National Manual of Assets and Facilities Management

Volume 5, Chapter 20

System Engineering Program Description

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1.0 PURPOSE

A System Engineering Program (SysEP) is an important pillar of any organization. This procedure describes the SysEP concept and methodology, and includes international best practice, wherever applicable.

The purpose of this document is to encourage the Entities to follow best practice during their utilization of SysEP methodologies, which should help them to run their Entities effectively with high capability and maturity levels.

This introductory chapter should be able to guide the Entities in terms of main System Engineering (SysE) concepts and methodologies. These concepts are explained individually in the upcoming chapters, in order to achieve success and improve business process through an effective SysE Program.

2.0 SCOPE

This procedure is developed, as a guide, specifically for the Operations and Maintenance (O&M) domain within the government Entities, which describes briefly the fundamental aspects of SysEP used within this domain. References herein are made to the commonly used SysEP concepts and methodologies within the organizations' operational scope; therefore, each Entity shall establish their own individual goals, objectives, and models concerning the usage of SysEP methodologies, according to their specific predefined business mission, vision, and strategic plan.

This document does not explain or develop any specific Entity SysE Program framework, method, process, integration mechanism, or maintenance control strategy in particular. However, it demonstrates the key aspects of SysEP concept, phases, process, methods, tools, and bond with other related chapters in order to understand their cohesion characteristics to achieve a concrete operational mechanism.

The following modules are described in the context of an O&M domain:

- SysE concept and methodologies
    - SysE tools
    - Bidirectional relations between SysE and the O&M domain
    - System assessment and monitoring control
    - System requirements
    - System acquisition and qualification process
    - Architecture and design phase of SysE lifecycle
    - SysE standards
- SysE Program structure description

Entities shall fulfil the Expro standards and guidelines while formulating the SysE Program methodologies.

3.0 DEFINITIONS

3.1 Defining System Engineering (SysE)

SysE is a wide discipline; in order to understand its context, a list of evolving definitions is provided below according to the timeline:

- A logical sequence of activities and decisions that transforms an operational need into a description of system performance parameters and a preferred system configuration (US military – Engineering Management, 1st May 1974)
- An interdisciplinary, collaborative approach that derives, evolves, and verifies a lifecycle balanced system solution which satisfies customer expectations and meets public acceptability (Institute of Electrical and Electronics Engineers (IEEE) – P1220 Standard, 26th September 1994)
- An interdisciplinary approach that encompasses the entire technical effort and evolves into and verifies an integrated and life cycle balanced set of system people, products, and process solutions that satisfy customer needs (Electronic Industries Alliance (EIA) Standard, SysE, December 1994)
- Multidisciplinary approach that is intended to transform a set of stakeholder needs into a balanced system solution that meets those needs (Moore et al., 2012)

In addition, the US Defense Acquisition University (DAU) in 2001 defined System and SysE as:

- **System** is an integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective
- **SysE** is an interdisciplinary engineering management process that evolves and verifies an integrated, lifecycle balanced set of system solutions that satisfy customer needs

Whereas, NASA defined System and SysE in their handbook (2007) as:

- **System** is a construct or collection of different elements that together produce results not obtainable by the elements alone
- **SysE** is a methodical, disciplined approach for the design, realization, technical management, operations, and retirement of a system

In general, the SysE approach consists of planning, process, management, analysis, control, validation, and verification. However, SysE as an approach comprises of two main perspectives, which are:

- Technical perspective
- Management perspective

Other definitions and acronyms are provided in the table below:

Term	Definition
Entity	Includes Government Ministry, EPMO, Engineering Management Company or any other agency authorized by the Government Ministry to work on its behalf
Operations and Maintenance	Operations and maintenance of facility and its assets. The Entity may be required to enter into single or multiple agreements with 2nd parties to perform O&M works or services
Process	Set of interrelated or interacting activities which transforms inputs into outputs
Acronyms	
A&D	Architecture and Design
ADL	Architecture Description Language
AMS	Asset Management System
AP	Acquisition Process
BIFM	British Institute of Facilities Management
COTS	Commercial Off-the-Shelf
CMMI	Capability Maturity Model Integration
DAU	Defense Acquisition University
DOE	Department of Energy
EIA	Electronic Industries Alliance
EOI	Expression of Interest
EPMO	Enterprise Project Management Office
GAO	Government Accountability Office
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronics Engineers
INCOSE	International Council on Systems Engineering
IPT	Integrated Product Team
ISO	International Standards Organization
KSA	Kingdom of Saudi Arabia
NASA	National Aeronautics and Space Administration
NM & FM	National Manual of Assets and Facilities Management
O&M	Operations and Maintenance

Term	Definition
PTR	Periodic Technical Review
QP	Qualification Process
SAD	System Architecture Description
SDD	System Design Description
SEAC	Systems Engineering Assessment and Control
SEI	Software Engineering Institute
SEMP	Systems Engineering Management Plan
SPT	Studying Performance Trends
SR	System Requirement
SSD	System Specification Description
SysE	System Engineering
SysML	System Modeling Language
UML	Unified Modeling Language
US/USA	United States of America

Table 1: Definitions

4.0 REFERENCES

- British Institute of Facilities Management (BIFM) – Sourcing Strategies
- Building Bridges Between Systems and Software with SysML and UML, Matthew Hause, 2008
- International Council on Systems Engineering (INCOSE) – Systems Engineering Handbook: A Guide for System Life Cycle Processes and Activities (Version 3.2.2), 2012
- National Manual of Assets and Facilities Management (NMA & FM) – Asset Management System Standard Requirements - ENT-ZAO-SD-000001
- National Manual of Assets and Facilities Management (NMA & FM) – Dashboard Development Scope - EXP-ITO-PL-000005
- National Manual of Assets and Facilities Management (NMA & FM) – Monitoring and Evaluation Operating Procedure - EXP-P00-PR-000001
- National Aeronautics and Space Administration (NASA) – Systems Engineering Handbook (NASA/SP-2007-6105 Rev1)
- National Manual of Assets and Facilities Management (NMA & FM) – Assets Register Standard Requirements - ENT-ZAO-SD-000002
- National Manual of Assets and Facilities Management (NMA & FM) – Condition Assessment Standard Requirements - ENT-ZCO-SD-000001
- Project of Survey and Study of the Current Operation and Maintenance Work Statues at Government Facilities – Executive Report (31 Jan 2016)
- Systems Analysis and Systems Engineering in Environmental Remediation Programs at the Department of Energy Hanford Site (link: https://www.nap.edu/read/6224/chapter/4#5), 1998
- System Engineering Fundamentals, January 2001, US Department of Defense System Management College (https://ocw.mit.edu/courses/aeronautics-and-astronautics/16-885j-aircraft-systems-engineering-fall-2005/readings/sefguide_01_01.pdf)
- US Department of Energy (DOE-STD-3024-98) Standard – Content of System Design Descriptions
- US Government Accountability Office (GAO) Cost Estimating and Assessment Guide – Best Practices for Developing and Managing Capital Program Costs

5.0 RESPONSIBILITIES

Role	Description
Entity	Utilize SysE approach as much as needed within their O&M activities, in order to achieve their optimal goals and objectives
Expro	Set the required SysE concepts in relation to O&M activities, and supports Entities with any further SysE knowledge and implementation
System Engineer	Merge, utilize, and transfer knowledge for all necessary SysE methodologies within the Entity O&M activities, wherever applicable

Table 2: Responsibilities

6.0 PROCESS

6.1 SysE Related Concepts within an O&M Domain

The SysE is a complete, iterative, and recursive method, which is applied consecutively from the first phase (Conceptualize) to the last phase (Enhance/Disposal) by a qualified, selected team, sometimes called the "Integrated Product Team (IPT)". It converts requirements into a system or set of artifacts (e.g., processes, models, procedures, descriptions) to provide decision makers with the information needed to help them run their business or act accordingly.

SysE main process could be summed up into six components or could be extended into ten or more. However, the processes are still the same; the differences lay on the elaboration of each step of the process. For Example, the 'Testing' component could be divided into four components, 'component testing, integration testing, acceptance testing, and in-planet testing'. In general, the main process of SysE is illustrated in Figure 1.

Figure 1: SysEP Common Standard Process

6.1.1 SysE Tools

A SysE approach embeds hundreds of methods, models, languages, and tactics which act as the tools that need to be utilized for producing SysE artifacts. Thus, O&M should utilize these tools, wherever applicable. For example, 'architecture and design' component, described in Section 6.1.6, can be developed by utilizing different languages such as:

- Architecture Description Languages (ADLs)
- Unified Modeling Language (UML)
- System Modeling Language (SysML)
- Textual languages
- Many other languages

In addition, architecture and design component can be modeled with:

- Context diagram
- Entity relationship diagram
- Case study diagram
- State machine diagram
- Activity diagram
- Sequence diagram
- Many other models

Describing the SysE tools further is out of this document scope

6.1.2 Bidirectional SysE Relationship with O&M Domain

The relationship between O&M and SysE approach could be utilized in:

6.1.2.1 SysE Approach within O&M Activities

This relationship direction utilizes SysE methodologies in all O&M activities including systems/services and projects development and management, where applicable. SysE approach, including its process, methods, tactics, models, and artifacts could be utilized within the O&M domain in aspects of Asset Management or other systems lifecycles, as illustrated in Figure 2.

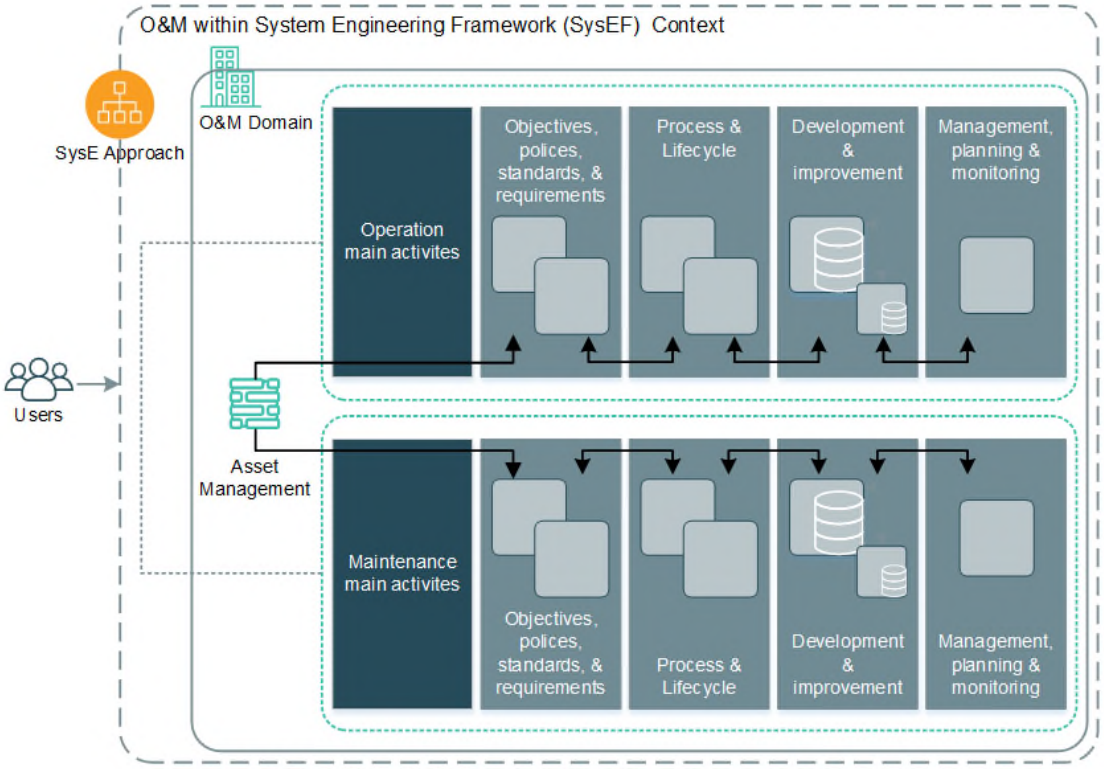

Figure 2: O&M Domain within SysE Framework

6.1.2.2 O&M Activities within a SysE Approach

In this relationship direction, O&M acts as a component from the SysEP lifecycle. This component represents any O&M developed systems and/or services which need to be operated and maintained while utilizing all SysE knowledge (e.g., methods, models, languages, tactics) in order to achieve the Entity O&M goals and objectives.

Figure 3 illustrates the O&M bidirectional relationship with the SysE process and standards:

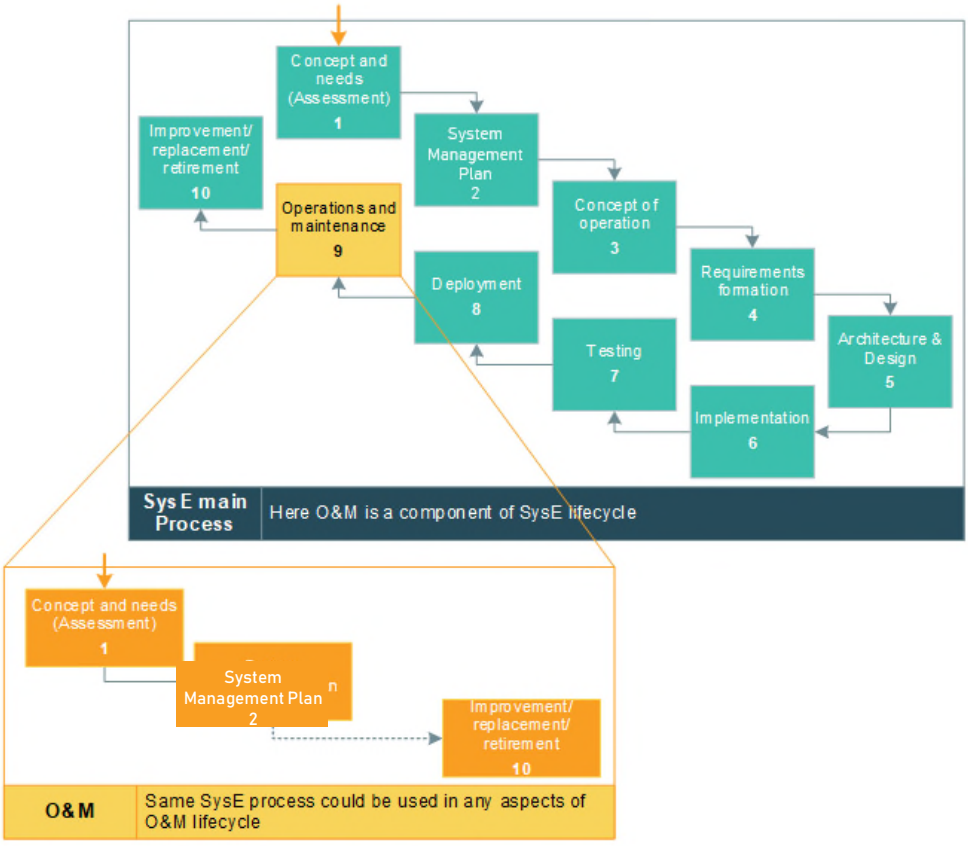

Figure 3: Bidirectional Relationship between SysE Approach and O&M Activities

6.1.3 System Assessment and Monitoring

System assessment and monitoring concept also known as “Systems Engineering Assessment and Control” (SEAC) within both SysE and O&M context, is a set of activities that help organizations run their O&M with adequate visibility into their project/asset’s technical progress and risks concerning predefined plans e.g., Systems Engineering Management Plan (SEMP) and risk mitigation plan. System assessment and monitoring allows an Entity to take appropriate preventative and/or corrective actions when performance diverges or may diverge from expected thresholds or values.

The above SEAC concept description is based on well-known standards definitions such as ones proposed by SEI, 2007, NASA 2007, SEG-ITS, 2009, and International Council on Systems Engineering (INCOSE), 2010.

SEAC activities are applied through well-designed processes, methods, and Periodic Technical Reviews (PTRs), which support any technical management decisions concerning O&M activities.

Refer to NMA & FM Volume 5, Chapter 20 – System Assessments & Monitoring, (EOM-ZO0-PR-000091) for further details.

The Capability Maturity Model Integration (CMMI) - Software Engineering Institute (SEI) 2010, introduces a designed method for enterprises to assess their SysE processes including the O&M aspects.

6.1.3.1 Studying Performance Trends (SPT)

Studying Performance Trends (SPT) is a wide domain which could target all angles of an existing organization, project, process, or a specific subject matter as required, as illustrated in Figure 4 viewpoints. The SPT approach takes significant effort and measurement, which should be undertaken according to a clear goal and overall strategic plan. The "goal, question, metric" paradigm (Basili 1992), emphasized that each collected data obtained from a specific measurement/metric should answer a question to satisfy a particular goal.

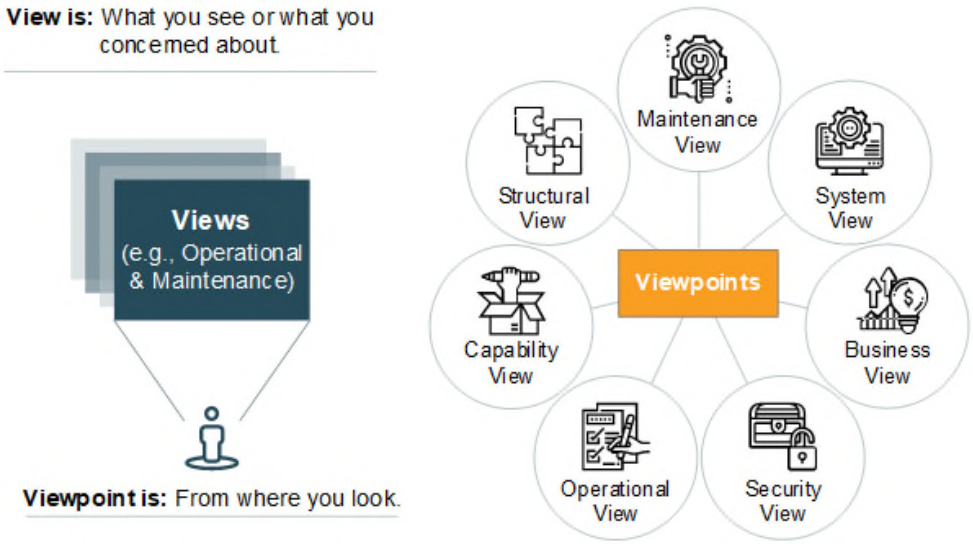

Figure 4: Example of O&M Views

6.1.4 System Requirements

The concept of System Requirements, associated with O&M activities, considers the required details, delivery methods, and techniques for the effective delivery of complex technical systems. These may have a direct or indirect effect on the O&M environment of an Entity in terms of cost effectiveness, maintenance, and asset longevity.

System Requirements ensure that design specifications are aligned with the customer's needs, through validation and verification processes, and constant stakeholder engagement at every stage of product/project or O&M activities. The main objective of System Requirements is to convert the stakeholder view of anticipated services (functional and/or non-functional), into a technical consideration of the required outcome that meets the O&M requirements and objectives.

Refer to NMA & FM Volume 5, Chapter 20 – System Knowledge Requirements Procedure, (EOM-ZO0-PR-000092) for further details.

6.1.5 System Acquisition and Qualification Process

A SysE approach has many advantages concerning O&M system acquisition process. These advantages include, but are not limited to:

- traceability factors help to connect system (e.g., Asset Management System (AMS)) design requirements to test alongside the O&M objectives
- Reduces errors in system delivery by enabling validation/verification within assets/systems lifecycle from requirements to acceptance test as they are created or purchased
- Improved system's stakeholder participation through setting O&M requirement and benchmarking processes
- Helps to follow standard process in acquiring best product available in the market
- Improved traceability factor of decision making
- Support management for any changes before/after system purchase process

- Helps in risk management during the Acquisition Process (AP)
- Improves organizational learning during the Qualification Process (QP)
- Helps select the correct product that satisfies the Entity requirement based on knowledge
- Avoid the selection of incorrect or incompatible systems/services for reasons such as high-cost or poor level of support

Utilization of Commercial Off-the-Shelf (COTS) products offers substantial reduction in the development time and lifecycle costs. COTS systems could be beneficial to the Entity if they are selected based on a concrete acquisition process, which allows owning robust systems that meet the business requirements. Furthermore, acquiring COTS systems does not have the same complexity as that of developing them from inception, based on different aspects such as schedule, functionality, environment, and performance requirements, because requirements are known in advance and can be tested before procuring the system, if the Entity includes this condition with their Expression of Interest (EOI) document.

6.1.6 Maintenance Activities Control

System maintenance may be undertaken through numerous methods to provide a successful outcome and prolong the life of components, maintain efficiency, and assist in the reduction of utilities. The preferred method of maintenance should always be Planned Maintenance, as it is most cost effective method and reduces the inconveniences of breakdown and disruption to service.

Effective maintenance controls improve operations reliability and help in better utilization of resources. Maintenance control is a set of activities, tools, and methods used to manage, and allocate maintenance resources to achieve the following objectives:

- Operations continuity
- Work control
- Quality check
- Process control
- Cost control
- Efficient operational reporting mechanism

6.1.7 Architecture and Design (A&D)

Architecture and Design (A&D) is an artifact that describes any system “hardware and/or software” from a high level perspective, to support the implementation process. This is phase in any SysE lifecycle which could be divided into different sub-phases or components, as illustrated in Figure 5.

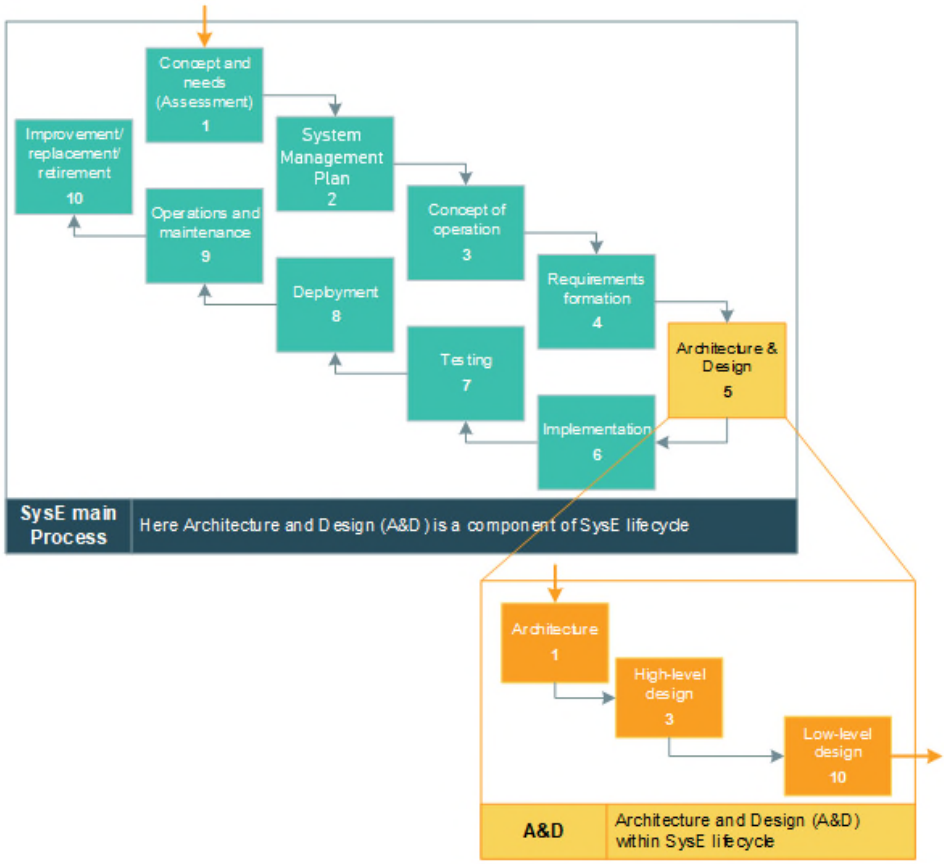

Figure 5: A&D Decomposition from a SysE Lifecycle

All system architecture processes and designs shall be documented well to be the input for programmers, testers, and users. Most common standard documents that document both architecture and design are:

- System Architecture Description (SAD)
- System Design Description (SDD)
- System Specification Description (SSD)

6.1.7.1 System Design Description (SDD)

SDD is the process and set of activities for defining all views of the system “hardware and software” including its:

- Structure design
- Physical design
- Behavior design
- Interfaces design
- Other designs as needed

These should be developed to support the O&M overall mission and satisfy its requirements. SDD explains the system features functionality based on predefined requirements. Thus, it should link between the

predefined requirements (i.e., O&M requirements) and the system structures and components, in order to ensure that the system design meet those requirements.

Using the necessary and applicable SysE languages, models, methods, and tools, in order to explain all the system components, operational decomposition, functionalities, data flows, data types, data format, ports, and other information is required. Figure 6 demonstrates an example of operation activities' decomposition.

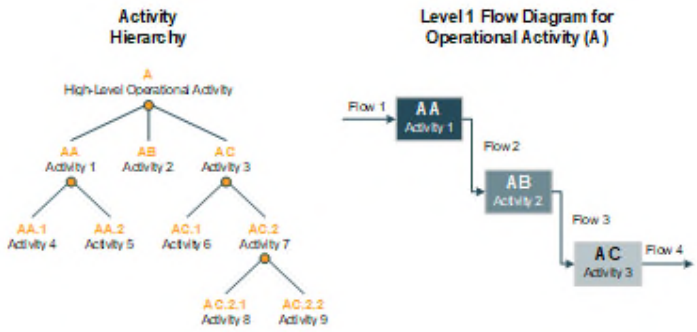

Figure 6: Operational Activity Decomposition Example

Furthermore, Figure 7 below demonstrates some of SDD views that should be described with their utilization of standards.

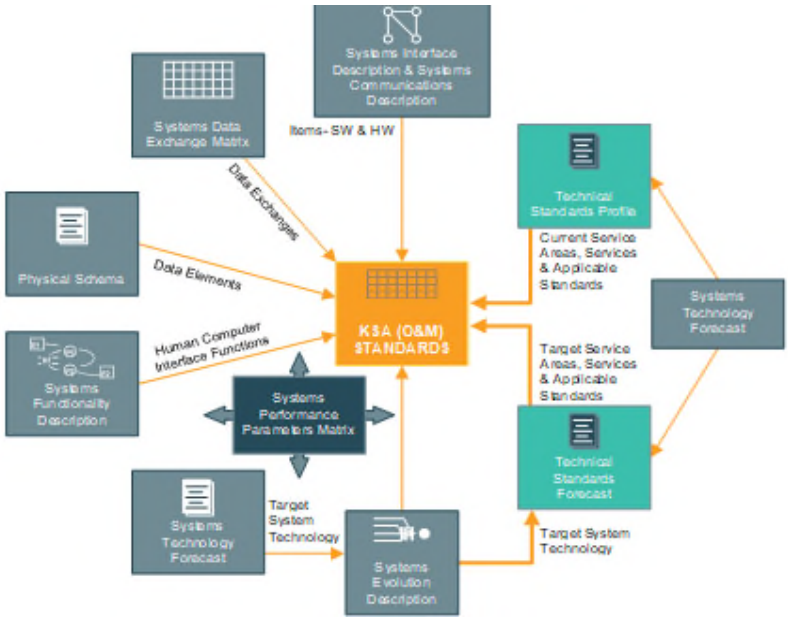

Figure 7: Some O&M SDD Views and Standards, by Utilizing US Department of Defense Framework

There are some engineering models and diagrams that are recommended to be utilized during any SDD e.g., use cases, sequence diagram, state machine diagram, requirement diagram. Therefore, designing a system is a critical activity that requires a specialist team.

SDD developments follow standard processes and methodologies. There are many best practices available that cover the aspect of system design such as, "INCOSE-2012, Systems Engineering Handbook; and NASA-2007, Systems Engineering Handbook".

The content of specific SDDs is likely to be different according to the type of physical system being described (for example, ventilation/confinement systems, electrical power systems, chemical processes).

Refer to NMA & FM Volume 5, Chapter 20 – System Knowledge Requirements Procedure (EOM-ZO0-PR-000092), for further details.

6.1.8 Significance of SysE Methodology

SysE methodology is an important approach that provides organizations with concrete information and technological support, in order to help them achieve their predefined goals and business needs. SysE approach has been proven through its wide utilization by industries and institutions around the globe. Every SysE method, process, and technique can be utilized from the top strategic level and management planning to the lowest details of a specific problem context and scenario. Figure 8 illustrates an example of the relationship between some SysE models and the level of thinking and problem context within the O&M domain. The three rounded boxes on the right show the types of models and scope within the SysE context, whereas the three circles show the thinking and consolidation aspects at software engineering, systems, and enterprise levels. Therefore, this document recommends any Entity to utilize the SysE approach, where applicable, during their O&M activities.

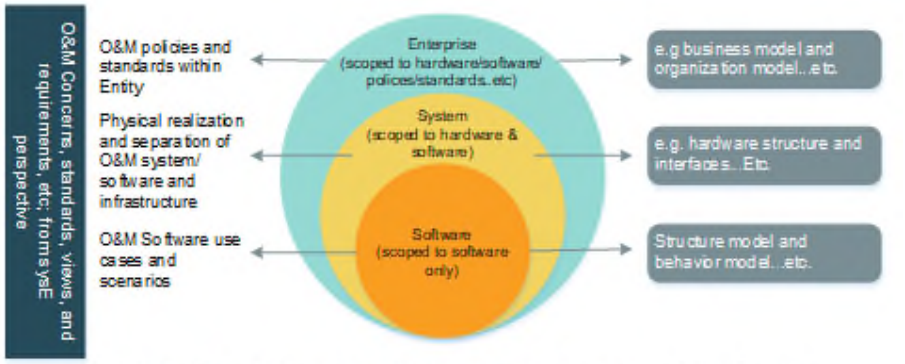

Figure 8: SysE Levels, Scopes, and Models Usage in Relation to an O&M Context

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6.1.9 SysE Standards

SysE is a mature domain that is utilized in today's industry, worldwide, in different aspects including O&M activities.

Institutions who were concerned about standards developed several useful standards for SysE lifecycle, which cover different viewpoints such as, process, quality attributes, assessments, documentations, and management.

Those standards are recommended for any Entities during O&M activities and their use of the SysE approach wherever applicable, as illustrated in Figure 9.

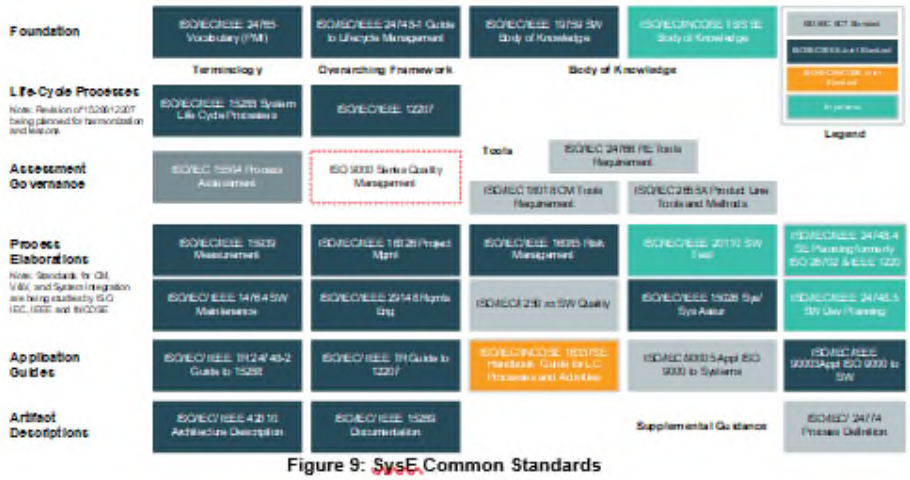

Figure 9: SysE Common Standards

Figure 9: SysE Common Standards

6.1.9.1 SysE Process Mapping

The International Standards Organization (ISO)/International Electrotechnical Commission (IEC) "15288 and 12207" SysE process standards cover processes and lifecycle phases as shown in Figure 10 below illustrates an example of process mapping between ISO/IEC 15288 and 12207 SysE standard, which cover processes and lifecycle phases.

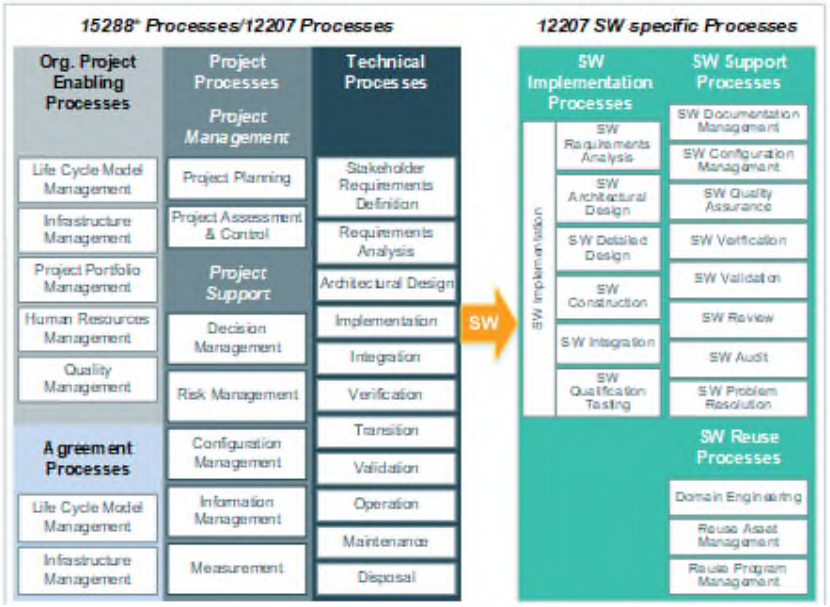

Figure 10: Example of Process Mapping between ISO/IEC 15288 and 12207 SysE standards

6.2 SysE Program Structure

SysE Program description is fully explained across a specific group of documents within Chapter 20 of Volume 5 of the NMA&FM, to explain the important aspects of SysE methods that are related to O&M domain. Figure 11 divides the SysE Program into three sections, as follows:

1. **Introduction** – Description of SysE concept within O&M context
2. **Requirements and Qualification** – Focus on how to develop stakeholder's requirements and guide them to acquire new systems services within O&M context

3. **Monitoring and Control** – Comprises two documents. Both components concentrate on system assessments, monitoring, and maintenance controls within the O&M domain

The three parts above consists of five components, which complement and meet the requirements of the Expro Projects White Book as follows:

- General concept of SysE Program
- System Requirements
- SysE Acquisition & Qualification Process
- System Assessments and Monitoring
- Control of Maintenance Activities

The five points above form the SysE Program concept within this chapter. Each of them should support and guide any Entity to gain, and apply their knowledge based on best practice as illustrated in Figure 11. The dark boxes represent the above components, whereas the green boxes represent the outcomes.

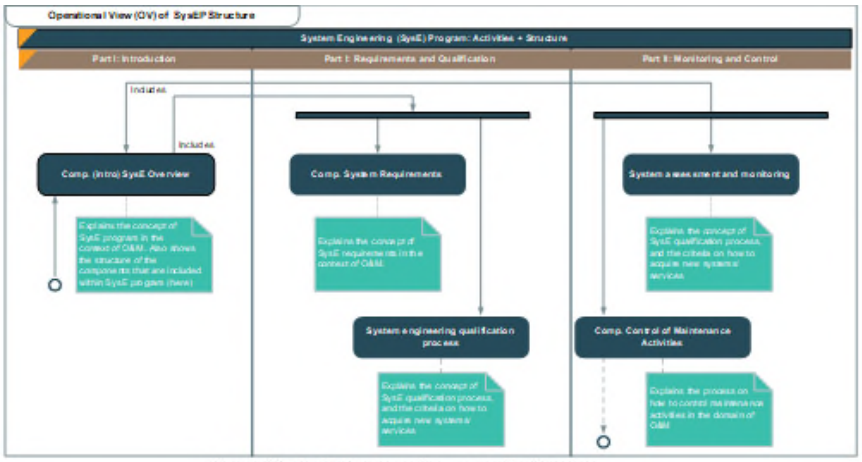

Figure 11: SysE Program Components Structure