REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*	**2. REPORT TYPE**	**3. DATES COVERED** *(From - To)*
08/25/2020	Conference Paper	

4. TITLE AND SUBTITLE
Improving Requirements Development Efficiency and Quality with Decision Aids

5a. CONTRACT NUMBER
W56KGU-19-F-0004

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Sotomayor, Harry; Pemberton, Barbara; Fetech, William; Butler, Paul V.; Lim, Amy; Talbott, Taylor;

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The MITRE Corporation
7515 Colshire Drive
McLean, VA 22102

8. PERFORMING ORGANIZATION REPORT NUMBER
PRS-20-2187

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Program Executive Office for Simulation, Training and Instrumentation

10. SPONSOR/MONITOR'S ACRONYM(S)
PEO STRI

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

13. SUPPLEMENTARY NOTES
preprint to the Interservice/Industry Training, Simulation, and Education Conference (I/ITSEC)

14. ABSTRACT
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15. SUBJECT TERMS
Military Planning; Decision Support Engineering; requirements management; project requirements; quality; efficiency; decision aids;

16. SECURITY CLASSIFICATION OF:			**17. LIMITATION OF ABSTRACT**	**18. NUMBER OF PAGES**	**19a. NAME OF RESPONSIBLE PERSON**
a. REPORT	**b. ABSTRACT**	**c. THIS PAGE**			Susan Carpenito
				10	**19b. TELEPHONE NUMBER** *(Include area code)* 781-271-7646

Improving Requirements Development Efficiency and Quality with Decision Aids

Mr. Harry Sotomayor,
Dr. Barbara Pemberton
U.S. Army PEO STRI
Orlando, FL
harry.a.sotomayor.civ@mail.mil,
barbara.j.pemberton6.civ@mail.mil

Mr. Paul Butler, Mr. Bill Fetech,
Ms. Amy Lim, Mr. Taylor Talbott
The MITRE Corporation
Orlando, FL
pvbutler@mitre.org, wfetech@mitre.org,
ahblim@mitre.org, ttalbott@mitre.org

ABSTRACT

For the past two years, the U.S. Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI) has researched, developed, and is currently implementing an approach for managing project requirements. PEO STRI began by establishing the Requirements Management Working Group (RMWG), an experienced oversight team of requirements engineering subject matter experts (SMEs) and enterprise architects. The RMWG is chartered to facilitate and promote strategic reuse of requirements management assets.

In 2020, the RMWG is developing a requirements decision aid, the Requirements Management Process Model (RMPM). The RMPM will assist projects with adopting and adapting enterprise assets – processes, tools, templates, and training materials. This paper describes the RMWG's process for creating the RMPM and how it will be used to identify PEO STRI enterprise assets appropriate to a given project. It defines the relationship between RMPM processes and project management approaches, and presents the planned path forward for prototyping this aid with PEO STRI program managers.

ABOUT THE AUTHORS

Mr. Harry Sotomayor is the Chief Technology Officer (CTO) at PEO STRI. Mr. Sotomayor is responsible for enterprise-wide system and software engineering standards, policy, and initiatives and science and technology planning. Mr. Sotomayor's experience includes acquisition and development of Live, Virtual, Constructive systems for training and simulation.

Dr. Barbara Pemberton is the U.S. Army PEO STRI Lead for Systems Engineering Processes and Requirements Management. Dr. Pemberton's areas of expertise include requirements analysis, systems and software engineering, and acquisition and development of training systems for the Air Force, Navy, Army, and industry.

Mr. Bill Fetech is a Lead Multi-Discipline Systems Engineer at The MITRE Corporation. He has 38 years of work experience and has authored over 15 MITRE Technical Reports on requirements management, developed and presented multiple classes on DOORS implementation, given presentations on requirements management at several conferences, and licensed two products to IBM. His current field of research is requirements management and modeling integration.

Mr. Paul Butler, Ms. Amy Lim, and Mr. Taylor Talbott are MITRE systems engineers who support PEO STRI by designing and providing training for enterprise solutions that optimize technical and business processes. Their current field of research is agile requirements management; at present they are supporting the Army by developing a training system that standardizes requirements processes, schemas, and tools for leaders and engineers.

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Mr. Harry Sotomayor,
Dr. Barbara Pemberton
U.S. Army PEO STRI
Orlando, FL
harry.a.sotomayor.civ@mail.mil,
barbara.j.pemberton6.civ@mail.mil

Mr. Paul Butler, Mr. Bill Fetech,
Ms. Amy Lim, Mr. Taylor Talbott
The MITRE Corporation
Orlando, FL
pvbutler@mitre.org, wfetech@mitre.org,
ahblim@mitre.org, ttalbott@mitre.org

INTRODUCTION

Requirements specify the behavior, attributes, and properties of a future system or software, enabling designers and developers to build and test hardware and software systems. The Institute of Electrical and Electronics Engineers Standard 610.12-1990 (IEEE-Std-610.12-1990) defines the term "requirement" as:

1. a condition or capability needed by a user to solve a problem or achieve an objective.
2. a condition or capability that must be met or possessed by a [software] system or system component to satisfy a contract, standard, specification, or other formally imposed documents.
3. a documented representation of a condition or capability.

Requirements management (RM) is the process of eliciting, collecting, documenting, analyzing, refining, tracing, prioritizing, and testing requirements while performing change management and communicating changes to end-users and other stakeholders (Larson & Larson, 2010). It is a continuous process that does not end with a product release, since user needs and stakeholder understanding of the system continually evolve, perpetuating a requirements life cycle that comprises definition, validation, documentation, and management. The primary stakeholders of RM are the individuals and organizations that will use the products described in the requirements.

The most significant challenges of RM (Firesmith, 2007; Harrison et al., 2019) are:

- Focusing on user needs and value delivery
- Understanding which requirements methods and tools are available to requirements engineers
- Understanding and supporting RM at the business and technical management levels
- Understanding the level of RM appropriate for each program
- Enabling organizations to recognize and acknowledge when they have inadequate engineering resources and skills to fundamentally manage enterprise–product–process requirements.

The authors examined the first three challenges in 2019 research (Harrison et al., 2019). They presented strategies for collaborating with users throughout the product life cycle to understand their needs, and traditional and agile processes and tools that harness change focused on the end-user. They also recommended practices for overcoming cultural barriers to requirements engineering at the business and technical management levels.

This paper describes the U.S. Army Program Executive Office for Simulation, Training and Instrumentation (PEO STRI) strategy for assisting projects in adopting requirements processes, tools, templates and training materials – assets that PEO STRI continually enhances and maintains for its Program Managers (PMs). The paper focuses primarily on the process that the PEO STRI Requirements Management Working Group (RMWG) used to identify the assets most appropriate for a project and develop a decision aid for PMs. It also presents PEO STRI's plan to prototype this process in FY20.

PROBLEM STATEMENT

The PEO STRI enterprise consists of PMs operating with autonomy to deliver complex training solutions for the warfighter within compressed schedules. PEO STRI strives to streamline, enhance, and optimize technical processes across the enterprise, and since 2018 has focused on developing RM core capabilities and resources. To attain this goal, the PEO chartered the RMWG to assess, design, develop, and institutionalize functional and non-functional requirements approaches across the enterprise and address the RM challenges identified above.

As noted above, Army organizations must recognize and acknowledge when they have inadequate resources and skillsets available to manage requirements (Kemper & Smith, 2019). Capability gaps in engineering resources take many forms, as shown in Figure 1. Briefly, they include:

Figure 1. Engineering Resource Capability Gaps

- Training engineering staff to be capable of decomposing user requirements into technical performance requirements in a testable form ("staff capability" and "requirements testability") (Kemper & Smith, 2019).
- Developing and maintaining staff knowledge necessary to consistently manage many engineering demands, including architecture requirements, business/training requirements, user/stakeholder requirements, functional requirements, quality of service or non-functional requirements ("comprehensively document the system", "managing large data sets", and "requirements engineering consistency") (Kemper & Smith, 2019).
- Developing, retaining, and leveraging the knowledge of experienced engineers with the individual skillsets to elicit, document, and trace requirements and execute the RM processes described in the introduction ("writing good requirements" and "manpower").

Failure to recognize and address these gaps significantly weakens an organization's RM abilities, resulting in incomplete and untestable requirements that do not meet the end-user's needs (Firesmith, 2007).

Organizations such as PEO STRI continually face these RM challenges, but also must balance technical needs against budgets, resources, and schedules. They must make difficult choices regarding how to optimally leverage engineering staff and RM processes, tools, and training materials. Naturally, organizations want to achieve the highest level of RM maturity possible, but understand that attaining higher levels require more time, effort, and money (Wiegers, 2012). They must therefore know what resources and assets exist to help them determine where on the scale of RM they belong, in order to "right-size" their requirements. Specifically, they must determine:

- What RM experience and skills do they need?
- What RM processes must they develop and execute?
- What RM tools do they need, and when should they be used in the systems engineering life cycle?
- What RM templates exist for structuring requirements documentation and requirements databases?
- What RM training do they require and when should it occur?

These questions led the RMWG to investigate ways to improve requirements development efficiency and quality. This investigation resulted in the development of a standard decision aid that guides requirements engineers (REs) in PEO STRI organizations on how to identify and use processes, training materials, templates, and best practices while leveraging existing assets from an enterprise database.

REQUIREMENTS MANAGEMENT PROCESS MODEL

> "Analysts report that as many as 71 percent of software projects that fail do so because of poor requirements management, making it the single biggest reason for project failure—bigger than bad technology, missed deadlines or change management fiascoes."
>
> - Christopher Lindquist

The RMWG basically followed a decision aid approach to implement an overall requirements process across the enterprise. Using the decision aid, REs can identify their specific needs and identify a standardized set of processes, templates, tools, and training materials to help achieve their objectives. Hereafter, this paper refers to the RMWG implementation of the decision aid as the Requirements Management Process Model (RMPM).

Development Methodology

Based on RMWG experience and research, requirements often do not meet standards (e.g., INCOSE), do not reflect end-user needs, are not testable, and often do not have an agreed upon interpretation by all stakeholders. To begin addressing these issues, in the 2019 I/ITSEC paper, the RMWG documented the initial processes and procedures that PEO STRI organizations were implementing and provided the following related recommendations: "Organizations should establish a baseline of products to ensure consistent and effective results. Create and integrate templates and schemas into the tools to increase efficiency and decrease errors." (Harrison et al., 2019, p. 11). The RMPM recommends use of templates and schemas in addition to standardized processes, tools, and training materials. This helps an organization establish a recommended baseline of products.

The RMWG developed the RMPM using primarily two sources. It adapted the first three tiers from the RM process described in "Effective Requirements Management" (Kumar, 2006). Leveraging its systems engineering expertise (Harrison et al., 2019), the RMWG then extended the process using a standards-based system design model. A subsequent section of this paper describes how the RMWG also used the standards-based system design model to validate the RMPM.

Structure

Figure 2 shows the current structure of the RMPM. The "upper tier" consists of common RM processes: planning, development, verification, validation, and change management. The "middle tier" consists of detailed processes that are further decomposed from the upper tier. The "lower tier" of the hierarchy would consist of components (either procedures or products) that a RE would implement to complete the detailed process.

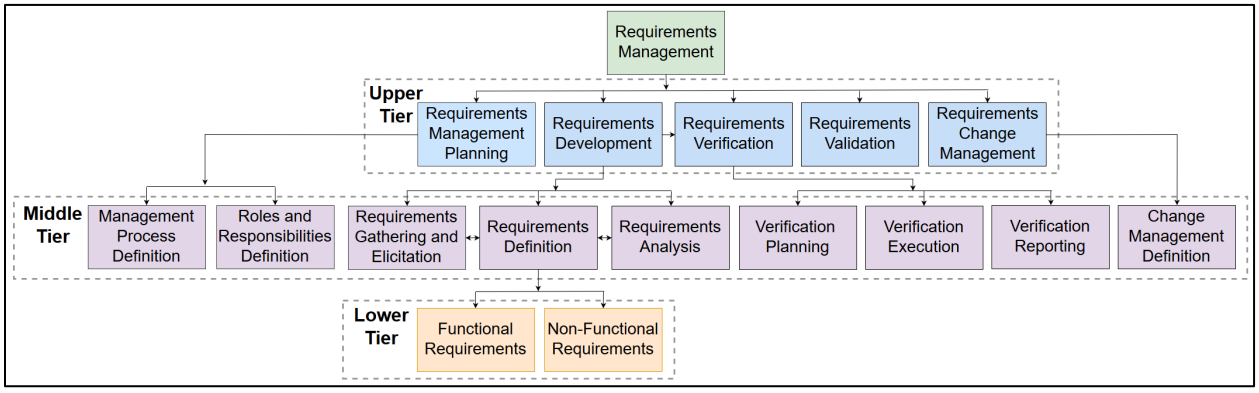

Figure 2. Initial Requirements Management Process Model

As REs traverse the hierarchy during implementation, they would use the middle tier processes to obtain a list of recommended tools to meet a given need. In this case, the tools (e.g., DOORS, Visure, Jira, etc.) are identified at the middle tier Requirements Definition stage. The components of the lower tier identify the assets (processes, training materials, templates, and best practices) that PMs use to adopt standardized approaches. In this example, Functional and Non-Functional Requirements are potential products to be created by this process.

Standards-Based Systems Design Model

Since the RMPM was adapted from the RM process (Kumar, 2006), the RMWG needed to validate its approach and determine if it had to define any additional processes, especially at the lower tier. The RMWG investigated whether various international systems engineering standards organizations had established RM standards, with research covering the International Organization for Standardization, Object Management Group (OMG), International Council on Systems Engineering (INCOSE), Institute of Electrical and Electronics Engineers, and Organization for the Advancement of Structured Information Standards[1] (Estefan, 2008).

Based on applicability, adaptability, and availability/cost, the RMWG leveraged the use of the INCOSE Object-Oriented Systems Engineering Method (OOSEM). OOSEM integrates a top-down, model-based approach that uses OMG SysML™[2] to support the specification, analysis, design, and verification of systems. The objectives of OOSEM (Estefan, 2008), listed below, are aligned with the chartered objectives of the RWMG:

- Capture and analysis of requirements and design information to specify complex systems
- Integration with object-oriented (OO) software, hardware, and other engineering methods
- Support for system-level reuse and design evolution.

OOSEM specifies seven major activities (Tolbert, 2020), as depicted in Figure 3.

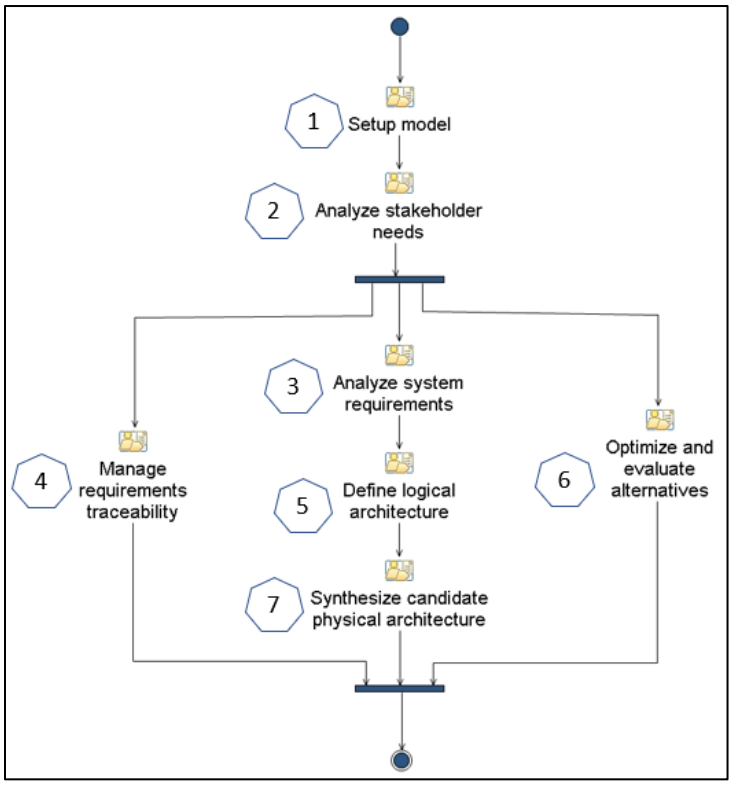

Figure 3. OOSEM Major Activities

The RMWG examined each OOSEM activity to determine RM applicability. To ensure RMPM completeness, the RMWG validated the RMPM by mapping the middle tier processes to the OOSEM activities, as shown in Table 1. It

[1] The RMWG leveraged qualitative analysis methods from Estefan (2008) as the basis for comparison.
[2] OMG SysML is an enabler of a Model-Based Systems Engineering (MBSE) approach to improve productivity, quality, and reduce risk for complex systems development.

discovered one OOSEM RM activity, "Manage requirements traceability," that was not defined in the RMPM, and thus identified as a gap. The RMWG updated the RMPM by adding this activity to the middle tier.

Table 1. OOSEM Activities to RMPM Process Mapping

OOSEM Activity	RMPM Middle Tier Processes	Validation Outcome
1. Setup model	• Management Process Definition • Roles and Responsibilities Definition	Validated
2. Analyze stakeholder needs	• Requirements Gathering and Elicitation • Requirements Definition • Requirements Analysis	Validated
3. Analyze system requirements	• Requirements Gathering and Elicitation • Requirements Definition • Requirements Analysis	Validated
4. Manage requirements traceability	• Must be added under Requirements Development	Gap
5. Define logical architecture	• OOSEM activity is not related to RM	N/A
6. Optimize and evaluate alternatives	• OOSEM activity is not related to RM	N/A
7. Synthesize candidate physical architecture	• OOSEM activity is not related to RM	N/A

In addition to using the OOSEM activities to validate the RMPM middle tier, the RMWG used OOSEM to define more components at the lower tier. To do so the group leveraged OOSEM tasks, which compose the OOSEM activities. The RMWG evaluated OOSEM tasks against the RMPM middle tier to determine if they represented a decomposition of a middle tier process; if so, the task was added to the RMPM as a lower tier component. An example of this decomposition is shown in Figure 4, where seven OOSEM tasks were added as components beneath 'Requirements Gathering and Elicitation'. This decomposition activity continued until the RMWG had evaluated all OOSEM tasks. The result was an updated RMPM with a fully defined lower tier. Because of size constraints the full RMPM is not presented in this paper but is available from the authors. The RMPM will continue to evolve based on RMWG analysis and user assessments with PMs.

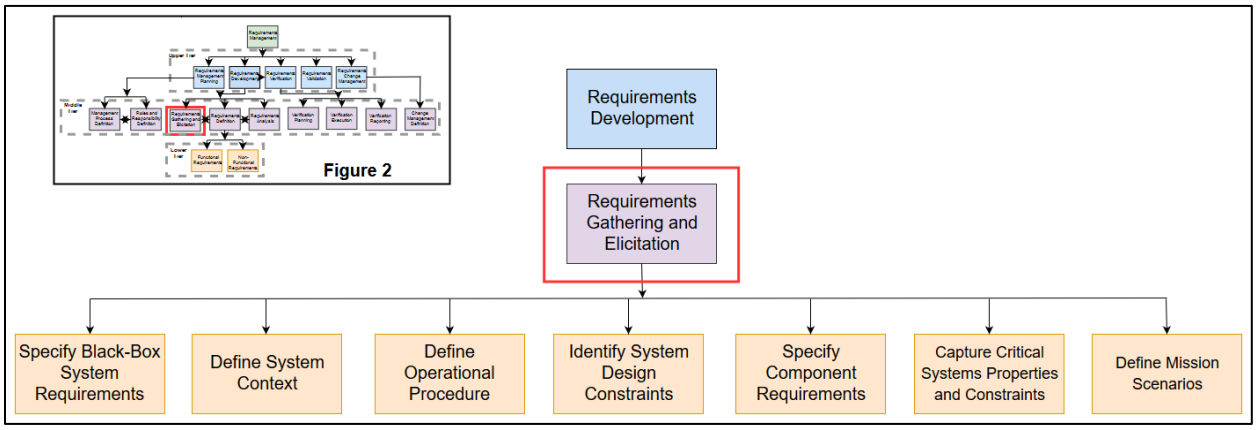

Figure 4. Requirements Gathering and Elicitation Decomposition with OOSEM Tasks

Web Application

The RMPM is currently in the development / prototype phase. The RMWG will incrementally decompose the RMPM to the lower tier and identify assets for each of those components. These assets will enable REs to provide consistently high-quality products based on industry best practices and lessons learned. The RMWG is exploring options for how to make this information easily accessible and easy to use across the enterprise. Based on previous experience in developing and deploying the Help and Instruction Guide (HInGe) tool (Harrison et al., 2019), the RMWG is pursuing a web implementation of RMPM. The HInGe application provided a useful platform to host requirements management artifacts for stakeholders enabling rapid access to information in a user-friendly interface. The RMWG is planning for the RMPM to become a component of the HInGe application that resides on PEO STRI's network and is available to all internal users.

The RMPM web application will guide REs through the process of selecting appropriate requirements assets for their project, and ensuring user requirements and needed capabilities are documented, updated, traced, managed, and tested throughout the systems engineering life cycle through deployment, regardless of the system development methodology used. Content that is understandable and a graphical user interface that is simple, clean, and modern were among the most common feedback received during HInGe user assessments. Based on lessons learned, the RMPM user interface (Figure 5) will help REs navigate the RMPM and locate the desired information in an efficient and well-organized manner. When a RE first enters the web application, the upper tier of the RMPM will be displayed (Panel A) and the boxes will expand upon selection (Panel B). When a middle tier process is selected, the RMPM will present REs with selection options from the lower tier (Panel C).

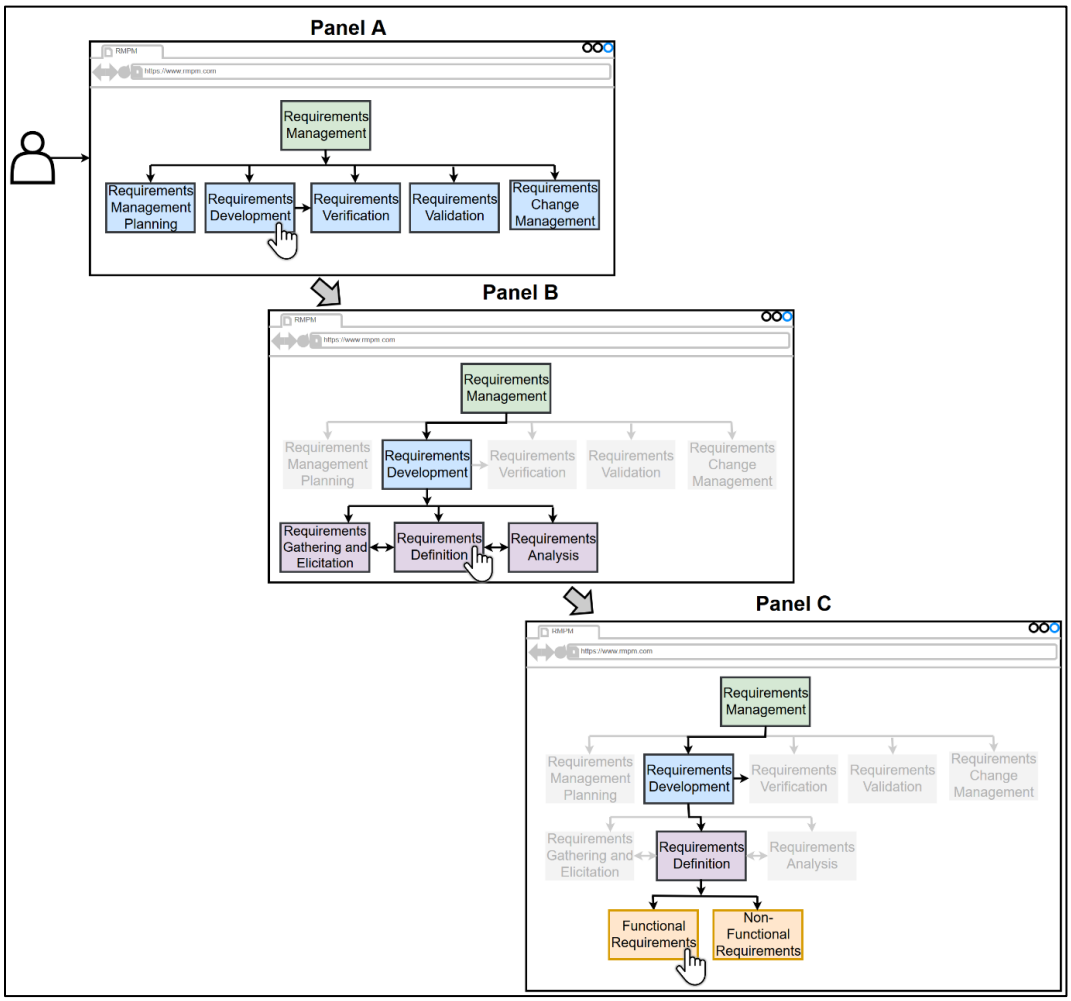

Figure 5. RMPM Web Application User Interface

Once the RE clicks on a lower tier box, the RMPM will display the identified assets as shown in Figure 6.

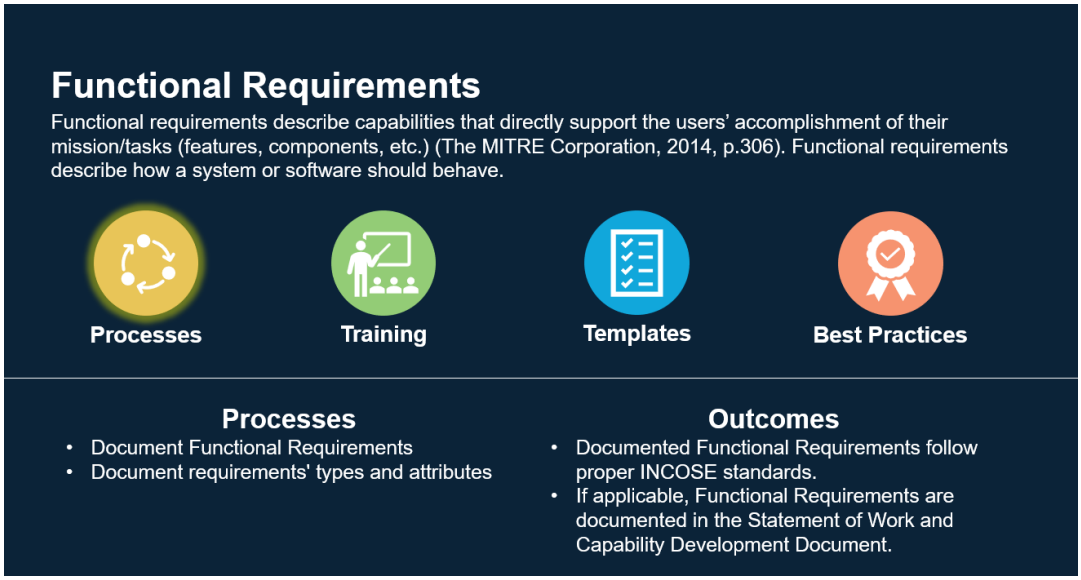

Figure 6. RMPM Design Diagram

RMPM and Systems Development Approach

The RMPM (upper left tier in Figure 7) is not specific to one systems development approach; it can be used in both the traditional waterfall approach and in Agile development. An Agile project approach involves the same types of work as a traditional project; for example, create requirements and designs, develop the product, document it, integrate the product with other products (if necessary), test the product, and deploy it for the user (Layton & Ostermiller, 2017). However, instead of completing these steps for all product features at once, as in a waterfall project, the project is broken down into iterations, often called sprints. From RMWG experience and lessons learned, Agile is difficult to implement in a waterfall framework. It is important that a project determine a specific systems engineering methodology and carefully consider risks of a hybrid approach (West, 2011). The acquisition approach and processes determine what technical documentation is developed; user capabilities/requirements are always developed.

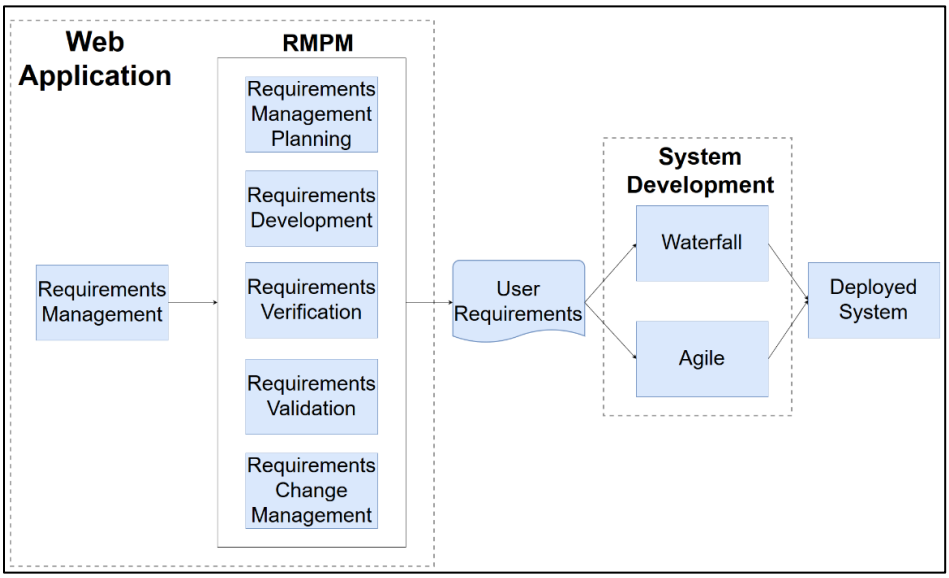

Figure 7. RMPM Relationship to Systems Development Approach

User Assessments of the RMPM Web Application

Once the RMPM reaches maturity and the web application has been developed, the RMWG will conduct user assessments. The primary objective of the planned evaluation is to determine if the RMPM application can serve as a standalone tool for REs with various levels of experience and skillsets to implement high-quality RM processes with minimal guidance. Based on experience with conducting user assessments on HInGe (Harrison et al., 2019), the RMWG will develop and conduct these web application assessments according to the following plan:

- Identify PM projects with a diverse set of experience and skills
- Identify the objectives and outcomes of the particular assessment
- Select a project and ensure the appropriate materials (for example, laptops and mice) are available to conduct the evaluation
- Define performance metrics and success criteria
- Prepare a list of tasks that meet the objectives of the web application assessment for requirements engineers to complete
- Prepare a survey to evaluate the usability of the web application
- Conduct an after-action review / hotwash session to elicit more feedback from users after they complete the assessment
- Evaluate the survey results and feedback.

If the assessments are positive (per success criteria), the RMPM will be distributed and maintained for PEO STRI.

The RMWG recognizes that the RMPM will not address all RM use cases. The purpose of the RMPM and the web application is to build a foundational knowledge base for high-quality RM. An experienced oversight team of subject matter experts (SMEs) will then coordinate with PMs to identify gaps and enhance the RMPM.

SUMMARY AND CONCLUSION

The imperative to "right-size" RM arises from the need to deliver solutions that satisfy the needs of project REs while following a requirements process that is repeatable, measurable, and affordable, and carries an acceptable level of risk. Organizations have long struggled to determine ways to improve requirements development efficiency and quality, while staying within their technical and management budgets. To assist PEO STRI in meeting this challenge, the RMWG is developing aids to assist projects with discovering and using requirements processes, tools, templates, and training materials for the PEO STRI enterprise.

The RMWG produced the RMPM, a decision aid that REs will use to identify and select processes and tools appropriate for their projects. The group validated the decision aid processes by analyzing and leveraging the INCOSE's OOSEM standard. The RMPM will provide an efficient and repeatable method for Army projects to determine enterprise assets (e.g., requirements processes, tools, templates, training materials). The RMWG plans to implement the RMPM as a web application.

The RMWG's next activity will be to prototype the RMPM web application. The RMWG will identify a PM/project to employ the RMPM in selecting enterprise assets and implementing them in its day-to-day engineering execution. The user assessments will serve as a proof-of-concept, focused on assessing the value and usability of the RMPM. The RMWG will document the user experience and feedback and integrate the lessons learned and successful practices, enhancing its RM processes for PEO STRI.

Only confident and experienced REs can initiate and manage the RM process on a project. Projects strive to assign the most experienced and skilled staff to these tasks, but in practice RE teams are composed of individuals having varied skills and backgrounds. An experienced advisor and a strong process model can help project teams avoid typical RM pitfalls and make informed decisions. The RMWG and RMPM provide that level of critical support to the Army, enabling PEO STRI to enhance and optimize its RM across the enterprise.

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