An Approach to Estimate the Life Cycle Cost and Effort of Project Management for Systems Centric Projects

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Abstract

One of the key challenges in predicting life cycle costs (LCCs) is to develop an accurate top down method that can be used in the early phase of a system's life cycle to estimate hardware, software, integration, and management costs. Models have been developed for systems engineering (SE) costing components of management, but the literature is void of project management (PM) costing methodologies. The lack of costing capability can cause project cost estimates to be unreliable and escalate to actual cost overrun, and ultimately lead to unfavorable financial performance and project outcome. Thus, the research study proposes a framework for evaluating PM costs required for the conceptualization, design, test, and deployment of large-scale systems centric projects. The ultimate goal of the research study is to construct a cost estimating model that can accurately and consistently predict the appropriate and adequate amount of PM effort for systems centric projects.

The proposed framework consists of two PM cost models which are investigated by this research effort via a series of surveys and interviews with industry PM practitioners and subject matter experts. The first proposed PM model is a synthesis of the Constructive Systems Engineering Cost Model (COSYSMO) framework with variations on the effort multipliers that are primarily driven by PM functions and characteristics commonly seen throughout aerospace and defense systems projects. The primary goal of the first proposed model is to determine the cost relationship between SE project size and PM effort, and whether PM cost and effort is proportional to SE cost and effort for aerospace and defense projects. The second proposed model is developed based on the PM processes, activities, attributes and characteristics that are universally shared and practiced by PM practitioners across various projects and industries. The focus of the second proposed model is to determine and construct a cost relationship based on project factors that dictate PM functions and characteristics, which are multiplicatively impacted by PM efficiency. This PM functions-driven model estimates the PM cost and effort required for systems development projects, regardless of its industry origin, to support PM practitioners and cost estimators across different domains.

The study is expected to provide several benefits that help project sponsors and cost estimators measure and quantify PM effort, ultimately generating reliable PM cost estimates. Project sponsors and cost estimators who utilize the proposed cost estimating models can expect their projects to receive specific benefits, which include: 1. Determine adequate amount of resources needed for PM effort, 2. Produce reliable and defensible cost estimates for PM effort, 3. Allocate appropriate amount of PM resources for specific PM functions, and 4. Allow more robust and accurate project planning and tracking of cost and resources. Moreover, once both

proposed models are validated and verified by industry experts and data, the research study can further measure and compare the accuracy and consistency given in each model to determine the applicability and appropriateness of each model for specific industry usage and calibration.

Introduction on Research Background

The focus of the research is on the management component of costs, which are further defined as SE and PM costs (DOD, 2010). In the defense domain, these costs have received significant attention because they are often underfunded and have been connected to major cost overruns in the defense acquisition systems (National Research Council of the National Academies, 2007). According to Stem et al. (2006), the costs of management are roughly a 50/50 split between SE and PM among most large defense programs, and the combined costs of SE and PM were accounted as 8% of total development costs for all defense systems programs that were contracted in the 1960's. Since then, the cost percentage has doubled to 16% in the 1990's; however, the increment of SE and PM costs was complex and difficult to be determined. Based on our observation, the 50/50 split may not be applicable for SE projects in other domains.

The aerospace domain has recently shown its interests in understanding SE and PM costs. The Applied Physics Laboratory (APL) of the National Aeronautics and Space Administration (NASA) has acknowledged increases in both the estimated and actual costs for SE and PM activities among its recent space projects, but was not able to provide a definitive rationale to explain the upward phenomenon (Shinn et al., 2010). The APL further concluded that current mission and instrument cost models are mostly driven by hardware and software factors, which can only account for a partial cost relationship to SE and PM costs. Furthermore, they reasoned that SE and PM costs may be strongly driven by management and engineering initiatives, policy changes and risk considerations (Shinn et al., 2010). They suggested that better SE and PM data collection and further analysis on project cost data must be established in order to support its current findings.

The relationship between SE and PM has been explored by several research studies. For example, Blacker and Winston (1997) and Gorski et al. (2004) utilized the Department of Energy's projects as examples and suggested that better project outcomes can be achieved when both SE and PM principles are performed concurrently. Other scholars attempted to analyze the tightly coupled relationship between SE and PM by differentiating processes and responsibilities (Dasher, G., 2003; Eisner, H., 2008; Isgrig, 2004; Kossiakoff and Sweet, 2003; Shenhar and Sauser, 2009; Stem et al., 2006; Watt and Willey, 2003), but they did not provide any basis for SE and PM cost methodologies.

In the SE community, a significant amount of research has been conducted by professionals and scholars investigating and estimating SE costs. For example, a survey sponsored by the International Council on Systems Engineering (INCOSE) has shown 52% of the systems projects expended 5% or less of total systems cost on SE tasks (Honour, 2004). As a systems cost estimating tool, COSYSMO is utilized to help systems engineers and systems cost estimators rationalize the economic implications of SE on systems development projects (Valerdi, 2006).

The PM literature reveals very limited information on PM related expenditures or costs, and this may be due to organizations frequently not identifying or measuring PM costs (Ibbs and Kwak, 2000b). Ibbs and Kwak (2000a) reported that their survey shows 80% of the participated companies spend less than 10% of total project cost for utilizing project management services, and the average PM cost is around 6%, which is higher than previously reported sources (Archibad and Villoria, 1967). However, the range of PM costs has a very wide range from 0.3% to 15% of the total project cost. In addition, Ibbs and Reginato (2002) indicated that the average cost of PM services is around 10% in their study. With various study results, it is evident that the magnitude of PM costs varies widely among organizations, which may be related to the major influential factors of project type and size, number of the projects and PM maturity level of the organizations (Archibald, 2003). Based on the literature review from this research effort, the literature is void of methodologies for determining PM cost and effort.

Value Adding to the Cost Estimation Body of Knowledge and Communities of Practice

In today's challenging economic conditions, systems development programs often encounter budget reductions that force program costs to be capped with limited resources. Systems programs constrained by limited resources have sought to reexamine their budgeting process and resource allocation method in hope of maximizing resource efficiency and program outcome. Several defense systems programs in Department of Defense (DOD) have attempted such effort (Jean, 2010); however, in order to ensure project success, every subset of project costs must be estimated and managed more efficiently and effectively, whether it is SE, software, or PM effort.

The focus of the research is PM cost and effort as aforementioned. The expected benefits of the research framework are that it will provide several capabilities that help project sponsors and cost estimators measure and quantify PM effort, allocate adequate funding and resources to each activity, generate PM cost estimates, and ultimately lead to a more efficient and effective program operation. Project sponsors and cost estimators who utilize the proposed cost estimating models can expect their projects to receive specific benefits listed as follows:

1. Determine adequate amount of resources needed for PM effort
2. Produce reliable and defensible cost estimates for PM effort
3. Allocate appropriate amount of PM resources for specific PM functions
4. Allow more robust and accurate project planning and tracking of cost and resources

Project Management Costing Model 1

The first proposed PM model is a synthesis of the current Constructive Systems Engineering Cost Model (COSYSMO) framework with variations on the effort multipliers that are primarily driven by PM functions and characteristics commonly seen throughout aerospace and defense systems projects. COSYSMO defines a parametric relationship that estimates and quantifies SE effort under nominal schedule in the units of person months. The size of the system is the weighted sum of the four systems size drivers, which consist of system requirements (REQ), system interfaces (IF), system algorithms (ALG) and operational scenarios (SCN), adjusted by 14 effort multipliers as the additive part of the model (Valerdi, 2005; Valerdi and Dixit, 2006). The function determining effort within COSYSMO is expressed in the equation below:

$$PM_{NS} = A \cdot \left(\sum_{k} (w_{e,k}\Phi_{e,k} + w_{n,k}\Phi_{n,k} + w_{d,k}\Phi_{d,k}) \right)^{E} \cdot \prod_{j=1}^{18} EM_{j} \qquad (1)$$

Where,

PM$_{NS}$ = effort in Person Months (Nominal Schedule)
A = calibration constant derived from historical project data
k = {REQ, IF, ALG, SCN}
$\mathbf{w_k}$ = weight for "easy", "nominal", or "difficult" size driver
$\mathbf{\Phi}_{\boldsymbol{k}}$ = quantity of "k" size driver
E = represents diseconomies of scale
EM = effort multiplier for the *j*th cost driver. The geometric product results in an overall effort adjustment factor to the nominal effort.

As a preliminary research result, the research effort has identified 18 PM effort multipliers that may be driven by PM functions and characteristics that are listed in Table I below (Akintoye, 2000; Anderson and Brown, 2004; Baccarini, 1996; Crawford et al., 2005; de Wit, 1988; Hamaker and Componation, 2005; Hartman and Ashrafi, 2002; Honour, 2010; Jain et al., 2008; NASA, 2010; Valerdi, 2005; Williams, 1999).

Table I. The Preliminary Set of 18 PM Effort Multipliers

PM Effort Multipliers	**Definition**
Scope Understanding	The degree of understanding project scope that includes systems requirements, architecture, design/blueprints and systems specifications (Valerdi, 2005).
Scope Volatility	The degree that top level project scopes are defined, documented, and stabilized. Initial scopes were substantially changed after project kickoff. Scope can be seen as project boundary in term of labor hours required to accomplish or deliver a product or service (Hartman and Ashrafi, 2002).
Scope Growth	Additional new project scopes are added to the exiting scopes (Hartman and Ashrafi, 2002).
Requirements Volatility	The degree that top level project requirements are defined, documented, and stabilized. Initial requirements were substantially changed after project kickoff (requirements are features and functions of a product) (Hamaker and Componation, 2005; Honour 2010; Valerdi, 2005).
Requirements Growth	Additional new project requirements are added to the existing requirement sets (requirements are features and functions of a product) (Hamaker and Componation, 2005; Honour 2010; Valerdi, 2005).

Table I. The Preliminary Set of 18 PM Effort Multipliers (continued)

PM Effort Multipliers	Definition
Budget Constraints	The degree that the project has a budget limit or constraint after the project has been authorized by sponsors (funding limit, stability, etc.) (NASA, 2010).
Schedule Span	The degree of flexibility for the project delivery date. The date the project is to be ready for initial operating capability in relation to the start date (Hamaker and Componation, 2005).
Project Complexities	• Project Complexity: Contains two dimensions – organizational and technological, and consists of various interrelated parts that can be operationalized in terms of differentiation and interdependency, or connectivity (Baccarini, 1996). • Migration Complexity: The extent to which the legacy system affects the migration complexity (Valerdi, 2005).
Systems Complexities	• Product Complexity: The physical deliverable of a project that is the number of subsystems of a product and their interrelationships (Williams, 1999). • Integration Complexity: The magnitude of technical integration requirements on systems capabilities and functions, interface performance, strategies, methodologies at system and subsystem levels (types – hardware integration, software integration, hardware and software integration, validation and verification complexity, human systems integration; levels – subsystems integration, components integration, unit integration) (Jain et al., 2008). • Testing Complexity: The degree of testing needed to be performed, versus analytical verification, considering the effort and procedures of testing, durations and number of repetition, verification and validation complexity, usability/user complexity/human systems integration (Hamaker and Componation, 2005).
Documentation Level	The level of detail/formality that is required of the documentation process (Honour 2010; Valerdi, 2005).
Level of Service Requirements	The level of difficulty and criticality of satisfying the environmental, security, maintainability, and reliability of Key Performance Parameters (KPPs) as required by services performed (Honour, 2010; Valerdi, 2005).
Stakeholder Cohesion	Represents a multi-attribute parameter which includes leadership, vision, diversity of stakeholders, approval cycle time, group dynamic, the integrated product team framework, trust, and amount of change in responsibilities (stakeholders are sponsors, contractors, partners, and team members, both passive and active) (Hamaker and Componation, 2005; Honour, 2010; Valerdi, 2005).
Project Management Maturity	The level of project management processes and practice established in an organization, such as Project Management Office (PMO) (Crawford et al., 2005; de Wit, 1988; Hartman and Ashrafi, 2002).
Project Management Experience/Continuity	The applicability, consistency and effectiveness of PM performance demonstrated by PM staff at initial stage of the project with respect to the domain, customer, user, technology, and tools (Crawford et al., 2005; Hamaker and Componation, 2005; Valerdi 2005).

Table I. The Preliminary Set of 18 PM Effort Multipliers (continued)

PM Effort Multipliers	Definition
Process Capability	The consistency and effectiveness of the project team at performing PM processes (Honour, 2010; Valerdi, 2005).
Technology Maturity and Risk	The degree of maturity, readiness, and obsolescence of the technology being implemented or integrated (Honour, 2010; Valerdi, 2005).
Tool Support	Coverage, integration, and maturity of the tools (apparatus, applications) in the project management environment (Honour, 2010; Valerdi, 2005).
Multisite Coordination	The level of collaboration barriers and number of locations of stakeholders, PM team members and resources (i.e. local, regional, national, international) (Honour, 2010; Valerdi, 2005).

This first model assumes that PM cost and effort are dependent on SE project size in which the cost relationship can be established based on the number of system requirements, interfaces, algorithms, and operational scenarios derived from a system design. In other words, PM cost and effort is a function of SE cost and effort, and the necessary amount of PM cost and effort can be estimated based on SE project size. Thus, based on this model, the total PM cost and effort required for systems development projects can be quantified and calculated through the 18 PM effort multipliers placed within the COSYSMO equation.

According to the cost model development methodology, initiated at the University of Southern California (Boehm et al., 2000; Boehm and Valerdi, 2008), the proposed research model structure and its 18 PM effort multipliers need to be validated and verified by industry practitioners and subject matter experts (SME). Their professional experience in project management, systems engineering, software engineering, and technology management can help determine an appropriate set of PM effort multipliers, as well as provide constructive insight for research model improvement.

<u>Project Management Costing Model 2</u>

The second research model is constructed based on the unique characteristics and functions of project management. The model is considered to be of the same expression form as the Constructive Cost Model II (COCOMO II) and its family products, such as COSYSMO. The proposed model is expressed as:

$$PM_{NS} = A \cdot \left(\sum_{k} (w_{e,k}\Phi_{e,k} + w_{n,k}\Phi_{n,k} + w_{d,k}\Phi_{d,k}) \right)^{E} \cdot \prod_{j=1}^{5} EM_{j} \qquad (2)$$

Where,
PM_{NS} = effort in Person Months (Nominal Schedule)
A = calibration constant derived from historical project data
k = {**REQ, PCR, CST, SCM, DCL**}
w_k = weight for “easy”, “nominal”, “difficult”, or “**low**”, “**medium**”, “**high**” size driver
Φ_k = quantity of “k” size driver

E = represents diseconomies of scale
EM = project management efficiency multiplier for the *j*th cost driver. The geometric product results in an overall effort adjustment factor to the nominal effort.

Contrary to the first proposed model, the second proposed model determines PM cost and effort independently without a sole reliance on SE project size. The cost relationship is established by project factors that dictate PM functions and characteristics, further impacted by PM efficiency. These PM effort factors are comprised of project requirements and scope (REQ), project complexity and risk (PCR), project constraints (CST), stakeholder cohesion and multisite coordination (SCM), and documentation and communication level (DCL), which are measured and quantified distinctively by the number, depth of complexity and difficulty, and degree of limitation in a given project setting. Moreover, the PM efficiency multipliers are measured by project managers' capability, PM process maturity and tool support. Tables II and III show the defined PM effort factors and efficiency multipliers in detail.

Table II. PM Effort Factors

PM Effort Factors (k)	**Defined by**
Requirements and Scope (REQ)	*Project Understanding* • Scope of requirements • Number of requirements • How mature PM responsible artifacts are defined − statement of work (SOW), work breakdown structure (WBS), etc. • Requirement creep: volatility and rate at which requirements are changing, new requirement increment
Project Complexity and Risk (PCR)	*Project Complexity and Risk Identification* • What is the level of risk for the project? • What is stakeholders' risk attitude – risk adverse? • How difficult is it to assess the risk? • How complex is the project? − project complexities • organizational, technological/product − e.g., PM related integration, coordination, etc. • Number of known project complexities and risks
Project Constraints (CST)	*Project Constraint Factors* • Schedule span − time constraints − deliverable date − amount of slack time allowed • Budget constraints − money/cost constraints • Resource constraints − human resources • Function/feature − minimum acceptable features • Quality − minimum acceptance by customers

Table II. PM Effort Factors (continued)

PM Effort Factors (k)	Defined by

Stakeholders Cohesion and Multisite Coordination (SCM)	*Amount of External PM Work Required*
	• Number of stakeholders
	• Diversity of stakeholders
	  – e.g., have opposing goals/objectives, have different world views
	• Communication challenges
	  – external clients, internal clients, contractors, languages, time zone difference, etc.

Documentation and Communication Level (DCL)	*Amount of Internal PM Work Required*
	• Amount and complexity of required documentation
	  – e.g., project plan, resource management plan, status reports, etc.
	• Amount and complexity of required communications
	  – cubical/office noise
	    • solving project issues
	  – e. g., number, length and frequency of meetings, etc.

Table III. PM Efficiency Multipliers

PM Efficiency Multipliers (EM)	Defined
People Capability – PM Attributes*	• Communication skills • PM experience • Information-sharing willingness • Delegates appropriately • Well-organized • Supports and motivates project team • Open-minded and flexible • Provides constructive criticism • Positive attitude • Technical competency • Team builder and player • Ability to evaluate and select project resources • Goal-oriented • Courage and conflict-solving skills • Problem-solver • Takes initiative • Creativity • Integrator (team, PM activities, etc.) • Decision-making skills

Table III. PM Efficiency Multipliers (continued)

PM Efficiency Multipliers (EM)	Defined
Process Maturity**	• PM process maturity (CMMI, The Berkeley PM Process Maturity Model) • Organization PM maturity (PMI-OPM3) 5 stage PM maturity standard: o Initial o Repeatable o Defined o Managed o Optimized
Tool Support**	• Level of tool automation 5 stage automation: o Very few primitive tools o Basic/micro tools o Extensive/few integrative tools o Moderately integrated environment o Fully integrated environment

* Adapted from Software Development Cost Estimating Guidebook (USAF Air Logistics Center, July, 2009) & Essentials of Project and Systems Engineering Management (Eisner, 2008)
** Adapted from Software Development Cost Estimating Guidebook (USAF Air Logistics Center, July, 2009)

Identification of Project Management Processes, Functions, and Responsibilities

In order to further proceed with the research effort, the boundary of PM processes must be defined. It is particularly important for the first proposed model, that although both PM and SE disciplines complement each other through collaborative project processes, the difference among these two disciplines must be distinguished. The distinction recognized is that SE integrates the technical input to projects, and PM utilizes management tools and techniques, such as the Gantt chart and Work Breakdown Structure (WBS) for project planning, execution, monitor and control, as well as risk management (Isgrig, 2004). According to Shenhar and Sauser (2009), a systems development project can be generally seen as consisting of a technical (SE) process and a managerial (PM) process, where both processes interact throughout the systems development life cycle phases. Figure I illustrates the general processes and functions between PM and SE.

The research effort has utilized the defense industry as a starting point to further differentiate these two disciplines in detail, which is particularly helpful to the first proposed model. As shown in Tables IV and V, the DOD (2010) has outlined the management and technical processes for the weapon systems development projects, where the specific roles and accountabilities are identified for both project managers and systems engineers. The scope of the research effort will only investigate the roles and responsibilities within the management process.

Figure I. General Processes between PM and SE in a Project (Modified from Shenhar and Sauser, 2009)

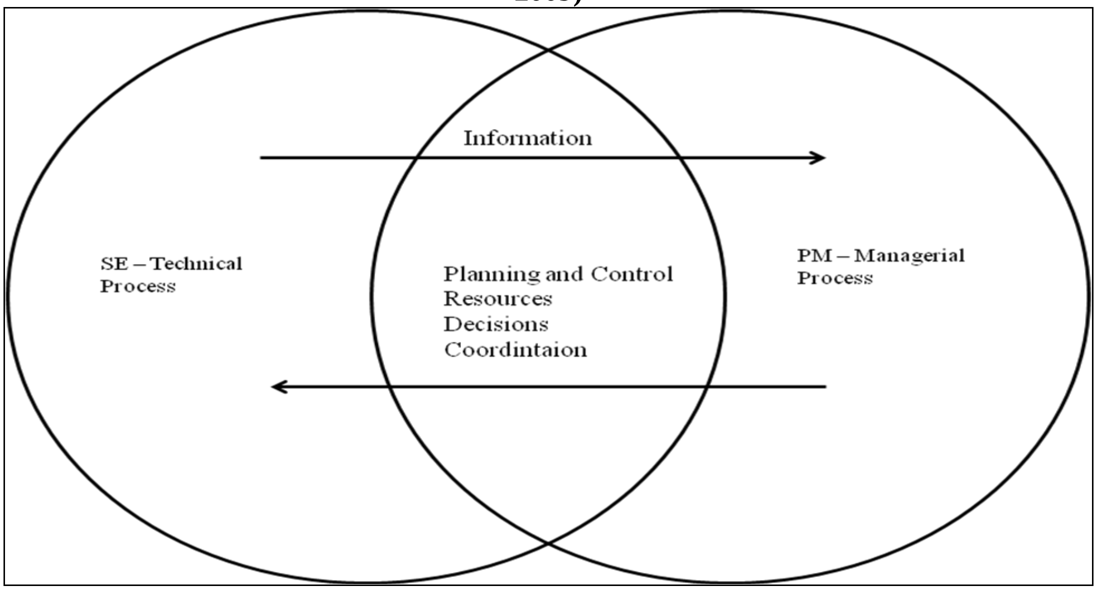

Table IV. The Separation of Technical Management Processes (PM) and Technical Processes (SE) in the Defense Systems Development Project Life Cycle (Modified from DOD, 2010)

Technical Management Processes (PM)	Technical Processes (SE)
Decision Analysis	Stakeholders Requirements Definition
Technical Planning	Requirements Analysis
Technical Assessment	Architectural Design
Requirement Management	Implementation
Risk Management	Integration
Configuration Management	Verification
Technical Data Management	Validation
Interface Management	Transition

Table V. The Roles and Responsibility of Program/Project Manager and Systems Engineer in the Defense Systems Development Project Life Cycle (Modified from DOD, 2010)

Project Life Cycle Processes	Program/Project Manager	Chief/Systems Engineer
Stakeholder Management	Primary	Support
Technical Planning	Support	Primary
Decision Analysis	Primary	Support
Technical Assessment (Includes Program Status: Technical Progress, Schedule & Cost Management)	Shared	Shared
Configuration Management	Primary	Support
Data Management	Primary	Support

Table V. The Roles and Responsibility of Program/Project Manager and Systems Engineer in the Defense Systems Development Project Life Cycle (Modified from DOD, 2010) (continued)

Project Life Cycle Processes	Program/Project Manager	Chief/Systems Engineer
Requirements Management	Support	Primary
Contract Management	Primary	Support
Requirements Analysis	Support	Primary
Architecture Design	Support	Primary
Implementation	Support	Primary
Risk Management	Primary	Support
Interface Management	Support	Primary
Integration	Support	Primary
Verification	Support	Primary
Validation	Shared	Shared

Research Procedures and Next Steps

As the PM processes are preliminarily defined as aforementioned, the research effort will further analyze PM activities and functions through a top down process decomposition method. A top down decomposition is to view an entity as whole, e.g. a system, and decompose each systemic layer to the lowest level of operation (Hoyle, 2006). Thus, the elements and constituents of PM effort can be easily comprehended and measured. The research effort will utilize the PM knowledge areas listed in the Project Management Body of Knowledge guidebook (PMBOK; PMI, 2004) as the examining basis, as it is commonly recognized and practiced by professionals across industries. The PM knowledge areas are listed as follows:

1. Project Integration Management
2. Project Scope Management
3. Project Time Management
4. Project Cost Management
5. Project Quality Management
6. Project Human Resource Management
7. Project Communications Management
8. Project Risk Management
9. Project Procurement Management

The PMBOK has listed 44 PM specific processes residing within these 9 PM knowledge areas. The research effort will examine each PM process to identify specific PM functions, documentation and process output artifacts that project managers are responsible to perform and produce throughout a project development life cycle. Once the specific PM functions, documentation, and process output artifacts are identified, the research will design a survey and conduct interviews with PM practitioners to examine and refine the preliminary result. As the models mature and can be validated and verified by industry experts and data, the research intends to collect historical cost data from public and commercial industries. Through collaboration, industry data will allow the research to measure and compare the accuracy and consistency given in each model, and determine the applicability and appropriateness of each model for specific industry usage and calibration.

Summary and Conclusion

A considerable amount of research effort has been devoted to SE cost estimating in which several methodologies and tools, such as COSYSMO, have been developed and validated by scholars and practitioners. Yet, the literature is void of methodologies for estimating PM cost and effort. Thus, the ultimate goal of the proposed research framework is to construct a PM cost estimating model that can fill the void and help practitioners generate accurate, reliable and defensible PM cost estimates. Two PM costing models have been proposed and are being investigated. The first model is a synthesis of the COSYSMO framework with variations on the effort multipliers that are primarily driven by PM functions and characteristics. The second model is constructed based on the unique characteristics and functions of PM.

A preliminary set of 18 PM effort multipliers for the first model will be verified and validated by SE and PM practitioners and professionals in the near future. The second model requires further identification of PM functions, documentation and process output artifacts. Once the preliminary result is achieved, a survey and interviews will be conducted with practitioners to validate and verify the findings. Furthermore, as the model structures mature, the research intends to collect historical cost data from public and commercial industries to test the accuracy and consistency of the models. The study is expected to provide several benefits that help project sponsors and cost estimators measure and quantify PM effort. The end users can expect their projects to receive these specific advantages: 1. Determine adequate amount of resources needed for PM effort, 2. Produce reliable and defensible cost estimates for PM effort, 3. Allocate appropriate amount of PM resources for specific PM functions, and 4. Allow more robust and accurate project planning and tracking of cost and resources.

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