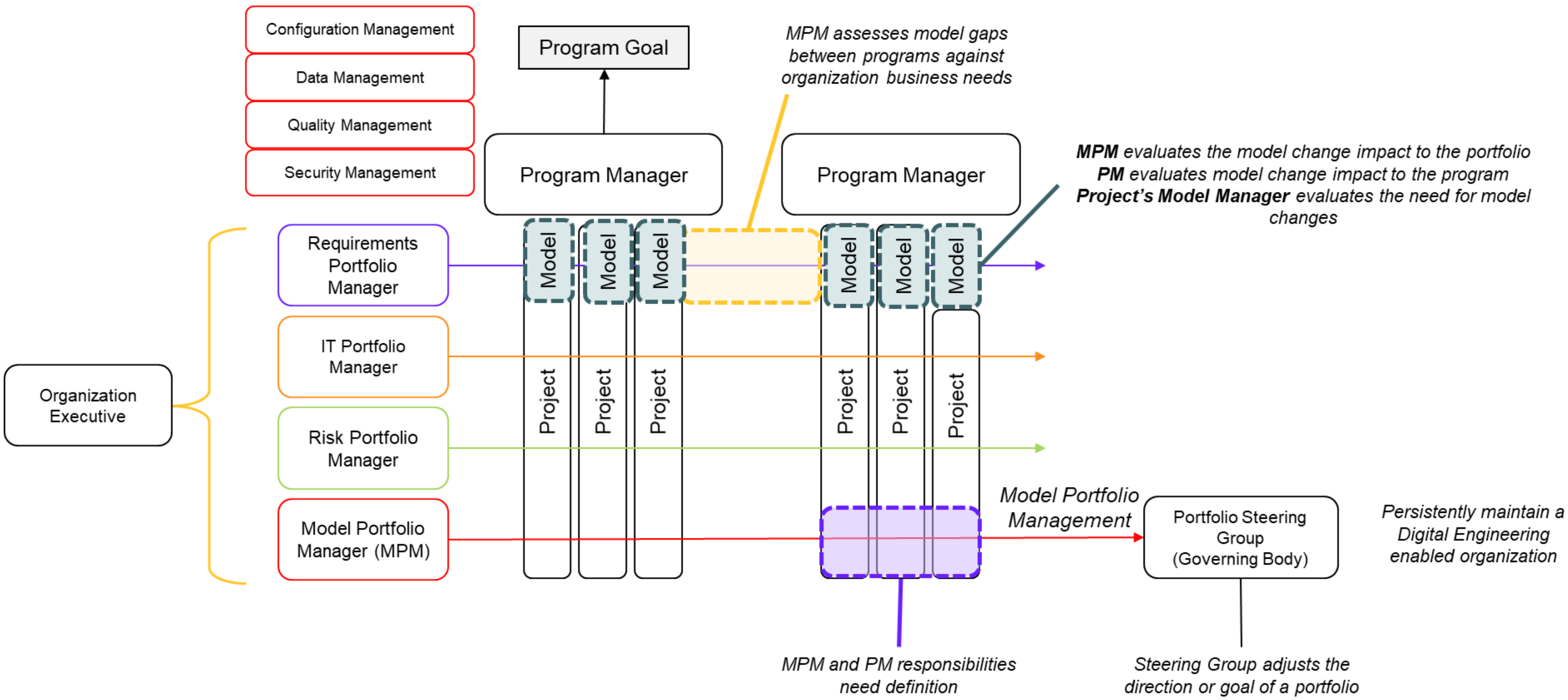

Figure 1. Model Portfolio Manager, Program Manager, and Project Model Manager

Each organization may have a defined approach for configuration management, data management, risk management, quality management, security management, and other technical management processes. Therefore, MPM works concurrently with technical managers/teams to identify and process portfolio items. Risk, Configuration, and Data Managers, for instance, assume the role of facilitating MPM items into their respective technical management approach. The intent of this guide is to encourage the use of existing organizational resources and methods to help the MPM, not to conflict or duplicate them.

Organizations may have overarching strategy documents or implementation plans written at a higher organizational level for Digital Engineering (DE), Model-Based Engineering (MBE), or with some similar title that drives the organization's deployment and use of models. These are used to inform, and perhaps provide requirements for, the MPM effort. Similarly, there may be documents that apply to singular models that would be useful to put into context.

Figure 2 below illustrates where this MPM Guide document may relate to other documents. Having a document tree like this helps to coordinate efforts; it puts plans, standards and guides in context, and may be useful to identify documents that would be useful but are not yet available.

In Figure 2, the top-level document is a Digital Engineering Strategy that has been adopted by large organizations. An example of this is the DOD DE Strategy [2] document that applies to all DOD. Some organizations have responded to the strategy document by defining a DE Implementation Plan that explains that their plan addresses the DE strategy. The DE Implementation plans do not have a standard format but all include a definition of DE/MBSE organizational objectives, an approach to assessing and closing DE/MBSE capability gaps, defining plans and projects for implementing DE infrastructure, and defining their hierarchal model relationships that put into context existing models and those that are needed—acquisition, procurements, and developments as illustrated under model applications.

In Figure 2, the MPM Guide defines the goals and tasks of the MPM team. These define "what" needs to be done. The blocks below the MPM address the "how" and "how well" tasks that are recommended for application to individual models that are jointly managed between the MPM and the individual model manager via the governing body shown in Figure 1. The blocks below the MPM Guide could be expanded to include other guides; for example, model security and access control.

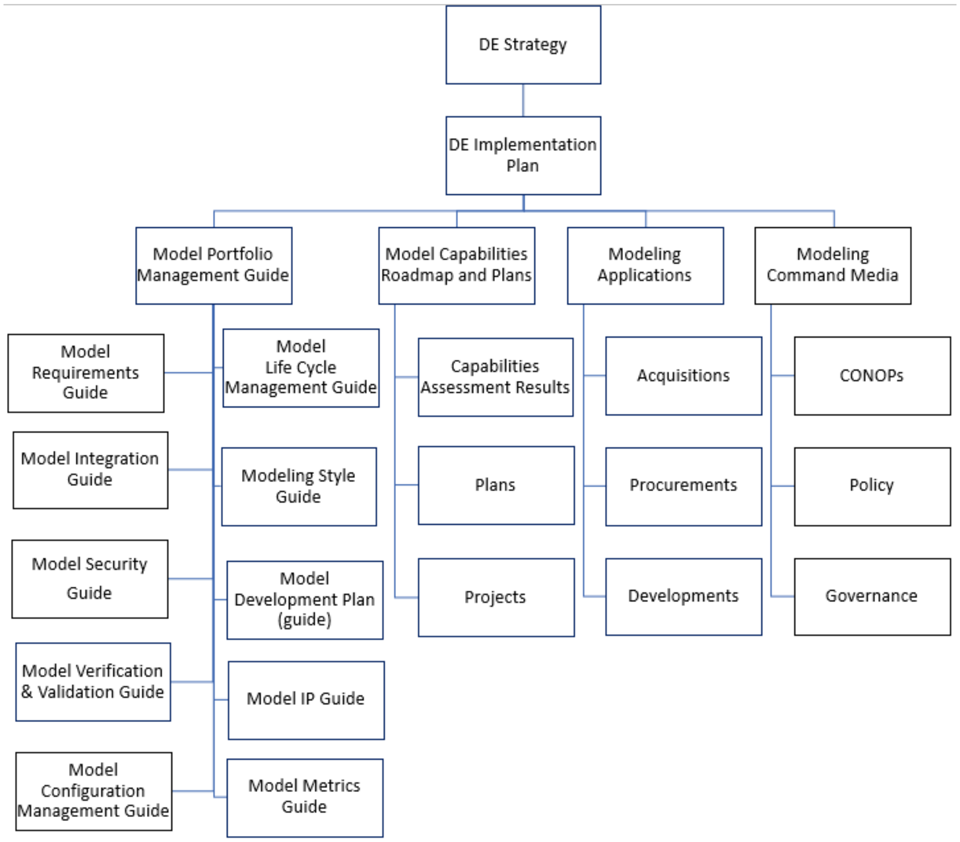

Figure 2. Model-Relevant Document Tree

1.4 DOCUMENT LIFECYCLE ORGANIZATION

The portfolio lifecycle is different from a project/model lifecycle. Projects and their models may have an individual lifecycle where the individual model may be eventually retired and archived. As long as an organization exists, the portfolio may never be fully retired, although parts of the portfolio may be retired. With these thoughts, this document has adopted the lifecycle of portfolio management from “The Standard for Portfolio Management,” Project Management Institute (PMI) [3], with the portfolio lifecycle being defined in Sections 3 through 6.

2. REFERENCE DOCUMENTS

This guide is designed to work in conjunction with, but not replace, other standards adopted by organizations. Specifically, organizations usually have adopted standards for configuration management, data management, and risk management. This guide is designed to identify the MPM tasks and concepts that would work with those standards.

Users of this document are encouraged to review ISO/IEC CD 24641, *Methods and Tools for Model-Based Systems and Software Engineering (MBSSE),* that is in draft as of June 2020.

Specifically, this document has identified these standards that it works in conjunction with:

- EIA649C Configuration Management Standard 2019-02-07
- GEIA859A Data Management 2012-04-01
- IEEE Std 1540-2001 Risk Management 2001-03-17

3. MPM INITIATION

The primary goals of the initiation stage include, but are not limited to, validating business and operational strategy, identifying the portfolio components included in the scope, and defining a long-term roadmap with financial goals, performance metrics, communication, governance, stakeholders' definition and roles, and ongoing management plans for the portfolio and its components. During this stage, the following work products are created [3]:

3.1 DEVELOP MPM STRATEGY

The portfolio strategic planning process consists of developing MPM strategy that is aligned with the strategic goals and objectives of the organization. The strategic goals and objectives of programs, projects, and systems included in the scope of the portfolio also need to be taken into considerations. The MPM strategy needs to be captured to provide guidance to the MPM governing body and the Model Portfolio Manager to establish strategic business and operational goals and objectives for the portfolio of models. The contents of the MPM strategic goals and objectives can be contained within a single document or several documents that address the following [4]:

- Justification for the need for portfolio management
- Vision statement describing the business and operational goals, benefits, and objectives of the portfolio
- A mission statement describing the means by which the goals, benefits, and objectives of the portfolio are to be obtained
- Alignment to the strategic goals and objectives of the organization
- Alignment to the strategic goals and objectives of programs, projects and systems in scope

3.2 MODEL MANAGEMENT CONOPS

This MPM document can be applied at any organizational level where the organization would like to manage its portfolio of models. The models being managed may be descriptive and/or analytical. An organization of multiple levels will make the decision where MPM is most effective and may institute a single MPM for the organization or allocated MPM to either organization tiers or to programs within an organizational hierarchy tier.

3.3 GOVERNANCE FRAMEWORK

Establishing the governance framework early in the portfolio lifecycle contributes to organizational success by managing the portfolio of models against the organizational modeling objectives. MPM may be applied to an existing collection of models. Having a governance framework will ensure the proper selection of the Portfolio Governing Body. Several factors influence the level and rigor of governance needed, including:

- The type, size, and complexity of components within the portfolio
- Regulatory, security, and intellectual property considerations
- Portfolio performance metrics
- The level of authority within the organization that decisions are made
- Organizational resources
- Standardization that ensures ubiquity and accessibility across models regardless of tools from which they were developed

A comprehensive governance framework can increase engagement and support from senior management. A well-defined framework can reduce communication gaps, resource conflicts, and risks.

3.4 PRIORITIZATION CRITERIA

Prioritization of models within the portfolio will depend on the organization's strategic objectives, risk, security concerns, resource constraints, and other considerations relevant to the portfolio entry criteria. The Portfolio Governing Body can direct the Model Portfolio Manager to prioritize models based on the general types of models (descriptive vs. analytical), risk categories (integration vs. complexity), or specific program phases (development vs. sustainment). The prioritization criteria influence the decision: which models to include/exclude from the portfolio (in essence, the breadth and depth of the portfolio). This should be done initially during the establishment of the portfolio so changes in strategic objectives, risks, and/or resources can be accounted. The prioritization criteria should impact the composition of the portfolio but should not have an impact on the models themselves. Models contained within the portfolio should include basic entry criteria:

- Link to strategic objectives of the portfolio
- Relationship to other models within the portfolio
- Having some level of metadata that can be quantified for prioritization

3.5 PORTFOLIO GOVERNING BODY

The Portfolio Governing Body is responsible for making decisions that control the direction of the portfolio of models. Portfolio governance may occur at different levels of the organization to support specific goals and objectives. All governance levels need to be linked together to ensure that there is alignment with the organizational strategy. The Model Portfolio Manager needs to be cognizant of the decision-making levels and the processes that govern how decisions are made, documented, and implemented.

Successful execution of portfolio governance is highly dependent on proper governance planning. The governance plan may be a standalone view (documented or modeled) or may be a subsidiary to the MPM Plan. As a guide, the portfolio governance plan lists the:

- Initial members of the governing body.
- Scope and objectives of the governance model.
- Scope and objectives of the organization.

To be most effective, the portfolio governance body must be aligned with the organization's strategic management processes and practices, ideally, utilizing an existing governing structure. Governance decisions should be documented (typically in meeting minutes) and included in the portfolio process assets.

3.6 STAKEHOLDER'S DEFINITION AND ROLES

"[Model] stakeholders include but are not limited to, end-users, end-user organizations, supporters, developers, producers, trainers, maintainers, disposers, acquirers, customers, operators, supplier organizations, accreditors, and regulatory bodies" [5].

Model portfolio management stakeholders tend to be at a higher level than the stakeholders at the model level. The challenge for the Model Portfolio Manager is to identify the key stakeholders to engage and communicate with since the list of all stakeholders for the portfolio may be too large to manage. At the minimum the three key stakeholders for the portfolio need to be identified:

- Sponsor
- Portfolio Governing Body
- Model Managers

Other stakeholders can be internal or external model users and associated organizational leaders and managers. The key steps for stakeholder management are the proper identification and engagement of all stakeholders. Table 1 shows high-level stakeholder roles, interests, and expectations that would guide the potential communication needed. The list of the key stakeholders and stakeholder categories should be captured in the stakeholder engagement section of the MPM Plan, which may be a part of the MPM Plan or a separate document.

Table 1. Stakeholder Roles, Interest and Expectations

Stakeholder	Roles	Interests	Expectations
Sponsor or Organizational Executive	Provide funding and resources	Alignment with goals	Informed regularly of key portfolio decisions and milestones
Model Portfolio Manager	Provides the management of the portfolio of models needed by the organization	Portfolio of models meets the organizational goals and objectives	At the sponsor's request, performs portfolio model management with the Portfolio Governing Body and model managers
Portfolio Governing Body	Oversees the portfolio priorities, manages spending, and manages timely delivery of benefits	Portfolio level risks and issues that require key decision and change management	Informed regularly of developments, change needs, and progress
Model Managers	Ensures model life cycle management	Mitigates portfolio level risks and issues impacting their model	Adheres to MPM agreements and is informed of portfolio changes, risks and issues

3.7 COMMUNICATIONS PLANNING

Communications planning includes the development of a communication strategy for how portfolio information is to be shared with stakeholders. The communication strategy should be addressed in the MPM Plan.

The goal of communications planning is to identify the relevant data ("what"), the frequency ("when"), and methods ("how") of sharing that data to satisfy the needs of key stakeholders ("who"). This may be captured in a communication plan. Several factors need to be considered when planning for portfolio communications. These include but are not limited to:

- **Governance** - Alignment with the portfolio governance, norms, policies, and procedures of the organization will dictate the depth and rigor of communication needed. Effective communication is essential for governance because it enables effective decision-making, monitoring and control.

- **Infrastructure** - Communication infrastructure includes all of the available methods of communication as well as the associated policies and procedures used to communicate status [3]. It may be possible to utilize existing infrastructure or meetings to report status. There may be the need to develop new methods to communicate portfolio status (i.e., portfolio dashboard).

- **Strategy** - The MPM Plan contains the initial list of stakeholders and their communications needs. All elements of the MPM Plan have communication requirements, such as risks that need to be communicated to the governing body, the portfolio manager, and stakeholders.

- **Metrics** - The content, format, and frequency of portfolio metrics should be defined in the Communications Plan. These should include the performance metrics needed for monitoring and control activities.

Table 2 of Appendix B shows a sample communication matrix for the portfolio.

3.8 MODEL PORTFOLIO MANAGER

The Model Portfolio Manager has the responsibility to establish and implement the administration and control processes for the Model Portfolio. The Model Portfolio Manager's focus is on doing the "right work" while Program Managers and Model Managers focus on doing the "work right" [3]. The Model Portfolio Manager is responsible for the coordination and integration of model components within the Model Portfolio. The Model Portfolio Manager may be an individual or a group of individuals serving different roles within the organization.

The Model Portfolio Manager may have several key roles—those of architect, facilitator, and integrator.

As an architect, the Model Portfolio Manager:

- Works with the Portfolio Governing Body, sponsors, stakeholders and other organizational counterparts to execute the MPM Plan in alignment with the organizational business and operational strategy.

- Establishes and maintains the framework and methodology for the portfolio.

- Develops appropriate guides, policies, and processes for the portfolio of models.

- Establishes and maintains the appropriate infrastructure and systems to support the strategic objectives of the portfolio.

- Oversees the commitment of personnel, capital, and other resources.

- Continually improves on the portfolio management processes to better align the portfolio components with changes in strategy.

- Manages stakeholder expectations and conveys to the Portfolio Governing Body how well the Model Portfolio is aligned and realigned with the strategic goals.

As a facilitator, the Model Portfolio Manager:

- Manages the day-to-day operations of the Model Portfolio infrastructure, processes, and resources.

- Serves as a liaison between Model Managers and the Portfolio Governing Body.
- Helps the Portfolio Governing Body in the selection and prioritization of models, and model elements within the portfolio to ensure alignment with strategic goals.
- Provides an assessment of model selection, prioritization, and identification of gaps and portfolio-level risks.
- Supports the Portfolio Governing Body in the decision-making process by ensuring timely and consistent information on metrics, changes, and impact to the portfolio of models.
- May participate in program reviews across all programs within the portfolio.

As an integrator, the Model Portfolio Manager:

- Integrates the portfolio components to maximize the utilization, re-use, and collective value of models within the portfolio, in essence, to make the value of the Model Portfolio greater than the sum of its parts.
- Captures the impact and value of the Model Portfolio against strategic goals.
- Receives and aggregates models, their components, and information on models from Model Managers.
- Oversees or coordinates with Model Managers on acquisition, integration, and assessment of the portfolio components (models and associated data).
- Identifies gaps and provides recommendations based on the information obtained from Model Managers.

3.9 MPM ROADMAP OF MODELS TO ORGANIZATIONAL MODELING GOALS

The MPM roadmap is a high-level graphical representation or model representation that details how the portfolio of models is tied to the strategic goals. The goal of the roadmap is to help with defining the architecture of the portfolio, identifying interdependencies among the portfolio components, and determining how they fit together to achieve the overall goals and objectives of the portfolio [3]. The roadmap may be a chronological depiction of the portfolio's intended direction in achieving the strategic goals. It is like a project plan depicting the dependencies between major milestones and key decision points. The MPM roadmap may be used for the development of the MPM Plan and to identify synergies and efficiencies across multiple levels of the organization. While establishing the MPM roadmap it is important to:

- Highlight the key benefits and value achieved by the portfolio. "A roadmap is an effective way to communicate the overarching plan and benefits to stakeholders to build and maintain advocacy" [2].

- Use it to assess progress towards achieving portfolio benefits.
- Update the MPM roadmap at least yearly or more often when there are major changes made to the portfolio.

The Model-Based Capabilities Matrix (MBCM) may act as a reference to begin identification of strategic goals in relation to models and model-based capabilities. The MBCM is an Excel-based spreadsheet composed of descriptive model-based capability rows and columns that define the capability stage. The cells in a capability row progress from a capability that has little or no model-based elements to the highest stage with the greatest amount of model-based capability for an enterprise.

3.9.1 Define Portfolio Components

The portfolio of models is a collection of different models at all levels within the scope of the portfolio along with associated data. The goal of this task is to define the collection of models along with the associated data that are the components of the portfolio. As resources and the organizational goals change, the portfolio components may need to be changed. It is critical for the portfolio components to be properly defined to allow for scalability as circumstances change over time. While defining the portfolio components, it is important to:

- Establish the appropriate granularity for components within the portfolio.
- Define the components within each level.
- Define the relationships and interdependency between components within each level.
- Define the relationship and interdependency between components between different levels.
- Identify security requirements and how those influence the portfolio components.
- Identify intellectual property rights and how those influence the portfolio components.
- Identify modeling standards and how those influence the portfolio components.
- For consistent traceability and configuration management, ensure that portfolio entries align to those defined in the requirements management taxonomy.

Portfolio components are often defined differently at the enterprise, program, or project level as the components are being pooled and coordinated across the organization. The levels should be agreed upon and understood early to support the integration of portfolio components. Models within the portfolio may be categorized to be at the enterprise, program, project, system-level, or even at the sub-system level, and unit level. The number of model types in the portfolio will influence the number of levels needed. Portfolios with many different types of models tend to have more levels than portfolios with models of the same type. There may be some models that span multiple levels within the portfolio.

Figure 3 depicts an example of portfolio components contained within a portfolio. This exemplar depicts three levels of portfolio components at the enterprise, program, and project level. Modeling standards, intellectual property, and security requirements span all levels on the bottom. The contents at each level are as follows:

- Project level: System Models, plugins, extension, scripts, and other data
- Program level: Program models, mission models, and projects
- Enterprise level: Enterprise models, reference models, model libraries, and programs

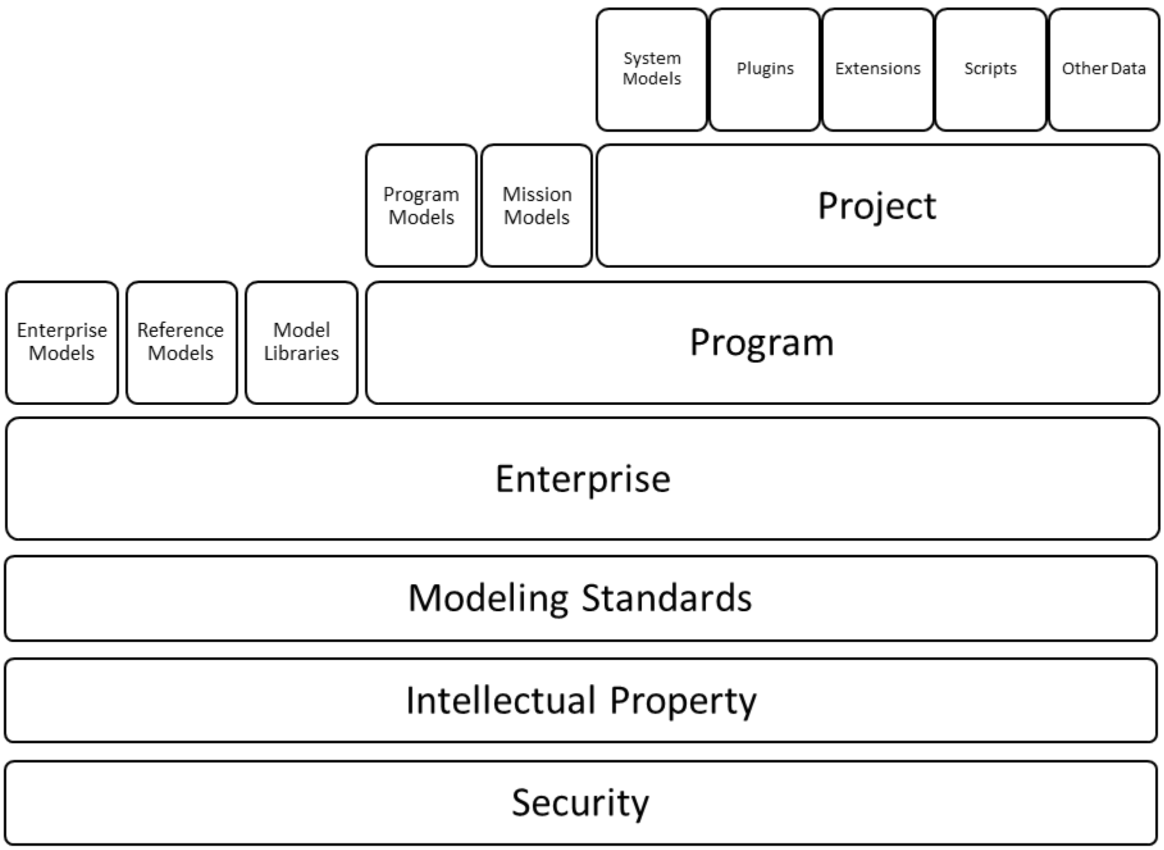

Figure 3. Portfolio Components

3.9.2 IDENTIFY SECURITY REQUIREMENTS

The goal of this task is to identify the security requirements impacting the portfolio of models that need to be taken into consideration by the organization. Security requirements, a type of nonfunctional requirement (NFR), may be addressed separately for the portfolio or as part of the overall organization's security requirements. There may be additional security requirements at the program and project level. While defining security requirements, it is important to consider:

- Classified information is properly handled and safeguarded in accordance with this policy and all related policies. (This includes, but is not limited to use, receipt, marking, safeguarding, transfer, transmission, and destruction. Some higher-level views of models may not be classified. However, at a lower-level view, there may be sensitive or classified elements that should not be seen by unauthorized personnel.)
- Personnel security requirements related to access, permissions, and roles.
- Security of the IT infrastructure as well as the models and other data stored in the portfolio.
- Information security requirements related to the preservation, confidentiality, integrity, and availability of information [6].
- Security training requirements for the portfolio as required.

3.9.3 IDENTIFY MODEL INTELLECTUAL PROPERTY RIGHTS

The goal of this task is to identify Intellectual Property requirements impacting the portfolio of models that need to be taken into consideration by the organization. Models developed by entities external to the organization may have intellectual property considerations about patents, trademarks, copyrights, and trade secrets. While defining intellectual property requirements, it is important to consider:

- Non-disclosure agreements as they apply to portfolio components.
- Sharing of portfolio contents within the organization may be permissible.
- Sharing of portfolio contents outside of the organization may require additional considerations.
- There may be additional requirements at the program and project level.

3.9.4 IDENTIFY MODELING GUIDELINES

The goal of this task is to identify modeling standards, policies and practices governing the portfolio of models that may be adopted by the organization. The governing body may establish modeling guidelines in addition to program level guidelines. These guidelines would establish which modeling standards, policies, and practices are applicable to the portfolio and how the standards, policies, and practices tailored to meet the needs of the portfolio. This would serve as the basis of model quality assessments covered in Section 5.3.1. While defining the applicable modeling guidelines for the portfolio, it is important to aggregate the requirements from all portfolio components that reference:

- Standards
- Policies
- Practices
- Guides

- Ontologies
- Metamodels
- Modeling languages
- Naming conventions
- Model constructs to ensure integration and reuse

3.9.5 IDENTIFY ANALYTICAL AND DESCRIPTIVE MODELS

There may be many ways to describe or represent a system within a portfolio. A model is a representation of a system; it is understood that scale models and other physical models should be excluded from the portfolio. These models are made to look like the real system and serve a purpose outside of the scope of the portfolio. A symbolic model is a type of model that is meant to be read by humans and computers [7]. A symbolic model can be further divided into descriptive models and analytic models. A model should be governed by a model type in accordance with ISO/IEC/IEEE 42010 [8]. A further classification of analytical and descriptive models is discussed below, but it should be noted that a model may include characteristics of more than one type. A hybrid model includes descriptive and analytical aspects, but models may favor one aspect or the other. For instance, the logical relationships of a descriptive model can also be analyzed in a hybrid model [9]. Figure 4 shows model types that may be included in the portfolio.

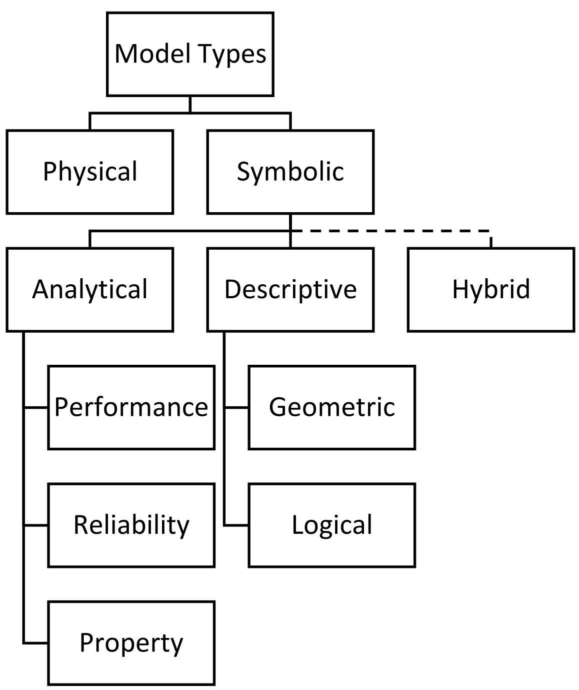

Figure 4. Model Types

Analytical models are defined as “primarily quantitative or computational in nature and represents the system in terms of a set of mathematical equations that specify parametric relationships and their associated parameter values as a function of time, space, and/or other system parameters” [7]. A system reliability model is an example of an analytical model that predicts the overall system reliability based on the reliability of system components. Analytical models are useful in predicting or assessing the system in whole or in part. Analytical models often are defined to omit their input conditions. Such analytical models are essentially "black boxes" that are supplied inputs and to return outputs. Those inputs and outputs are not normally considered to be within the boundary of what we call the "model." This type of model is useful in assessing how certain system characteristics perform, change, and overtime or with different parameters. Analytical models are useful in performing functional (logical) analysis, tradeoff analysis, verification, and validation of requirements.

Descriptive models are defined as one that “describes a system or other entity and its relationship to its environment. It is generally used to help specify and/or understand what the system is, what it does, and how it does it” [7]. A system logical model is an example of a descriptive model that is used to represent functional, connectivity, and traceability relationships and dependencies between requirements, structure, behaviors, and parametric constraints. Descriptive models often include their input conditions and may include inputs to analytical models. Descriptive models are useful for a traceability analysis, assessing the completeness of the model, and validating model correctness. Systems Modeling Language (SysML) may be used describe the system-level descriptive model.

3.9.6 IDENTIFY PLUG-INS AND SCRIPTS

Plug-ins and scripts may exist for descriptive models as well as analytical models. Plug-ins are used to extend the capabilities of the modeling software. Scripts allow for automation of tasks within modeling tools or independent of modeling tools utilizing model data. Plug-ins and scripts maybe key enablers of the portfolio of models and may be reused across models. See Section 4.3.2 for a listing of plug-in and script categories and candidate list of plug-ins and scripts to include in the portfolio.

3.9.7 IDENTIFY MODEL LIBRARIES

Model libraries are modeling resources that contain data types and frequently used model elements for reuse across models within a project, program, portfolio, and/or organization. Model libraries are a “set of language, process, and tools needed for an enterprise to create, maintain, organize, and use a collection of common foundational model library elements” [10]. The level at which modeling libraries are created and maintained is not relevant if access to those libraries is available to all models within the portfolio. The reuse of elements from libraries not only speeds up the creation of models but can also be helpful in integrating models by using common interface components. For example, the model for an airplane and the model for the boarding ram can use the same aircraft door element from a library. See Section 4.3.3 for a listing of model library categories and candidate list of model libraries to include in the portfolio.

3.9.8 IDENTIFY SUPPLEMENTARY COMPONENTS

The goal of this task is to identify data that is needed to support organizational goals. This data may be contained or be accessible from the portfolio for integration, simulation, and analysis. Other data in the portfolio may be:

- Meta-data on models to be used to classify models based on taxonomy or search for model elements within the Model Registry, see Section 5.1.1.
- Common Ontology so we can integrate models.
- Discipline specific models to provide specific analysis per discipline (for example: electrical, mechanical, etc.) [5].
- Digital Twins, and Digital Threads.
- Critical Program Information (CPI)/Key Program Information (KPI) and Key Performance Parameter (KPP)/Key Performance Indicators (KPI).
- Computer-Aided Design (CAD)/Computer-Aided Manufacturing (CAM) and Manufacturing Data.

3.9.9 INFORMATION TECHNOLOGY (IT) INFRASTRUCTURE

Information Technology infrastructure needs to be identified and implemented early in the MPM planning to support the management of all portfolio components identified in Section 3.9.1. The IT infrastructure should be available and secure to enable the integrated, shareable models and data for capture, retention, transmission, communication, and retrieval of models and data with stakeholders [5]. It may possible to utilize existing organizational IT infrastructure or augment it in support of MPM IT needs. There may be special consideration given to the administration and control of the portfolio components, particularly security controls. To ensure the efficient management of IT needs, the Model Portfolio Manager needs to:

- Identify the necessary tools, processes, procedures, and standards to support the portfolio components.
- Ensure that the procurement, maintenance, and support for needed hardware and software tools are planned and executed.
- Define the availability, access, security, archival, storage, and quality controls that need to be implemented to meet security requirements identified in Identify Security Requirements 3.9.2.
- Provide training to users and administrators on the use of IT infrastructure toolset used for managing the portfolio.

3.9.10 Portfolio Performance Metrics

The performance of the portfolio depends heavily on its ability to satisfy the mission need. Prior to planning the portfolio development process, the decision-maker must first establish a set of performance metrics for the portfolio. Performance metrics are developed to validate that the portfolio (and all its contents) aligns with the strategic objectives of the acquiring organization. While a method for assessing the portfolio's performance is developed during this phase, the analysis will not be performed until the models undergo development. The following tasks are conducted to establish a set of portfolio performance metrics:

- Identify a list of objectives that need to be met for the portfolio to be effective in achieving the mission need.
- Identify a list of measures of effectiveness (MOEs) that measure the success of the portfolio in achieving the objectives defined.
- Identify a list of key performance parameters (KPPs) that characterize the major performance drivers of the portfolio.
- Use the defined MOEs and KPPs to identify the measures of performance (MOPs) that characterize the functional attributes of a successful portfolio.
- Determine the hierarchical relationship (ranking) between measures identified in the previous step (e.g., Utility tree, Bayesian Networks, Influence Diagram).
- Develop a set of metrics to assess the portfolio on how well it satisfies the list of derived MOPs (e.g., Percentage of the portfolio that aligns with each objective).
- Establish a threshold for each metric that determines the success of the criteria.
- Document the metrics and design an assessment template, along with rationale for decisions made, for future use. Model Portfolio Managers should keep in mind that the list of metrics is simply a collection of possible metrics to choose from; not all the identified metrics are required for analysis. Metrics may be developed and/or discarded throughout the portfolio's lifecycle due to shifting organizational objectives.

Sample portfolio performance metrics can be found in Table 3 under Appendix B.

3.9.11 Portfolio Risk Management

Portfolio risk management is a combined effort between the portfolio stakeholders and their organization's technical management team that manages risks. The Risk Manager, the individual who leads the organization's Risk Management team, is responsible for facilitating the integration of MPM risks into the Risk Management system. Both parties work concurrently to identify, analyze, mitigate, and monitor risks at the portfolio level. Prior to planning, it is important that MPM and the risk team understand where their responsibilities lie in managing portfolio risks. The following activities describe how MPM governs risk management:

- Coordinate with the Risk Manager to establish an approach for managing risks at the portfolio level. As further explained in Section 4.2.1, MPM is responsible for the identification and monitoring of portfolio-level risks. The organization's Risk Manager/Team is responsible for the analysis and mitigation of those risks.

- Establish a Portfolio Risk Management CONOPS that clearly lays out how parties will communicate and collaborate to manage risks at the portfolio level. This includes deciding what tools/software are required to maintain efficiency when sharing information back-and-forth. A portfolio risk registry, which is a collection of risks to be managed with respect to impact on the portfolio, should be planned and established here.

- The organization should refer to Sections 5.4.6 and 6.2 for guidance on MPM risk management identification and monitoring activities, respectively.

4. MPM PLANNING

The primary goals of the planning stage are to develop the MPM Plan and reach agreement on the management of portfolio components in scope, budgeting required to successfully execute components, identification of interdependencies between portfolio components, identification of risks and issues, resourcing requirements, prioritization of portfolio components, confirmation of governance body/sponsor and stakeholder accountability, portfolio metrics to measure success, the scope of components within the portfolio, and product and/or services requirements and specification. During this stage the identification of synergies and efficiencies across multiple levels of the organization are established. During the planning stage, the MPM Scope, Plan and Resources are identified [3].

4.1 DEFINE MPM SCOPE

It is important to have a well-defined scope for the portfolio. The starting point of the scope should be the portfolio components identified in Figure 3. The goal of this task is to establish boundaries of the portfolio and clearly define the depth and breadth of the portfolio of models. The scope of the portfolio may change with changes in the strategic goals and objectives of the organization and should be revisited regularly. The scope of the portfolio should be balanced against the available resources and expected benefits gained from the portfolio. The biggest risk posed by a poorly defined scope is scope creep, where the benefits of the portfolio may not be reached because of the scope becomes too broad compared to the available resources. In planning the scope, several activities must be addressed:

- Work with the stakeholders to identify and prioritize all the external requirements that the portfolio must meet. A requirements traceability matrix can be used to monitor progress towards meeting requirements from various stakeholders throughout the portfolio life cycle [11].

- Compose a well-defined scope statement, which is a written description of the portfolio scope, major deliverables, assumptions and constraints [11].
- Establish the Work Breakdown Structure (WBS) to divide the work required for the portfolio into tasks. Each task in the WBS will contain a unique identification number/code, description of the work and a responsible organization or individual [11].
- Define the roles and responsibilities of individuals, and teams on the project. All parts of the scope need to have a role assigned or the task may not be accomplished. This is commonly done in a Responsibility Accountability Matrix (RAM).

4.2 ESTABLISH MPM PLAN

The goal of the portfolio planning process consists of developing an MPM plan that is aligned to the MPM goals and objectives. The MPM plan defines the key components in the MPM Life Cycle and authorizes the allocation of resources. The plan provides the structure of the portfolio, which includes the hierarchy and organization of the models, programs, and projects within the portfolio. The plan also identifies the key enabling processes for portfolio execution. The contents of the MPM plan can be contained within a single document or several documents that address the following [4]:

- Alignment to the MPM strategic goals and objectives defined in Section 3.1
- Assumptions, constraints, dependencies, and external factors that may influence the portfolio
- Key Performance indicators and target metrics
- Policies, procedures, and guidelines
- Governance, change management, and quality considerations
- List of key stakeholders and communication needs
- Resources needed for portfolio management (costs, staff, training, etc.)
- Portfolio roadmap and key milestones
- List of identified risks and issues
- Scope statement that clearly defines what is in and what is out of scope

Refer to Appendix C for a recommended outline of the MPM Plan.

4.2.1 MPM Within Technical Management Processes

Technical Management (i.e., RM, CM, DM, etc.) generally uses organizational approaches to manage parts of individual models in a controlled environment. At a higher level, MPM seeks to manage those model parts that are critical to the model portfolio's success. There is a need for MPM to provide these Technical Management roles with items that fit the context of the portfolio such that there is little need for readjusting the respective Technical Management approaches. The organization(s) using this document should adhere to their respective Technical Management processes. Within these processes, MPM technical management items regarding the adoption, development, integration, and use of models in the model portfolio should also be managed. Therefore, MPM is responsible for the identification and monitoring of these items at the portfolio level and the organization's respective Technical Management Managers/teams are responsible for carrying out the processes. For those Technical Management processes acknowledged, this document adheres to the standards referenced in Section 2.

4.2.2 Model and Data Registry

The model registry is used to optimize the performance of a collection of models to fit the strategic objectives of the organization. Therefore, the portfolio of models is an output of the model registry. In planning the registry, several activities must be addressed:

- Identify the purpose of the registry.
- Identify key stakeholders and users of the registry.
- Establish a registry team. This team is responsible for managing and maintaining the registry throughout the MPM lifecycle. Relevant expertise, at the minimum, would include project management, database management, and quality assurance.
- Establish an oversight plan for the team to manage the registry. This includes administrative roles, data access management, and any other management activities expected from the registry team.
- Determine the scope of the registry with respect to the models and data.
- Determine the relevant data to support the purpose of the registry.
- Outline the objectives of the registry and determine how those objectives will be achieved.
- Establish the eligibility criteria for potential users of the registry.
- Establish data collection procedures.

An example of what a model registry may look like can be found in Appendix B: Samples.

4.2.3 Model Views Accession List (MVAL)

For models in the model registry, a digital view is accessible to relevant stakeholders who request to review model views, with the understanding that they may not yet be deliverable. A model artifact is a piece of information that contributes to the deployment of a model, while a model view organizes and visualizes the information in a digestible format. The MVAL is an index of model views made readily available for the

Model Manager. Specifically, the MVAL is a view that provides users with a visualization of model views, from the perspective of the portfolio's interests, that relate to the success of the portfolio. It is important to note that model views are artifacts (pieces of information) as seen from the MVAL, but for consistency the term "model view" will be used as applicable. To automate the transfer of information, the MVAL should be interoperable with the models and databases that contribute to the portfolio. The following activities should be reflected in the MPM plan:

- Identify a set of accession requirements that govern how model views are to be managed with respect to the MVAL.
- Identify those model views that are critical to the portfolio's achievement of strategic goals made by the organization. Associate what stakeholders may hold interest over the model views and how they may be viewed within the MVAL.
- Develop a model to capture relationships and interdependencies that exist among the model views within the MVAL. The goal here is to provide portfolio stakeholders with a visual representation of the model views that contribute to the success of the portfolio.
- Establish a model view description for each model view to be used in the context of the MVAL. This description includes the format, content, and intended use of the product in question. The description should reflect any changes made to the model configuration throughout its lifecycle.
- Assign accession numbers to model views in the MVAL to track accession information. An accession number should be used to identify a unique model view and provide a history of accession data (e.g., time, date, and person accessed).
- Generate reports based on accession number data for model views of interest on the MVAL.

A sample MVAL format can be found in Table 4 under Appendix B.

4.2.4 MODEL DATA ACCESSION LIST (MDAL)

For models in the model registry, working data items are accessible to relevant stakeholders who request to review model data, with the understanding that this data may not yet be deliverable. A data item is a portion of model data that can be considered an individual item in the context of the objective at hand and may include trade studies and analyses, test data, or even decisions and rationale made while developing the models, not to be confused with model artifacts that encompass a larger spectrum of information (such as meta-data). The MDAL is an index of generated data items made readily available for review by the Model Manager. Much like the MVAL, the MDAL is intended to provide portfolio stakeholders with model views of data items that contribute to the success of the portfolio. To automate the transfer of information, the MDAL should also be interoperable with the models and databases that contribute to the portfolio. The following activities should be reflected in the MPM plan:

- Identify a set of accession requirements that govern how data is to be managed with respect to the MDAL.

- Identify those data items that are critical to the portfolio's achievement of strategic goals made by the organization. Associate what stakeholders may hold interest over the data items and how they may be used within the MDAL.
- Develop a model view of each data item. Use models to depict relationships and interdependencies that exist among the data items within the MDAL.
- Establish a Data Item Description (DID) for each data item to be used in the context of the MDAL. This description includes the format, content, and intended use of the data in question. The DID should reflect any changes made to the model configuration throughout its life cycle.
- Track data items in the MDAL using accession numbers. Similar to the MVAL, an accession number is used here to track a data item and provide a history of data accession.
- Generate reports based on accession number data for data items of interest on the MDAL.

A Sample MDAL format can be found in under Table 5 under Appendix B.

4.2.5 Model Management Roles, Responsibilities, and Permissions

After having defined the stakeholder roles, interests, and expectations in Table 1 (p. 10), this information is used to plan the way model data is accessed by its key stakeholders. This task is necessary to avoid confusion and redundancy within the roles of the stakeholders with respect to accessing portfolio contents. The output of this task should clearly identify who the key stakeholders are and what actions to the portfolio they are expected to take. The following activities shall be established in the MPM plan:

- A set of roles that partition the stakeholders by desired level of access. These roles may be established based on the key stakeholders (i.e., Sponsor, Portfolio Governing Body, and Model Manager). For instance, the Model Manager would have more of a variety of permissions than the Sponsor, considering the Sponsor's role, interests, and expectations lie at a higher level.
- A set of responsibilities attached to each role with regards to managing the portfolio. A responsibility may be executed across different roles, or specifically designated for one role. The Model Manager decides how these responsibilities are delegated among the established roles.
- The set of functions that each stakeholder can perform with the granted access. The Model Manager may choose the CRUD (create, read, update, delete) operations to assign permissions to each role. For instance, the Sponsor would likely only need a read permission, whereas the Model Manager would require all the permissions, since they are working with the models and data directly.

4.3 MODELING RESOURCES

A modeling resource is any asset that a model or modeler can or must utilize to provide modeling capabilities. The goal of this task is to define the resources that may be required to make it possible to model within an organization. As capabilities or organizational goals change, the utilization of those modeling resources will undoubtedly be affected, so it is critical that those resources be properly defined to allow the flexibility to adjust to a dynamic environment.

While defining modeling resources, it is important to consider:

- Why and how certain resources are being used.
- What resources the modeling is dependent on (to perform basic functions, to perform advanced functions, to perform specific functions).

It is important to note, resources may be defined differently at the program or project level as the resources are being pooled and coordinated across the organization rather than in isolated spaces. This distinction should be understood early to minimize confusion. Expected outcomes of understanding modeling resources includes:

- Quick access to intra- and inter-connections related to models.
- Coordinated awareness between programs and projects.

Additionally, the organization should consider the implications heightened security locations may have on the ability to use or have the modeling resources.

4.3.1 MODELING SOFTWARE

The goal of this task is to define the resources directly related to the modeling software that may be employed. The following contains resources commonly found with commercial software:

- Client Software (desktop application, web service, etc.)
- Licensing (Floating Licenses, Dedicated Licenses, number of licenses)
- System Requirements
  - Operating System (Windows, macOS, Linux, etc.)
  - Display Resolution (1920x1080, 1024x768, none, etc.)
  - Disk Space (1GB, 3GB, 16GB, etc.)
  - Graphics
  - Other tools (Excel, Word, SQL, etc.)
  - Etc.
- Supported Virtual Environments (Citrix XenServer, Microsoft Hyper-V, Parallels Desktop, etc.)

- Integrated Workspaces (Servers, Clouds, etc.)

4.3.2 Plug-ins and Scripts

The goal of this task is to define the resources that extend the capability of the modeling software. It is important to note that these resources may also have their own software requirements. Below are some examples:

Plug-ins or Scripts:

- Visual Basic for Application (VBA) in Excel
- Formulas (in Excel, in MATLAB, etc.)
- Software Macros (Automated Generation, Automated Reading, Automated Manipulation, etc.)
- Software company provided (Toolbox, Add-Ins, etc.)
- Interfaces with other tools (Excel, CAD/CAM, PLM, etc.)

Regardless of how the plugin or script interacts with the modeling tool, an understanding of the following will help in categorizing the above resources:

- Communication Type (Web API vs. Web Service API)
- Coding Language (Python, Java, etc. if applicable)
- Coding Libraries (pandas, etc.)
- Cost (if commercial)
- Level of immediate usage (download and use, some setup required, requires specific integration)

There are as many scripts and plugins as there are functions and needs. Clearly creating distinctions in the context of the company's portfolio of models will be critical in organizing practical groupings of plugins and scripts.

4.3.3 Model Libraries

The goal of this task is to define the resources available for the model. The portfolio does not need to manage every individual library, but it should, at least, be aware of them to better coordinate the models within the portfolio. The use of "inform" is intentionally broad and the resources can be grouped into either of the following:

1. Inform through data (the model being built transforms or manipulates the data from sources):
    - Source Databases (Team servers, SQL, DOORS, Jama, Image repositories, etc.)

- Website Repositories (Space-Track, DOORS Next Gen, NanoSat Database, etc.)
- Local Directory List (Excel, Word, PDF, SQL, etc.)
- Output from other models (Fok Radiation Belt Electron Model, Analytical Models, etc.)

2. Inform through reference (the model being built is or includes a versioned instance of an existing model)

- Component Databases (SysML Classes, Simulink Block Library, etc.)
- Heritage Models (prior built models, based-on previous models, etc.)
- Public Reference Models (OMG SmallSat Model, Open-Source Algorithms, etc.)
- Proprietary Reference Models (Company/Corporate Reference Model, etc.)
- Government Reference Models (Acquisition Reference Model, Systems Architecture Model, Interface Reference Models, etc.)

5. MPM EXECUTION

The primary goals of the execution stage are to lead the delivery of all components within the portfolio, actively manage and resolve risks and issues across and within the portfolio and its components, facilitate portfolio and component communication, monitor benefits realization potential based on component delivery, and manage portfolio assets and resources limited to the portfolio. During this stage the identified synergies and efficiencies across multiple levels of the organization are realized. During the execution stage, the following activities are performed [3]:

5.1 ESTABLISH MODEL REPOSITORY (PHYSICAL AND LOGICAL)

The goal of this activity is to establish working zones for the descriptive or analytical models that have been or are currently being developed across the organization and precludes any integration between models that may happen. This provides developers and managers a consistent location to house their models, model extensions, and scripts.

Prior to establishing a model repository, the organization should do the following to determine synergies or efficiencies with existing infrastructure:

- Survey other organizational levels or partnerships for existing model repositories.
- For any existing repository, determine the scalability, maintenance requirements, and alignment to organizational purposes for the model repository.

If an existing model repository is not available or does not align with organizational needs, the organization should do the following while establishing one:

- Define the types of models prevalent throughout the enterprise; model types are minimally defined as analytical or descriptive and may also include CAD among others.
- Define the relationship that the models have with data (model is the data or model uses data).
- Identify each model's physical locations and why the models are located there.
- Define the resources necessary to create infrastructure (licenses, cloud technology, servers, etc.).
- Define the information technology resources necessary for the model to run.
- Define the owner and users of model repositories and their responsibilities.
- Define a plan (roadmap, criteria, process, etc.) to transition disparate models to the repositories.

At the stage where models are held at their respective repositories, the collection of these models can be considered a portfolio of models, but it has not been optimized for the interest of the organization. The models are being housed in common areas, but it is not until the relationships between the various models have been determined and a way to see across the common areas is made available that this portfolio of models has been optimized to provide actionable items. This gap is addressed by establishing a model registry.

5.1.1 Establish Model Registry

This is where the collection of models begins to become a portfolio of models optimized for the interest of the organization. The goal of this task is to understand what models are within the enterprise, regardless of their holding area, and provide a space to begin creating relationships between related or seemingly unrelated models.

Before creating the model registry, it is critical to:

- Understand whether the organization has models to warrant creating a managed registry (an inability to immediately list out models or if there are multiple sources of information may be a sign that a registry is needed).
- Understand what efforts exist to relate or integrate models and what implementation issues may exist between them.
- Understand what you want to do with the registry once it converges with the current state of the enterprise (consider the Portfolio Performance Metrics identified earlier in this document).

The registry is being built to answer specific questions the organization has about its models. Some capabilities enabled by the registry could include the ability to:

- Share modeling issues that may have common solutions and pair them with development efforts.

- Share consistent modeling issues that can be prioritized across efforts.
- Share modeling implementation plans to mitigate the risks across efforts.
- Share an understanding of resource allocation.

While creating the model registry, the organization should do the following:

- Define the users of this registry and their access; read-only, update.
- Define how users should access the registry.
- Define the process by which models are collated (collected or combined) and the resources to enable that.
- Define the process of maintaining current information within the registry.

The registry should include considerations for the following to help establish relationships between models or categorize them under common themes:

- Point of contact for each model
- Program, project, or team the model is supporting
- Customers or stakeholders of the model (government, commercial, internal, etc.)
- Purpose of the model (what questions the model is trying to answer?)
- Model Type (Descriptive, Analytical, Simple, Complex, research, prototype, etc.)
- Location of the model (Cloud, Server, URL, Local Computer, Third Party repository, etc.)
- Creation Date
- Current Status (Working model, Phase, Milestone, Version etc.)
- Users of model (the kind of individuals who would be using the model for their functional needs)
- Language of the model (MATLAB, Python, UML, SysML, etc.)
- Restrictions on the data (NDAs, Classifications, Proprietary, etc.)
- Current funding for modeling effort (Overhead, Direct Costs, R&D, etc.)
- Rate of spending on modeling effort

- Dependencies on other models or data sources for various reasons (Dependent, Output-to, Input-From, Generalization, Composition, etc.)

- Various other meta-data as determined valuable to linking models

A simple table of a model registry may be found in Appendix B.

5.1.2 Establish Model Accession list (MoAL)

For the model portfolio, working models, particularly models intended for multi-model integration, should be accessible to relevant stakeholders who request to review models, with the understanding that the integrated model is not yet deliverable. A working model is a component of the integrated model that has not been matured to the state where practical integration and data transfer may occur. This may include incomplete macros, incomplete data, unstructured sandboxing while developing the model. Similar to the MVAL and MDAL, the Model Accession List (MoAL) is an index, but focuses on creating an index of working models made readily available for review by model integrators. Specifically, the MoAL provides users a view of active efforts to integrate models before they are practically usable to support transparency and coordination for the success of the portfolio. To automate the transfer of information, the MoAL should be interoperable with the models within the portfolio. The process for establishing a MoAL includes the following activities:

- Identify a set of model requirements that govern how models are to be managed with respect to the MoAL.

- Establish a model item description (MID) for each model to be used in the context of the MoAL. This description includes the format, content, and intended use of the model in question.

- Track models in the MoAL using accession numbers.

- Generate reports specifying what model has been accessed, when, and by whom.

- Relate MoAL items with Model Repository (as possible).

5.2 IDENTIFY AND CONSOLIDATE MODEL VIEWS

Model views are visuals that have some dependency on a model and can be delivered to relevant reviewers. In most cases, one or more model artifacts will be used to populate a model view (becoming diagrams, tables, dependency matrices, etc.). The goal of this task is to understand the various products that may be delivered to customers and to prepare at the portfolio level to enable, support, and standardize them for consistent and effective communication.

5.2.1 Recognizing Digital Artifacts and Views

In modern modeling, model artifacts may be captured as digital artifacts. In general, digital artifacts are best understood within a digital environment (CAD prototypes, rendered environments from sensor input, point clouds, etc.) and would be impractically difficult to remove the digital artifact from its environment. It is important to note that unlike traditional artifacts that are seen as both documents and the data the document contains, digital artifacts exist only as data and require a visualization tool to enable the consumption of the information, otherwise known as a digital view. A suboptimal data format or an inability to properly visualize the data would result in a poorly constructed digital view, so managing both aspects before, during, and after the delivery of a digital view is key. This task is to understand the digital artifacts that may be an output of any activity within an organization and provide the model portfolio manager a list of efforts that set the groundwork for differentiating model artifacts from other types of digital artifacts while sharing those artifacts as views at all levels of the organization (including external customers).

Perform the following:

- Collate all digital artifact formats used, neutral or otherwise (e.g. basic matrices, *.obj, *ply, etc.).
- Survey modeling teams for digital formats used within their effort(s).
- Survey modeling teams for when digital artifacts were forced into suboptimal formats due to visualization constraints.
- Consider the interaction requirements to understand the digital artifact (kinds of sensory input, user instructions, etc.).
- Survey the digital views across a variety of criteria: most recognized, most used, most easily understood, etc.

5.2.2 CREATE MODEL VIEW IDENTIFIERS AND DESCRIPTION

This task outlines things to consider while organizing model views for advocacy within the organization for accessibility reasons or training incoming modelers. Although similar to the MVAL, it should be a way to coordinate with all members of an organization rather than just the portfolio manager. This will introduce a common language. At a certain steady state, there will be a list of model artifacts that are regularly referenced, while organizing the list, consider the following:

- Differentiate between model view identifier and name
- Describe the purpose of the model view
- Describe the customers of the model view
- Define the constraints of the model view

This practice will make it easier for automated tools to access the model views and extract the necessary model data.

5.2.3 UTILIZING FRAMEWORKS

Frameworks are a consolidation of communication avenues for a set of domains and are regularly updated to account for changes in the industry, the needs of the user base, and the prevalent technology. In the context of a portfolio, the organization could synchronize and standardize an organization's modeling efforts (either through recommending or mandating compliance) or provide better context to modeling practices to support modeling decisions. Regardless of the purpose, the following tasks provide support to initialize the portfolio of models' intent to utilize frameworks:

- List the frameworks used or recognized throughout the organization (e.g., UAF, UPDM, Modelica, BPMN, etc.).
- Determine the reason a framework is or is not used.
- Recognize patterns in usage (e.g., departments use certain frameworks, etc.).

5.2.4 Consolidating Custom Views

Custom views are the domain specific, stakeholder specific, or otherwise tailored views that help individuals (or group thereof) communicate the various aspects of a system that, to their knowledge, does not adhere to a standard. It may be convenient to dismiss these views as one-off or unique views that most likely would not be used elsewhere, but it is the responsibility of the portfolio to understand custom views that are not readily reusable today may be highly beneficial in the future. A member of the modeling team determined that this custom view (unseen elsewhere) was necessary to convey information to their customer and that determination should be recognized and archived. In time, the custom view or a suite of custom views may help to evolve standards internally or externally. The following process could be helpful in consolidating custom views and relating them:

- Recognize current avenues to consolidate custom views (e.g., reporting form, search function, etc.).
- Develop a Custom View ontology to type, group, or otherwise identify views.
- Consolidate the kinds environments and contexts that allows the custom view to exist.

It is important to recognize that although the custom views fill gaps from the bottom-up, the cyclic feedback between the portfolio and individual modelers is established and managed from the top-down.

5.3 MODEL ACQUISITION

5.3.1 Model Quality Assessments

Model quality assessments should be conducted per existing quality processes of the organization, any deviation from the organization's quality processes should be documented in the MPM Plan. Model quality assessments may be a valuable measure of model quality to help the Model Manager, Model Portfolio Manager, Portfolio Governing Body, and other stakeholders identify areas of concern when models are acquired or developed. The goal of such assessments is to reduce the risk of integration that would require considerable additional work to integrate models into the portfolio. By verifying that modeling standards and guidelines are met, the Model Portfolio Manager may ensure that the integration and maintenance of the models within the portfolio are not prohibitively difficult or costly. The ability of model providers to comply with quality standards will aid in model integration. Assessment details need to be determined given the specific needs of the portfolio guidelines and standards. The quality of a model is not the same as the quality of the design the model represents. The assessment of model quality is often done in terms of adherence to modeling guidelines [9]. Section 3.9.4 establishes which modeling standards, policies, and practices are applicable to the portfolio and how they are tailored to meet needs.

5.3.2 MODELING ASSURANCE LEVELS (MALS)

Higher Model Assurance Levels (MALs) provide higher value and reduced risk. Using the MAL scale, the more technical model depth, the higher the model quality. Models may be rated on a scale from 1.1, "Sparse Conceptual Models" to 3.8, "Advanced Allocated Model used to drive implementation testing" [12]. MALs are like Technology Readiness Levels (TRLs) that result from a Technology Readiness Assessment, as a higher MAL provides a general sense of the quality like how a higher TRL provides a sense of maturity. MAL scores are quantitatively determined based on the following MAL Quality Attributes:

- General
- Requirements
- Structural Content
- Behavioral Content
- Data Content
- Non-functional Requirements Modeling
- Vulnerability
- Validation and Verification (V&V) Performed
- Authoritative Source of Truth (ASOT)

The MAL Quality Attributes are further divided into MAL Characteristics and scoring is done against the MAL Detailed Criteria. The MAL score for the model is a weighted aggregate score from all subsystems within the model that is baselined. For additional details on how MAL scores are obtained see [12]. MAL assessments can be performed to:

- Determine if goals for modeling were met.
- Monitor progress by performing multiple assessments through the model lifecycle (e.g. Preliminary Design Review (PDR) and Critical Design Review (CDR)) to determine if the model is progressing.
- Identify and manage risks associated with the model.

An Aerospace Technical Report (ATR) can be found in the references for additional information on MALs. [12] [13].

5.3.3 Modeling Metrics

Section 3.9.10 outlines the process for developing a set of key performance parameters and metrics that determine the portfolio's performance. With the established metrics, the portfolio is assessed based on how well its models combine to meet the need(s) of the organization. The following activities are included in measuring the success of the portfolio:

- Use the established organizational objectives, success criteria and factors, and metrics to assess how well the portfolio fits the need(s) of the organization.
- Explore root causes for cases in which the portfolio fails to meet a certain objective or need.
- Identify individual models that contribute to the portfolio's failure to perform as expected.
- Collaborate with model developers and other model stakeholders to establish a plan for either retiring the model or increasing its capability to meet the need of the organization.
- Reassess the portfolio once the necessary adjustments have been made.

5.4 PREPARING FOR MODEL INTEGRATION

The MPM goals of this activity are to:

1. Examine the models for model taxonomy, meta-models, patterns, model standards, to set portfolio targets for future model adoption and development that will optimize the efforts.
2. When connecting models to create a digital twin or digital thread, ensure that the connecting models have compatible taxonomy, meta-models, and model standards.
3. Ensure that when performing model integration or assembly, proper approaches are taken for model comparisons and merges (i.e., iterative and conservative import/export, synchronizations and use the concept of identifying differences and merging the resultant features).
4. It is important to note that integration does not necessarily mean the models are dependent on one another. The models may evolve individually. The integration of models allows models to more easily leverage one another as transformation nodes for the actual data.

5.4.1 Model Integration Criteria

The goal of this task is to define the entry criteria of when models within the portfolio may be integrated. These criteria are largely driven by the functional demand of the organization and should be coordinated with the Portfolio Governing Body but can be limited by the data structure or tools used throughout the portfolio.

Establish a model integration criterion. The following are use cases for integration between two (or more) models within the organization, where a merged model replaces the component models that build it while an appended model has a facilitated dialogue with another model:

- Merge when models have no prior knowledge of each other
- Merge when models have prior knowledge of each other
- Append when models have no prior knowledge of each other
- Append when models have prior knowledge of each other

To develop the criteria, systematically understand the pros and cons of the following in the context of one (or more) of the above use cases:

- The processes developed to transfer information and the reason they exist
- Instigator of integration request (modelers vs. managers: at any level)
- The company's priority in the above use cases
- The natural style of model development within the company
- Limitations from data structures
- Limitations from tools

The criteria could also include basic information such as:

- Minimum or maximum model maturity to prevent excessive or unnecessary integrations
- An identified need from a coalition of stakeholders, modelers, or management

5.4.2 CREATING MODEL INTEGRATION RESOURCES

The goal of this task is to develop the resources to support the integration of models at a scale which benefits the portfolio such as reducing repetitive work, coordinating efforts in a synchronized manner, or reducing start-up needs for new programs. The following are listed to provide Model Portfolio Managers an idea of the efforts that can begin from the Model Portfolio Manager seat.

Implementing standardization (to coordinate modelers):

- Ontology (defining key objects and the relationships between them and their alternatives)
- Form of data exchange (e.g., Point-to-Point, centralized, language, etc.)
- Tool structure (e.g., data organization, Application Programming Interface (API), etc.)

- Create a plan for the evolution of model fidelity (e.g., how the models or resources can evolve to include more complexity without damaging the integrity of the integration)

Implementing integrated model workflow plans (to coordinate between resources):

- Resource allocation (hardware, funding, etc.) timelines (e.g., Space-Track.org limits query requests per User, Cluster Simulation requests, License Utilization, etc.)

These resources may exist at varying levels and as disparate portions. It would be the responsibility of the portfolio manager to understand the degree to which each of the items listed above are developed and why.

5.4.3 INTEGRATING MODELS AT MULTIPLE SECURITY LEVELS

The goal of this process is to identify or set patterns between security levels and leverage them to share as much information as possible to the various levels while maintaining the integrity of the models. The following tasks are conducted to isolate patterns relevant to the company's security needs, so that efforts can begin to address them:

- Identify the degree to which data is held within each of the models in the portfolio (e.g., data is only input or output from a model vs. a model holds a copy of the data).

- Identify the accessibility of a model to a security infrastructure (e.g., whether the model has implementations in place to access credentials or security keys either automatically or manually).

- Identify patterns of data integration that elevate the security level (e.g., project name (L1) + location (L1) = project name and location (L2)) and how they exist within models.

The above tasks give the portfolio manager the minimum tools to begin to integrate models across security levels by codifying the capability a model must be broken apart and interact with itself and others. Solutions can be thereafter created to secure the data and models across all the models within the portfolio. The following presents additional considerations to evaluate the efficacy of model integration with respect to the security infrastructure by questioning whether the portfolio can:

- Choose to portion mark models or restrict entire models (understanding whether a dedicated closed team or a multi-level team with delegated responsibilities can function).

- Choose what information can move from one level to the next (the codification of security rules that models can understand is critical).

5.4.4 MODEL DATA INTEGRATION

The performance of the models is heavily dependent on the ability to obtain valid data. Each program will have consolidated and vetted information relevant to their needs. It will be up to the portfolio to understand where information can be consolidated for repeatable use across existing and incoming programs. Seen from a portfolio level, integrated models are the linking of transformation nodes and the models should not be mistaken for source data that would otherwise be found in databases or libraries. The following tasks are meant to consolidate data sources to maintain the validity of the modeling activities across the portfolio:

- Identify all the sources of data that are being fed into existing models (e.g., articles, online databases, other analyses, etc.).
- Identify the primary sources of data and understand whether the model is acting as a secondary or tertiary source for users (depending on the piece of data, it could be either secondary or tertiary and a clear understanding will help when integrating models or data).
- Determine what data requires a corporate database and what data is well hosted externally.
- Determine to what level of detail the data should be presented at each level of a program.
- Determine the hierarchical relationship (ranking) of different sets of data and develop a taxonomy that resonates with the users.
- Develop documentation to properly utilize the integrated data and support a cultural shift to using the corporately vetted database.

5.4.5 PREPARING AN ENVIRONMENT AND ROADMAP FOR INTEGRATED MODELS

The goal of this task is to ensure an adequate environment is provided when integrating models with the portfolio. This includes, but is not limited to, tasks to consider what is necessary to support a model(s) utilized in a distributed manner.

Make considerations for the following while creating a roadmap and building the portfolio environment for an integrated model(s):

- Maturity of models (i.e., the level to which the model is representative of a system, can provide/generate views, or is deliverable to stakeholders)
- Geographic distribution of workforce (messaging or communication systems)
- Temporal distribution of workforce (modelers will interact with models at different times)
- Model(s) hosted on various networks (isolated, external, or otherwise) and their access restrictions
- License/Tool Access due to network, location, IP Domain, etc.

Understand current capabilities in building point-to-point or hub-and-spoke integration to better understand its potentially compounding effects on the portfolio:

- Timelines (design – development – delivery)
- Resources (funding, expertise, etc.)

- Maintenance of integration (monitoring, evaluating, updating)

5.4.6 PORTFOLIO RISK IDENTIFICATION

Portfolio risks can be categorized under three different types: model risks, portfolio-level risks, and model interdependency risks. Individual model risks are identified and managed by respective individual model stakeholders, thus making MPM responsible for identifying portfolio-level and interdependency risks. According to the PMI Standard for Portfolio Management, portfolio-level risk is that which, should it occur, may affect the portfolio success criteria. The consequences of a portfolio-level risk may lead to an increase in the probability that the portfolio success criteria are not met, thus putting the success of the portfolio at risk. Additionally, although a portfolio can show signs of success when interdependencies exist among its models, the complexities that arise from these interdependencies can create risks of their own. The following activities are described to identify portfolio-level and interdependency risks:

- Compile historical data for capturing risks at a portfolio level and incorporate it into the overall approach.
- Identify common or potential risk sources that may contribute to the increase in probability of risk occurrence.
- Identify the appropriate portfolio management objectives. These may include objectives such as value maximization, strategic alignment, balance of models, and right number of models.
- Identify the appropriate portfolio success factors. These may include factors such as quality of information/data, inter-project ability, and competency.
- Develop a list of portfolio-level risks based on the threat proposed to the portfolio success criteria and the probability that the success criteria will not be met due to the proposed threat.
- Develop a list of interdependency risks based on the complexities that exist among interdependent models in the portfolio of models.
- Populate the identified risks into the risk registry.

Sample portfolio-level risks can be found in Table 7 under Appendix B.

5.5 CM OF MODELS IN THE MODEL REGISTRY

As with risk, MPM also holds the responsibility of identifying configuration items (CIs) at the portfolio level. A Model Configuration Item is a model product, or artifact, that needs to be managed for an IT service. To bring Configuration Management (CM) up to the portfolio level, MPM must identify those model deliverables that come together to meet a strategic objective, which are defined as portfolio CIs. The interdependencies of model assets within the portfolio contribute to the achievement of organizational strategic objectives.

Therefore, these interdependencies serve as the basis for the success of the portfolio, and any changes made to these items without proper control present major risk. Executing MPM includes identifying those portfolio CIs and moving them up to the organization's CM Database (CMDB) for control. The following activities describe the role of MPM within CM of the models in the model registry:

- Identify a list of CIs that will contribute to the success of the portfolio by achieving certain strategic objectives.
- Develop a list of Key Performance Indicators (KPIs) to evaluate each portfolio CI for its completeness, compliance, and correctness. The result of this analysis should communicate the health of the CMDB in the context of the portfolio.
- Define baselines that characterize portfolio CIs as they matriculate through the CM process. These thresholds should be analyzed and monitored by MPM in conjunction with CM.
- Register the identified CIs with the CMDB.
- Record attributes, relationships, and dependencies between the identified CIs.
- Review and verify that all configuration requirements (separately defined by the configuration team) are satisfied by the identified CI information.
- Establish a method to monitor to the portfolio CIs concurrently with the configuration team to ensure that the CMDB maintains the validity of the configuration and the accuracy of items in the system.

Monitoring of the portfolio-level configuration items and associated activities are described in Section 6.4.5

5.5.1 Model Configuration Items

The digital twin, and digital threads are examples of a model configuration item where they are a logical part of the model that is maintained in a controlled fashion; i.e., have a trackable revision history [5]. Management of these model configuration items is made more complicated if the digital twin or digital thread extend across more than one model.

5.6 MODEL MANAGEMENT ACCESS

Recall from Table 1 that the key stakeholders of MPM include the Sponsor, Portfolio Governing Body, and Model Manager. To ensure cohesion and transparency, the Model Manager establishes model and model data access for all key stakeholders who require some level of involvement with program model development. The Model Manager decides which stakeholders (at the portfolio level) are given access to models and model data, as well as what functions and capabilities are available for those who are granted access to the portfolio. Executing model access is described by the following activities:

5.6.1 ROLES

- Determine what model artifacts and data should be available to other parties for access. Consider the stakeholders' interests and level of involvement in the model portfolio.

- Implement the established roles from Section 4.2.5 into the access control database and assign the roles to the relevant stakeholders.

- Add, delete, or change roles as necessary.

5.6.2 PERMISSIONS

- Use the established responsibilities for each role from Section 4.2.5 to assign the relevant permissions to each role in the access control database.

- Add, delete, or change permissions as necessary.

5.6.3 COMPETENCIES

- Determine what competencies are inferred from the established roles. The roles, permissions, and expected use of the two should be clearly established and understood by the stakeholders. To understand what and where competencies lie, consider the following questions:

  - What does the stakeholder need to know how to do to perform the operation?

  - Is the stakeholder capable of performing the operation?

  - Which stakeholder is expected to perform which operation and for what reason?

6. MPM MONITORING AND CONTROL

The goals of the MPM monitoring and control are to assess portfolio performance and recommend changes to the portfolio to meet organization modeling needs and ensure compliance with standards. The purpose of monitor and control is to make changes to optimize the portfolio of models and the portfolio management process based on results performance metrics and risks. This process includes the following elements [3]:

6.1 MPM METRICS

Key Performance Metrics are used in conjunction with business management tools to support the management of the portfolio of models. As explained in Section 5.3.3, the Key Performance Metrics are used to assess the success of the portfolio with respect to achieving the organization's strategic objectives. To monitor the portfolio's success over time, MPM should use the metrics to continuously assess the portfolio's performance over an established iterative process by repeating the steps listed in Section 5.3.3. By doing so, the model portfolio will maintain its intended functionality and continue to meet the organization's need. Additionally, performance areas that are not well achieved throughout the portfolio will be diagnosed and addressed through maintenance.

6.2 PORTFOLIO RISK MONITORING

MPM works in tandem with the risk team to monitor the lifecycle of portfolio risks in the registry following the implementation of mitigation tactics. MPM performs tasks to sense changes in the risk registry, track mitigation progress, and ensure that the risk registry is updated appropriately. The process of monitoring portfolio risks is described by the following activities:

- Maintain a view of the risk registry that only shows portfolio-level and model interdependency risks. This view is produced by the risk team to establish a concurrent working environment such that MPM officers may track changes made to the portfolio risks along their lifecycles.

- Conduct periodic audits to assess the risk mitigation process and its effectiveness. Evaluate the threat level and probability of occurrence for each risk item before and after mitigation takes place to evaluate the effectiveness of the mitigation strategy.

- Conduct periodic audits to ensure that portfolio risks are properly updated in the registry. Assess where the risk item is currently in its lifecycle and compare the status to the documentation provided in the registry. Ensure that the documentation reflects the risk item's current status.

- Monitor the portfolio for mitigated risks that may redevelop over time and alert the risk team of any early warnings.

Portfolio risk monitoring is an ongoing task as the portfolio develops over time. MPM should use risk monitoring activities to analyze the health of the portfolio and see to it that portfolio risks, as they are identified, are periodically approached with mitigation tactics. Should a portfolio risk be eliminated, MPM should continue to monitor the portfolio for symptoms that may indicate risk reoccurrence.

6.3 PORTFOLIO OPTIMIZATION

Optimization is the process of making a portfolio as effective as possible by maximizing available conditions, constraints, and resources. The Model Portfolio Manager identifies the optimization goals, approaches, and metrics. Typically, the primary goal of portfolio optimization is to ensure that the available human, material, and financial resources are best applied to the appropriate remaining components of the portfolio [3]. The following is a list of ongoing major activities to continuously optimize the portfolio of models:

- Adjust portfolio resource capacity.

- Balance resource allocation to meet portfolio objectives outlined in the MPM Plan.

- Conduct portfolio level lessons learned and share experiences.

- Review and update portfolio governance documents based on lessons learned.

- Revisit value metrics to identify opportunities for improvement.

- Realign the portfolio-based changes in business strategy.

As organizational objectives shift, portfolio optimization should sense and respond to such changes. It is important for MPM to reevaluate its optimization strategy periodically to confirm alignment with the strategic objectives of the organization.

6.4 MAINTENANCE OF MODELS

The goal of the following processes is to consider the efficient maintenance of models from the perspective of the portfolio of models. The portfolio of models may not be directly related in the actual maintenance of the models, but it will be involved in setting up tools, processes, and networks to quickly transition many models as necessary.

6.4.1 MONITORING AND UPDATING MODEL VIEWS

The goal of this process is to put systems in place to monitor the reception, usage, and delivery of model views and recognize when support for visualization processes, particularly from models and model data across the portfolio, may be necessary. This portfolio-level process is meant to monitor the kinds of views being distributed internal and external to the organization and respond pre-emptively to changing corporate goals or customers. That information could be used to evaluate the data, at minimum, in the following parameters:

- Efficacy of views to convey intent and information
- Changing patterns of view usage (either from or to customers)

The following are data points that would be useful to monitor at minimum:

- Base view type (dependent on views defined by organization and stakeholders)
- Source of view (created from model data or received from customer(s))
- Delivery or reception date
- Frequency of access (if publicly available)

The following activities support a start to monitoring model views:

- Define the intent of monitoring views
- Baseline the company’s current capability to monitor views to and from customers
- Evaluate the baseline against intent and define a roadmap to evolve monitoring capabilities
- Communicate with modelers and program managers for monitoring usability (usability is critical to maintaining current information rather than being unused and forgotten)

After an ability to monitor model views is possible, the portfolio manager needs the ability to update model views and keep them relevant to stakeholders. The following activities describe what the portfolio manager can do [14]:

- Define the decisions that models support
- Survey decision-makers for visualization preferences (functionally)
- Collate the data transfer processes from data to models to visualization (and map them)
- Determine the transfer volume between current supported capabilities
- Determine the scalability of existing data transfer
- Define a roadmap to increase volume of visualization that remains understandable to decision-makers
- Define metrics to evaluate visualization tools

The following outcomes should be available as a result of a successful implementation of the activities:

- Consistent and evolving support to decision-makers
- Model Visualization Roadmap
- Mapping of current model (or data) to visualization capabilities enabling alternate visualization routes

6.4.2 Recognize Model Data Management Needs

The goal of this task is for the portfolio of models to recognize the resources necessary to manage model data, particularly as the model data is delivered or converted. At the portfolio-level, the creation and reading of individual model data is less critical than the ability to make the model data available to whomever or whatever asks for it. This requires an understanding of the model data's structure and maturity. The following are a list of activities to support that [14]:

- Survey the types of model data prevalent among models
- Survey the tools that use any form of model data
- Map model data to tools and identify gaps from tools to types of model data
- Determine the frequency of use between specific tools and types of model data

The following is a list of activities to evaluate the infrastructure:

- Evaluate the practices or processes in place to monitor model data in place, in transit, and public distribution
- Evaluate the hardware and software that models (and the data) currently use. Compare with the minimum necessary to perform cross-model evaluations

6.4.3 Model Data Consistency

The goal of this task is to put processes in place to isolate discrepancies, resolve discrepancies, and propagate changes to model data, so that individual models are consistent with their data sources and each other, regardless of whether the models are integrated or not. The monitoring and resolution processes are described in the following activities:

- Survey model data sources, model data identifiers (names, etc.), model data description
- Define model data terms and distinguish them clearly (e.g., “Estimated Launch” vs. “Actual Launch,” but a single “Launch” field exists)
- Define discrepancy resolution processes (e.g., hierarchy of sources, splitting or merging, significant figures, etc.)
- Define data change processes in conjunction with programs or as a default from the portfolio of models
- Determine key metrics for consistency (evaluating every data point is the responsibility of the individual programs and modelers)

6.4.4 Adjusting Model Libraries

The goal of this task is to understand when adjustments to how the portfolio interacts, utilizes, or coordinates with model libraries may be necessary. As discussed previously, model libraries are assets (whether internal or external) that inform the model in a variety of ways and can include archived models that act as reference. The following are a list of continuous activities to support this task:

- Monitor usage (e.g., time stamp, access frequency, number of models reliant on, etc.) of libraries to isolate areas needing increasing attention (i.e., a library showing consistently high usage could represent a level of trust from engineers and modelers or an overly high reliance on a single source showing decreased resilience if the library is compromised)
- Control access for external model libraries (e.g., Space-Track.org limits access frequency)
- Monitor access to internal model libraries (e.g., increased access to a library deserves higher funding for maintenance)
- Consolidate/Merge model libraries of similar functions

- Coordinate transitions between utilized model libraries when capacities are strained

6.4.5 Model Configuration Management

The configuration management of portfolio CIs is monitored through verification and auditing to ensure accuracy, completion, and documentation among all configuration activities. Configuration verification includes routine monitoring of other processes within the MPM process to confirm that the configuration management process is functioning properly. Auditing warrants a periodic, formal self-assessment used to maintain the integrity of the CMDB. MPM should use the KPIs developed from Section 5.5 to help with this process. The configuration verification and auditing process is described by the following activities:

- Compare baselines and standards with actual components in the IT environment
- Verify that each portfolio CI has a correct and authorized version
- Verify the physical location of each portfolio CI
- Verify that the current environment of the portfolio reflects what is documented in the CMDB
- Verify that all change requests have been resolved
- Verify that portfolio CI specifications comply with established configuration policies
- Validate that all required documentation is available for each portfolio-level configuration item

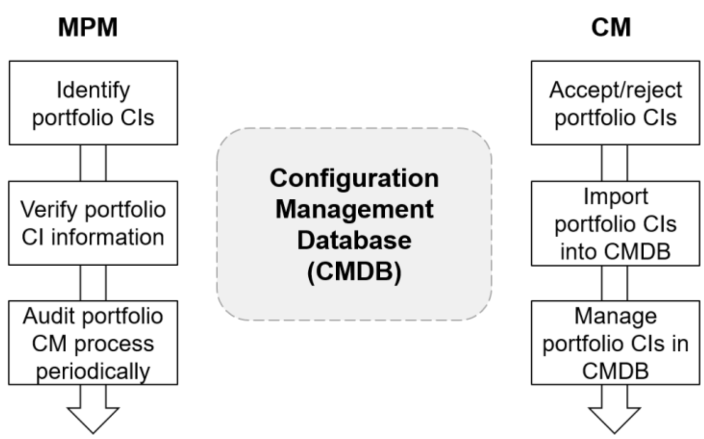

Figure 5. Responsibilities of Portfolio CM

Recall that MPM is initially responsible for identifying only the portfolio CIs. Figure 5 illustrates the responsibilities of both MPM and CM in the context of managing portfolio CIs. Verification and auditing fall under the responsibility of MPM as CM controls the portfolio CIs concurrently. Like portfolio risks, portfolio CIs should be monitored on an ongoing basis.

6.4.6 MODEL REUSE

Establishing a model reuse program is useful for optimizing modeling efforts by creating a repeatable process for future use. The organization may identify certain patterns of interest for which parts of the portfolio can potentially be reused. In order to reuse existing models consistent with the specified patterns, the organization must capitalize on reusable models, methods, and tools. The following activities describe the capitalization and reuse of existing models.

Establish a reuse plan:

- Specify the goals and context of the reuse program.
- Identify a team of reuse engineers to lead the program.

Establish a reuse registry:

- The purpose of this registry is to store data, models, and views selectively curated for reuse. Users of the registry should be able to:
  - Classify models from different sources and store them.
  - Store extracted and refactored models.
  - Manage changes and versions of reused model data and views.
- Establish a set of quantitative metrics that indicate the reusability of models in the reuse registry. For example, reuse metrics can be used to analyze potential reuse models based on factors such as cost-benefits, maturity, or frequency of expected reuse. Establish a benchmark for the metrics that separates the reusable models from the non-reusable models.

Perform reuse analysis:

- Identify patterns in models that present opportunity for capitalization. Start by collecting models from different sources that may relate to organizational need(s) and defining common patterns and variations. Create meta-data models to represent these patterns.
- Extract individual and interdependent models from the portfolio that fit the identified patterns. Store them in the reuse registry.
- Refactor the selected models to adapt to the patterns. Store them in the reuse registry.
- Apply the established reuse metrics to the set of models in the reuse registry. The result of this analysis should be a set of models that achieve at least a satisfactory score in terms of reusability.

Capitalize on modeling methods and tool extensions by performing the following tasks:

- Investigate methods used to develop the models intended for reuse.
- Write guides to standardize the modeling methods. This may include a list of modeling languages and standards used to develop the models.
- Publish method guides for reuse along with required training.
- Investigate tool extensions developed for models in specific contexts.
- Adapt the tool extensions to fit similar models for reuse.
- Provide a list of tool extensions and contexts available for reuse.

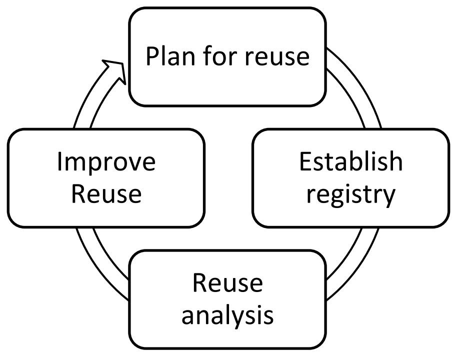

Figure 6. Model Portfolio Reuse

Model portfolio reuse should correlate with portfolio optimization. Reuse engineers should continuously sense changes in optimization strategy as organizational objectives shift and develop plans to capitalize on existing models, methods, and tools as necessary.

6.4.7 Model Retirement and/or Archive

Portfolio models that are proven to be obsolete are subject to retirement and archive. The retirement process is thoroughly documented. To ensure accuracy among models, certain older versions may be retired. Supporting older versions is sometimes unnecessary and can cause confusion among model consumers. The process for retiring and archiving models in the model registry is described by the following activities:

- Establish a classification method that identifies retired models as “retired” in the model registry.
- Establish a digital location to archive retired models.
- Establish a process for recommissioning retired models.
- Identify the candidate model for retirement. Document the justification for retiring the model and report the rationale to the portfolio owner.

- Assess the impact of the potential absence of the retiring model from the portfolio. Will the model be replaced with an updated version? Is there no longer a need for the model, or any further versions of the model? Verify that there is no longer a need for the candidate model in the portfolio.
- Validate the completeness and correctness of the retiring models.
- Retire expired models from the model registry and update the database with the newer model versions. Make sure that it is evident to the users that the newer version shall be used.
- Store retired models in the digital archives.
- Monitor access and any actions taken on the retired model views.

The contents of the portfolio may change as frequently as the portfolio need changes. Therefore, it is important to establish a retirement and archive process for storage purposes as models are added and removed from the portfolio to fit strategic objectives.

Appendix A. **GLOSSARY OF TERMS**

Analytical Model	Primarily quantitative or computational in nature and represents the system in terms of a set of mathematical equations that specify parametric relationships and their associated parameter values as a function of time, space, and/or other system parameters [7].
Criteria	A principle or standard by which something is judged or decided upon [15].
Descriptive Model	Describes a system or other entity and its relationship to its environment. It is generally used to help specify and/or understand what the system is, what it does, and how it does it [7].
Digital Artifact	Any combination of professional data, information, knowledge, and wisdom (DIKW) expressed in digital form and exchanged within a digital ecosystem [16].
Digital Thread	Digital Thread refers to the communication framework that allows a connected data flow and an integrated view of a physical asset's digital data throughout its lifecycle cutting across traditionally siloed functions [from CIMdata]
Digital Twin	An integrated digital representation of a physical entity, system, or enterprise that can be used to understand and predict its capability, use, status, or performance. [The Aerospace Corporation] The digital twin is a high-fidelity model of the system which can be used to emulate the actual system [INCOSE Systems Engineering Body of Knowledge]
Digital View	A visual presentation on an electronic display device of one or more processed digital artifacts, enabling the consumption of digital artifact content according to stakeholders' unique activities at any phase or step in the system lifecycle [16].
Digital Viewpoint	A digital view that uses conventions, formalisms, and standards to define the systematic procedures to select, compile, lay out, and present digital artifacts in a digital ecosystem such that it meets stakeholders' unique needs [16].

Discipline Specific Model	A Discipline Specific Model is an interconnected set of model elements which represent a single discipline.
Enterprise	A complex, socio-technical system that comprises interdependent resources of people, information, and technology that must interact to fulfill a common mission [17].
Governing Body	A group of individuals who formulate the policy and direct the affairs of an institution in partnership with the managers, especially on a voluntary or part-time basis [18].
IT Infrastructure Management	The administration or control of the information technology environment to enable digital engineering and model-based activities within an organization. This includes managing access to the general environment, regardless of access to the individual models.
Lifecycle	The series of phases or changes in the life of an object or process.
Management (Manager)	The administration or control of all or part of a company, organization, or grouping. (The person responsible for…) [19].
Maturity	Maturity refers to the state of something on its evolutionary curve. NOTE: The thing is considered immature if there are still flaws that prevent users from benefitting from the thing.
Metric	A system of standard of measurements [20].
Model	A representation of some concrete or abstract thing of interest, with a specific purpose in mind. The model is related to the thing by an explicit or implicit mapping [21].
Model Artifact	Any combination of professional data, information, knowledge, and wisdom (DIKW) expressed in model form and exchanged within a model-based ecosystem. [Extended from Digital Artifact]
Model Configuration Item	A Model Configuration Item is a logical part of the model that is maintained in a controlled fashion; i.e., have a trackable revision history [5].

Model Data	Data either retained within the model and representative of the system of interest or utilized by the model to perform transformation functions. Distinguished from meta-data, data that describes the model itself.
Model Intent	The intent by which the model was created for. This is usually represented by the question that the model is trying to answer
Model Management	The administration or control of the model that supports the development of a product or service with particular attention to immediate needs.
Model Performance Analyst	Responsible for how the model represents the subject with respect to performance (e.g., mission and operations – validation, requirements – verification, etc.)
Model Portfolio Management *(Manager)*	The administration or control of a collection of models, the purpose of which, is to achieve strategic objectives with particular attention to utilizing organizational resources in an efficient manner. (The person responsible for…)
Model Portfolio Management Lifecycle	A continuous set of activities that is recommended to be performed by Model Portfolio Managers for the Model Portfolio Management process to be successful.
Model Portfolio *(Portfolio of Models)*	A collection of models (whether descriptive or analytical, related or otherwise) that have been grouped together and where the evaluation of that collection has been identified as being critical to evaluating the organization's investment strategies.
Model Technologist	Responsible for technology selection criteria, awareness, and recommendations
Model View	A visual presentation of one or more processed model artifacts, enabling the consumption of model artifact content according to stakeholders' unique activities at any phase or step in the system lifecycle. [Extended from Digital View]
Model Viewpoint	A model view that uses conventions, formalisms and standards to define the systematic procedures to select, compile, lay out, and present model artifacts in such that it meets stakeholders' unique needs. [Extended from Digital Viewpoint]

Portfolio	A collection of projects or programs or other work grouped together to facilitate effective management of work to meet strategic business objectives. The projects or programs of the portfolio may not necessarily be interdependent or directly related [22].
Portfolio Components	The collection of models along with the associated data at all levels within the scope of the portfolio.
Portfolio Management	The administration or control of a set of products or services to achieve strategic objectives with particular attention to utilizing organizational resources in an efficient manner.
Practice	The actual application or use of an idea, belief, or method as opposed to theories relating to it.[23].
Principle	A fundamental truth or proposition that serves as the foundation for a system, belief, idea, or chain of reasoning [24].
Process *(Procedure)*	A series of actions or steps taken in order to achieve a particular end [25] [26].
Program	A group of related projects managed in a coordinated way to obtain benefits and control not available from managing them individually. Programs may contain elements of work outside of the scope of the discrete projects in the program [27].
Program Management	The administration or control of a set of products or services categorized by a common organizational goal or strategy with particular attention to timelines and optimization within the program.
Project Management	The administration or control of a product or service with particular attention to quality, development, and capture of knowledge.
Stakeholder	An individual or organization with a right, share, claim, or interest in a system or in its possession of characteristics that meet their needs and expectations.
System Model	A system model is an interconnected set of model elements which represent key system aspects including its structure, behavior, parametric, and requirements.

Technology Readiness Assessment	A systematic, metrics-based process that assesses the maturity of critical technology elements, such as sustainment drivers [9].

Appendix B. **SAMPLES**

Communication Matrix

The communication matrix is a listing of the communication needs of the portfolio. It lists the information to be communicated, frequency, recipients, and methods used for communicating. The table below is a sample set of information that may be part of a communication matrix for the portfolio.

Table 2. Sample Communication Matrix

Communication	Frequency	Recipient(s)	Method(s)
Governance Decisions	Quarterly	Sponsor Governing Body	Governing Body Meetings
Dashboard	Monthly	Sponsor Governing Body	Governing Body Meetings Intranet portal
Performance Reports	Monthly	Sponsor Governing Body Portfolio Stakeholders	Governance Meetings Email Distribution Intranet portal
Risks and Issues	Monthly	Governing Body Portfolio Stakeholders Model Managers	Email Distribution Intranet portal

Portfolio Performance Metrics

Portfolio performance metrics are directly connected to the portfolio's ability to achieve the organization's needs and objectives. Therefore, portfolio performance metrics are unique to their respective organization. The table below lists a sample set of metrics to assess the portfolio's performance.

Table 3. Sample Portfolio Performance Metrics

Metric	Metric Type
Total number of models in the portfolio	Integer
Number of model interdependencies	Integer
Number of models (organized by model type)	Integer
Number of models (organized by satisfied organization objectives)	Integer
Alignment with organization objectives	Grading Scale
Number of portfolio use cases	Integer
Accuracy of model data	Percentage
Diversity of target audience (organized by discipline/COI)	Percentage

The assessment criteria must be documented and justified for each established performance metric. This eliminates any ambiguities that may arise when the assessment takes place.

Model View Accession List

The MVAL is meant to serve as an index for model views to be registered for access by relevant stakeholders. Below is an example the kind of information that should be useful in the MVAL.

Table 4. Sample Model Artifact Accession List

Model View Accession Number	Model View Type	Model View Size	Date Published	Version	Associated Model(s)	Description	Etc.
Number 1	Model View 1	Size 1	Date 1	Version 1	Model 1	Desc. 1	…
Number 2	Model View 2	Size 2	Date 2	Version 2	Model 2	Desc. 2	…
~~	~~	~~	~~	~~	~~	~~	~~

The model view accession number should be the key attribute used to identify and track model views in the MVAL. MPM will need to coordinate with the configuration manager to track model views and control them through the MVAL.

Model Data Accession List

Similar to the MVAL, the MDAL serves as an index of model data. Below is an example of what an MDAL might look like.

Table 5. Sample Model Data Accession List

Data Accession Number	Data Type	Data Size	Date Published	Version	Associated Model(s)	Description	Etc.
Number 1	Data 1	Size 1	Date 1	Version 1	Model 1	Desc. 1	…
Number 2	Data 2	Size 2	Date 2	Version 2	Model 2	Desc. 2	…
~~	~~	~~	~~	~~	~~	~~	~~

Model Registry

To reiterate, the model registry is to understand what models are within the enterprise, regardless of their holding area, and provide a space to begin creating relationships between related or seemingly unrelated models. Below is a simple example of a potential model registry output.

Table 6. Sample Model Registry

Model "Name"	Model Manager (POC)	Customer	Customer POC	Purpose	Location	Language	Etc.
Model 1	POC 1	Cust 1	Cust POC 1	Purp 1	Loc 1	Lang 1	…
Model 2	POC 2	Cust 2	Cust POC 2	Purp 2	Loc 2	Lang 2	…
~~	~~	~~	~~	~~	~~	~~	~~

The output may be changed to fit the needs of the organization, but what is critical to determine is how the organization intends to populate this output. The implementation that supports this output should take into consideration the following:

- Ability to maintain information at a reasonable cadence as to provide value to users
- Progress the development of the implementation at a reasonable pace as to provide incrementally increasing value to users; utilizing feedback as feature milestones

Portfolio Risks

Table 7. Sample Portfolio Risks

Portfolio Risk
Imbalance of types of models
Lack of strategic alignment to the organization's need
Portfolio Governing Body's reluctance to retire models that do not align with strategic objectives of the portfolio/organization
Incompetency of the model manager and/or Portfolio Governing Body
Lack of quality in cooperation among model managers, Portfolio Governing Body, and other stakeholders
Lack of interdependencies between models
Too many interdependencies exist between models
Inaccuracy and lack of quality in model data
Model agreements with other stakeholders (up, interfacing with other organizations, down to models) are not being adhered-to
Models in the portfolio at out of compliance with recommended standards, libraries, etc..
Adopted models or developed models are not trusted or verified
Environments the models are running on will be obsolete, changed, replaced, or discontinued

Appendix C. **MPM PLAN TEMPLATE**

Paragraph	Topic/Section	MPM Guide Section
1	Introduction	
1.1	Purpose	
1.2	Model Management CONOPS	3.1.1
1.3	MPM Strategy	3.1
2	Reference Documents	1.3
3	Management of the portfolio	
3.1	Governance framework	3.1.2
3.2	Benefits management	4.2
3.3	Change management	4.2
3.4	Communication Management	3.1.2.4, 6.2.6
3.5	Configuration Management	5.5
3.6	Data management	4.2
3.7	Financial management	4.2
3.8	Model Portfolio Management	6.1
3.9	Procurement management	4.2
3.1	Quality management	4.2, 5.3.1
3.11	Resource management	4.2
3.12	Risk management	4.2
3.13	Schedule management	4.2
3.14	Scope management	4.2
3.15	Stakeholder management	3.1.2.3
3.16	Security Requirements	3.2.2

3.17	Model Intellectual Property Rights	3.2.3
3.18	Modeling Guidelines	3.2.4
3.19	Information Technology (IT) Infrastructure	3.2.9
4	Management of portfolio components	
4.1	Portfolio Components	3.2.1
4.2	Model Repository	5.1
4.3	Model and Data Registry	4.2.2
4.4	Model Libraries	4.3.3, 6.2.5
4.5	Component Databases	4.3.3
4.6	Source Databases	4.3.3
4.7	Modeling Resources	4.3
4.8	Modeling Software	4.3.1
4.9	Model Acquisition	5.3
4.10	Model Quality Assessments	5.3.1
4.11	Model Integration	5.4
4.12	Maintenance of models	6.2
4.13	Model Reuse	6.2.7
4.14	Model Retirement	6.2.8, 5.3.2
5	Management of the data from the Portfolio of Models	
5.1	Model Data Accession List (MDAL)	4.2.4
5.2	Model Views Accession List (MVAL)	4.2.3
5.3	Portfolio Performance Metrics	3.2.10
5.4	Modeling Metrics	5.3.3
5.5	Portfolio Optimization	6.1.2

Appendix D. **ACRONYM LIST**

ASOT	Authoritative Source of Truth
CAD	Computer-Aided Design
CDR	Critical Design Review
CI	Configuration Item
CM	Configuration Management
CMDB	Configuration Management Database
CPI	Critical Program Information
CRUD	Create, Read, Update, Delete
DE	Digital Engineering
DID	Data Item Description
DM	Data Management
DoD	Department of Defense
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INCOSE	International Council on Systems Engineering
ISO	International Organization for Standardization
IT	Information Technology
KPI	Key Program Information (Indicators)
KPP	Key Performance Parameter
MVAL	Model View Accession List
MAL	Modeling Assurance Levels
MBE	Model-Based Engineering
MBSE	Model-Based Systems Engineering
MBSSE	Model-Based Systems and Software Engineering
MDAL	Model Data Accession List
MID	Model Item Description
MOA	Memoranda of Agreement
MoAL	Model Accession List
MOE	Measure of Effectiveness
MOP	Measure of Performance
MOU	Memoranda of Understanding
MPM	Model Portfolio Management
MVAL	Model View Accession List
NDIA	National Defense Industrial Associations
NSG	National Systems Group
PDR	Preliminary Design Review
PMI	Project Management Institute
RAM	Responsibility Accountability Matrix
RFP	Request for Proposal
RM	Requirements Management
SMC	Space and Missile Systems Center
SME	Subject Matter Expert

SysML	Systems Modeling Language
TOR	Technical Operation Report
TRL	Technology Readiness Level
V&V	Validation and Verification
WBS	Work Breakdown Structure

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The Aerospace Corporation
2310 E. El Segundo Boulevard
El Segundo, CA 90245

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Cognizant Program Manager Approval:

Richard O. Day, ASSOCIATE SYSTEMS DIRECTOR
DIGITAL ENGINEERING
ARCHITECTURE ENGINEERING
NATIONAL SYSTEMS GROUP

Aerospace Corporate Officer Approval:

Tanya Pemberton, SENIOR VP NATIONAL SYSTEMS GROUP
OFFICE OF EVP

ST0320

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Model Portfolio Management Guide

Content Concurrence Provided Electronically by:

Albert C. Hoheb, PROJECT LEADER SR
ARCHITECTURE & DESIGN SUBDIVISION
SYSTEMS ENGINEERING DIVISION
ENGINEERING & TECHNOLOGY GROUP

Special Programs Security Approval Granted Electronically by:

Talia Y. Jordan, SECURITY SPECIALIST IV
EXPORT CONTROL-OTR
GOVERNMENT SECURITY
OFFICE OF THE CHIEF INFORMATION OFFICER