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Engineering Management Framework in Support of Modeling & Simulation Application for Domain Specific Procurement

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ENGINEERING MANAGEMENT FRAMEWORK IN SUPPORT OF MODELING & SIMULATION APPLICATION FOR DOMAIN SPECIFIC PROCUREMENT

by

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ABSTRACT

ENGINEERING MANAGEMENT FRAMEWORK

IN SUPPORT OF MODELING & SIMULATION

APPLICATION FOR DOMAIN SPECIFIC PROCUREMENT

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A strategic process is desirable for project-based organizations in order for them to be efficient and effective when developing Modeling & Simulation (M&S) systems. This thesis proposes an overarching process that combines traditional M&S and Engineering Management methodologies in a new framework to support M&S organizations during the procurement process.

This thesis proposes both a Strategic Project Management Process (SPMP) and a systems engineering process for M&S federation development projects. The systems engineering process utilizes the artifacts of Model Driven Architecture (MDA) to support building M&S federations driven by operational requirements. Detailed research of this systems engineering process revealed a project specific SPMP that offers organizations a management tool for M&S federation acquisitions and supports a better understanding of the task(s). The SPMP is based on engineering management core processes of strategic management and knowledge management and is designed to support the operation of a M&S organization.

The thesis also contains an empirical study of a U.S. Army procurement project that federated two heterogeneous simulation models to solve a complex problem. The goal of

this study was motivated by the need to support the project management with a consistent view of the sponsor's challenges in compliance with relevant processes.

The theme of this thesis is a process for project-based organizations to utilize as a **best practice** enabling them to increase their productivity and overall effectiveness when developing M&S federations during procurement.

My greatest gratitude goes to my entire family who are great supporters and especially to my wife Lisa and my friend Craig whom had convinced me to take my education to the next level, if it was not for them I would not be writing this today. Thank you!

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Thank you Dr. Andreas Tolk for giving me an opportunity to work in the Modeling & Simulation field during my Engineering Management studies at Old Dominion University. Also, thank you for your encouragement and guidance throughout my studies and research at the Virginia, Modeling, Analysis, and Simulation Center (VMASC).

Lastly, I thank my colleagues at VMASC for providing support and guidance as well as the Faculty of Old Dominion University for providing an outstanding education in Engineering Management and Modeling & Simulation.

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LIST OF ACRONYMS

AHP	Analytical Hierarchy Process
BA	Body Armor
C^2	Command and Control
COBP	Code of Best Practice
COTR	Contracting Officer Technical Representative
FEDEP	Federation Development and Execution Plan
HLA	High Level Architecture
IWARS	Infantry Warrior Simulation
L/L	Lessons Learned
LC	Life Cycle
MDA	Model Driven Architecture
M&S	Modeling and Simulation
MoM	Measures of Merit
ODU	Old Dominion University
OneSAF	One Semi-Automated Forces
PEO	Program Executive Office
PM	Project Manager
R&D	Research and Development
SME	Subject Matter Expert
SOW	Statement of Work
SPMP	Strategic Project Management Process
VMASC	Virginia Modeling, Analysis, and Simulation Center
WBS	Work Breakdown Structure

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1. INTRODUCTION

1.1 Problem Statement

The systems engineering process presented in this thesis was initiated in support of a recent study by Old Dominion University's Virginia Modeling, Analysis, and Simulation Center (VMASC) in collaboration with the United States Military Academy (USMA). Developed by an Old Dominion University team, this strategic process recommends a "best practice" that aligns existing methods – Modeling & Simulation (M&S) and project management – in a new way to support organizations during the procurement process of M&S federations.

The systems engineering process utilizes the artifacts of Model Driven Architecture^{TM} (MDA) to support building M&S federations driven by operational requirements [4]. Detailed research of this systems engineering process revealed a project specific *Strategic Project Management Process* (SPMP) that offers organizations a management tool for M&S federation acquisitions and supports a better understanding of the problem. The study was motivated by the need to support the project management with a consistent view of the sponsor's challenges in compliance with relevant processes as described [4]:

- ❖ The essential tasks to be used for the evaluation should be identified to support the selection or development of relevant vignettes or scenarios.
- ❖ Simulation systems should be selected based on their ability to support the evaluation of these tasks. The simulated system capability should be the driver for the decision.
- ❖ The process should be applicable to evaluate alternatives for supporting simulation components and enable the project manager to make informed decisions.

The journal model for the references herein is The Journal of Defense Modeling and Simulation: Application, Methodology, and Technology, the journal of the Society of Modeling and Simulation International.

- The federation of these simulation systems should be supported utilizing the best middleware available for the task. This decision should be driven by the functionality of the middleware and its necessity in the federation development process.
- The integration of systems and middleware should be supported to the maximum extent. The decisions of model integrators should be reduced to a minimum, thus avoiding ambiguity of interpretations. Existing solutions should be reused as much as possible.
- *Minimize* the number of supporting simulation systems that represent the scenario.
- *Minimize* the costs of obtaining the simulation systems and supporting data.
- *Maximize* the use of simulation system under governance of the project manager.
- *Maximize* the acceptance of systems.

Strategic management of a project can be defined as the management of multiple projects inside a project-based organization to achieve a common vision, mission, or goal. To carry out strategic management, it is implied that the performance of projects are measured at the project level, by means of Measures of Merit (MoM), and at the organizational level, by means of complicated measures. These measures – also known as metrics – aggregated together within the project-base organization provide a method of comparing projects to each other and allowing management to make informed decisions.

The empirical data used in this thesis is in support of an acquisition task currently being conducted by the U.S. Army. The Army's Program Executive Office (PEO) - Soldier has the complex task of acquiring and integrating a system for soldier equipment that meets their mission requirements. To better assess tradeoffs in different soldier architectures, they seek an improved simulation capability that better represents the individual soldier on the battlefield. No single model provides this capability. The Army is pursuing a strategy of integrating different simulation models to take advantage of the strengths of each. This thesis also defines questions in support of acquisition decisions supported by the systems engineering process.

Moreover, this thesis describes a proposed process, provides an example, and summarizes the various necessary requirements to apply this process – by using systems engineering and engineering management methodologies. The SPMP proposed in this thesis is based on several relevant and community accepted methods and standards – considered as "recommended practice". Due to an enormous variety of supporting methods and standards, the proposed SPMP can be neither complete nor exclusive.

1.2 Background Information – The Task

The U.S. Army's Program Executive Office (PEO) - Soldier has obligations to analyze the unit-level effectiveness of alternative soldier architectures – that is a soldier's entire ensemble of equipment, to include future situation awareness and command and control (C^2) systems. The latest requirement is to acquire a new type of body armor (BA) for the entire force. PEO Soldier desires to use a simulation model to support this procurement obligation.

The current effort is an integrated approach that is exploited by using two pre-existing simulation models tied together within a federation. One Semi-Automated Forces (OneSAF) and Infantry Warrior Simulation (IWARS) are two simulation models used by the Army. The former, simulates the battle-space management (mid resolution) and the latter, infantry force-on-force (high resolution). PEO Soldier, established on November 1, 2007, a research and development (R&D) initiative – funded at $750K – to integrate these two heterogeneous simulation models together – referred to as federating. This initial integration will act as a test platform for future tasks.

Old Dominion University's (ODU) VMASC was awarded a contract to conduct research on how (1) the two simulation models should be integrated, (2) oversee the integration efforts by two independent project groups (OneSAF and IWARS), and (3) propose a reusable systems engineering process for future M&S federation development challenges. The OneSAF and IWARS programs were directly responsible for software engineering, program management, etc. with respect to their corresponding simulation model during the integration. PEO Soldier is located in Fort Belvoir, VA, the OneSAF program is located in Orlando, FL, the IWARS program is located in Boston, MA, and the U.S. Army's analysts work in White Sands, NM.

1.3 Analysis Disclaimer

The objective of this thesis is to provide a "recommended practice" by utilizing a proposed SPMP in conjunction with data derived from research. This thesis contains empirical data from research conducted by the author while working at VMASC and the class work of the author while attending ODU. Of particular note, two courses of study will be used heavily in this thesis; a *Project Management* centric view and an *Information Technology: Systems Analysis and Design* specific view. Both of theses courses required extensive research utilizing the above methodologies to produce end-of-course "final" reports. A portion of the data in the analysis is notional and should be considered for academic purposes only. Segments of the project management analysis was found to be incomplete due to the nature of the project, therefore, fictional data was devised and approved by subject matter experts (SME).

1.4 Project Manager (PM) Related Issues of Federation Development

A classic project manager (PM) may view a M&S federation problem as a typical software engineering management problem. However, developing a M&S federation is extremely unique in and of itself and requires special consideration throughout the development cycle. For example, a M&S model selection may require multiple organizations, multiple platforms, multiple methodologies, etc. to unify and solve a complex task – in a sense creating a very dynamic project. The added complexities of this dynamic project need to be addressed in ways a typical PM may have never experienced or dealt with before.

PEO Soldier's project tasked two different Army organizations (OneSAF and IWARS) to combine their M&S models together to solve a complex M&S problem. Integrating these two model organizations along with a Contracting Officer Technical Representative (COTR) and VMASC, a total of five organizations (stakeholders), produced a very multifaceted operating environment.

Despite typical problems associated with project management, managing five organizations added an element of difficultly beyond the norm. What made matters more difficult for this particular project is the fact that every organization was located in a different part of the U.S. As with most organizations, each has its own beliefs, philosophies, missions, goals, etc. that creates a unique culture for each.

In the following subsections, several important subjects with respect to project management and developing M&S models will be discussed. PMs should be familiar with these subjects when considering managing M&S federation projects. The following subjects were noted (but not limited to) within the PEO Soldier project: *the understanding of common* *elements with all participating organizations* (Section 1.4.1); *social, technological, and management characteristics* (Section 1.4.2); and *macro and micro management* (Section 1.4.3).

1.4.1 Missions and Required Capabilities

Truly integrated operations depend on a solid foundation of common elements understood between all participating partners and organizations [7]. One method is to establish a Mission Essential Task List (METL) that lists the operational tasks required to doctrinally accomplish a given mission. These tasks may also be mapped to a common Universal Joint Task List (UJTL). Several separate initiated U.S. DoD programs, as well as some Homeland Security efforts, are planning to base their metrics of performance on Mission Essential Tasks (MET).

Despite the need for better harmonization in all of these efforts, a military task is identified and necessary capabilities to perform these tasks are captured. The targeted result is a list of METs, related capabilities, and metrics to measure the performance (this will be discussed in Section 3.4). It should be noted that a MET should not be tightly coupled with a system or a capability implementation. The MET should describe the conceptual capability which – at least in theory – can be delivered by several systems or system components.

These ideas are tightly connected with the military Missions and Means Framework (MMF) – the context is defined by a military mission and the military means that are needed to conduct the mission. The MMF is DoD Architecture Framework that provides an operational view describing what operational nodes are needed and which operational activities are conducted.

To assure scientific evaluations based on experimentation, a metric is needed that captures (1) what data is collected and (2) how this data is used to define success or failure.

To conduct the evaluation, these task elements must be put into a meaningful operational context. This is done by setting them into the context of a scenario or a vignette. The design process for setting up a scenario is as follows:

- All tasks that are conducted by the system are added to the task list to be evaluated.
- All tasks that are supported by tasks conducted by the system are added to the task list to be evaluated.
- All tasks that are influenced (higher order effects) by the system are added to the task list to be evaluated.
- Operational vignettes or scenarios comprising all tasks on the task list to be evaluated (if necessary prioritized by operational effects) are defined.

The result of these steps is a scenario, or a list of vignettes, that comprises all tasks and metrics needed to evaluate the system.

1.4.2 Social, Technological, and Management Characteristics

Keating proposed *Project Management Systems* (PMS) to facilitate an understanding of project management and to provide a system that is based on the systems science model [12]. His research concluded that true "integration" of all of the elements within a project leads to success. Keating defines PMS as:

> The structure set of technical and human entities that interact both formally and informally within a specific context to produce project results. The product of interactions are patterns of decision, action, and interpretation that drive project performance.

Keating defines technical entities as mechanisms such as techniques (e.g. project plans), procedures (e.g. resource management), policies (e.g. authority), or processes (e.g. performance measures) to help achieve project objectives; and human entities are considered people or groups, such as stakeholders [12]. Interactions between the two entities are recognized formally and informally and have a common contextual characteristic within a project called project context. This project context can be defined by a set of conditions within an environment that persuades project outcomes. Therefore, Keating implies that there is a systemic relationship between entities within a project [12].

It was observed during the development of PEO Soldier's M&S federation that three unique characteristics (social network, technological, and management as shown in Figure 1), emerged with respect to project management. The key to the success of the PEO Soldier's project was the alignment of all three characteristics. In the initial stages of the project there were delays and setbacks due to misalignment of the above mentioned characteristics. Without alignment, project success and performance may be marred with one or more of the characteristics becoming flawed.

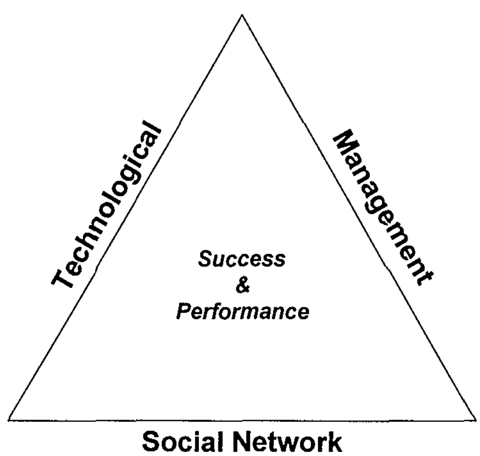

Figure 1. Social, Technological, & Management Alignment

Generally speaking, it can be said that "networks achieve results" or "networks make it happen". For example, when you ship a package from your local post office it does not instantly appear at the destination – it was shipped via a network. If you take a micro view of that network, you will find that there are many hidden connections within the network that processed your package and shipped it to its final location. This example can be compared to social networking.

As with services, people within organizations can be viewed as a network too. Connections between people sometimes are often hidden and are not trivial. Measures by management, outside agencies, tools, etc. are needed to "bring together" a team to solve complex problems. As the project organization came together members were unfamiliar with each other and the processes they were about to observe – a solution was needed.

A new form of social networking is gaining traction on the internet and is becoming an online phenomenon. Several online resources (e.g. Community of Science (CoS), XING, LinkedIn ™) allow people to communicate, exchange personal information (e.g. "get to know each other", check credibility of technical backgrounds), and discover with whom they are associated. LinkedIn[1] ™ was randomly chosen as the online resource to allow members to connect with each other and to start the socialization process within the newly formed project organization. An observed side-effect of LinkedIn ™ was the hidden connections to other colleagues within the M&S field. These hidden connections allowed members to connect with others inside and outside of the organization to help solve complex problems associated with the M&S federation development.

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[1] LinkedIn ™ is an online social networking tool with more than 25 million experienced professionals from around the world. It allows users to summarize processional accomplishments and helps users connect with present and former colleagues, clients, and partners by "connections".

Luthans defined socialization as: "is the role of persons, groups, and especially organizations that greatly influence an individual's personality" [1]. Therefore, it can be said that organizations contribute to human behavior. However, the opposite can be said about humans; they too can influence and drive organizations depending on the social makeup of the people within. People and organizations behave differently depending on the values, norms, points of views, interpersonal skills, etc. that they posses. For that reason, newly created organizations, i.e. a project organization, may need time to adjust to the diverse values of others.

For example, a new employee joins an organization and has an adjustment period known as "getting to know their working environment". He or she needs a period of time for adjustment, so they may learn who is in charge and when, informal networks, political stances, unspoken rules, influences of others, etc. If a project organization is not given ample time and special attention to adjust, expected results may differ and/or be delayed.

Schein defines organizational culture as "a pattern of basic assumptions – invented, discovered, or developed by a given group as it learns to cope with its problems of external adaptation and internal integration" [15]. It has been proven that success of projects is influenced by the culture of an organization [13].

There are two culture challenges PMs must contend with. First, PMs must organize and develop a "suitable" organizational culture that fits the problem. Second, PMs must understand the social makeup of the people – i.e. their strengths and weaknesses – and all subcultures with which the project is connected. In other words, PMs need to have an understanding of all cultures involved with the project, so he or she may interact effectively with all concerned. These challenges are not intuitive and require experience and time to develop. Cultures cannot evolve overnight; they often need time and resources to establish; however, once they are functioning effectively, success can be achieved.

PEO Soldier's task required the usage of heterogeneous M&S models owned and operated by dissimilar organizations within the Army. Each of the organizations maintained different beliefs, goals, management styles, etc.; these differences initially caused the project problems. Moreover, the project often experienced technological struggles as to which methodology should be used. This issue was caused by the different types of technology available and their role within the project – each group thought their solution was the "best solution". Matters like this are delicate and should be treated in a diplomatic way to ensure that all parties involved are given equal opportunity to express their views. Therefore, when creating a new project organization, special consideration should be implemented for the people and technologies involved.

The final characteristic observed during the PEO Soldier project was management. Management is very dynamic, and no one solution can be utilized for all given instances. Combining forces within organizations that have different cultures and management styles, may cause clashes and initial problems within a newly formed project organization. Once again, these differences require special dedication of top-level managers to ensure that management policy is established, communicated, and followed down and throughout the project organization.

Aligning social networking, technological differences, and different management styles can be difficult. However, a PM can play a key role in aligning all three characteristics together to form a solid organization that is able to perform and deliver a successful product by the end of a project.

1.4.3 Macro & Micro Management

With the complexity of developing M&S federations it is important to maintain two different project management approaches: *macro* and *micro*. Each may be viewed in similar ways; however, they are very different in the nature in which they are utilized. In general terms the macro approach may be considered for top-level management, and the micro approach may be considered for technical management. The micro approach should not be considered a mid-level management approach. It is important for technical managers to have autonomy and not have to report every detail to their top-level managers; they should only have to report major developments and/or status updates.

The role of the PM can and will vary from person-to-person and project-to-project. Some PMs may want to know finer details of a project whereas others may want the technical managers to handle and represent the technical details. Depending on the intended use and situation, PMs may want to maintain and utilize both approaches.

For example, M&S model development utilizes a methodology called Verification[2] and Validation[3] (V&V) – in other words quality control. Technical managers should have in-depth knowledge of and a complete understanding of the process and manage it for the duration of the project. It is not recommended that the PM and sponsor be heavily involved in V&V; they should maintain a focus on the project itself and ensure that the final product conforms to the set forth requirements.

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[2] Validation: The process of determining the degree to which a model and its associated data are an accurate representation of the real world from the perspective of the intended uses of the model. [DoD 5000.61]
[3] Verification: The process of determining that a model implementation and its associated data accurately represent the developer's conceptual description and specifications. [DoD 5000.61]

Based on the experience gained during the PEO Soldier project, below are two recommended management team constructs: macro and micro. These constructs may be modified to best fit the project-at-hand.

Table 1. Macro Management Team

Team Members
Senior Managers
Sponsor
Project Manager
Contracting Officer Technical Representative (COTR)
Academic Advisors
Implementing Team Managers

Table 2. Micro Management Team

Team Members
Implementing Team Leaders
Contracting Officer Technical Representative (COTR)
Team Leaders
Technical Leaders
Technical Advisors
Implementing Team Managers
Implementing Team Leaders

1.5 A Proposed Strategic Project Management Process (SPMP)

Systems engineering and project management are two core engineering management processes supported by core "quantitative" disciplines within engineering management problems [3]. Traditional approaches to systems engineering focus on a single system being engineered and managed (i.e., project managed) while challenges as described in [4], require a strategic management approach that promotes a process flow in which the outputs of one project (e.g., deliverables, knowledge, work documents) are captured for the benefit of other sequential projects within and outside the project-based organization. Two other core processes of engineering management are critical and must be incorporated into this process flow: knowledge management and strategic management [3].

The NATO Code of Best Practice (COBP) for Command and Control (C^2) Assessment [5] is an operations research process which recommends best practices for the structure of a project. NATO's COBP deals with similar challenges as explained in [4] and the introduced phases are captured in Figure 2.

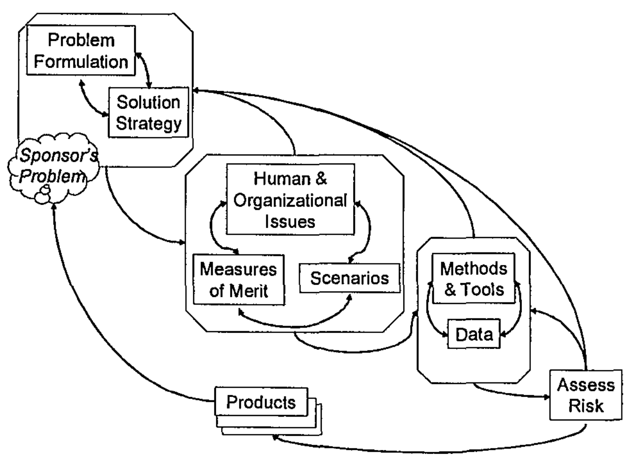

Figure 2. NATO COBP for C2 Assessment Phases

While evaluating traditional project management methodologies and artifacts (e.g., the statement of work (SOW), work breakdown structure (WBS), resource management) and NATO's recommended COBP phases, three core phases were recognized and linked to develop a reusable project specific strategic project management process (SPMP). This SPMP opens the way for reusability of the outputs of a single project and should enable the project-based organization to become more effective and efficient over time.

Figure 3 captures the combined phases – from engineering management and NATO's COBP – to illustrate a SPMP flow that can be utilized for M&S federation development. Of the three core phases (*initial planning, refining and implementation*) each requires supporting documentation and sub-processes to deliver a product.

Table 3. SPMP Core Phases and Outputs

Core Phase	Output Product
Initial Planning	Project Proposal
Refining	Project Work Plan
Implementation	Final Product

Supporting documentation, noted in Figure 3, contains key information and necessary knowledge required to take a M&S conception to reality – i.e. the development cycle. It should be noted that each phase has sub-processes where several reiterations may be needed to facilitate proper coverage of the requirements and to apply lessons learned (L/L), best practices, and near-miss events from previous projects (i.e. knowledge management).

Project management and the technical implementation success of a single project hinges on past experiences and the transfer of knowledge from preceding projects. Different artifacts are identified to promote this continuous improvement cycle: study plan, project journal, and risk management. A study plan and/or project journal maintained, communicated and socialized to all members promotes a well informed team. Risk analysis and management is recommended in order to avoid unforeseeable difficulties and/or setbacks and is enabled by using knowledge collected from previous projects to assess and address the consequences of reducible and irreducible uncertainty.

Therefore, it can be said that risk management and risk mitigation can be viewed on two different levels: the project level and the project-based level. Each of these levels will have different required actions and outcomes. For example, at the technical level, risks might have to negotiate a delay in project deliverable(s) due to technology and at the project-based level, risks might have to deal with repercussions of that project being delayed.

Standardizing the project management products in order to support their understandability, transparencies, and reusability is a necessity to enable a strategic project management approach as recommended in this thesis. If introduced correctly, no additional work is required within the project as the project management products are needed within the project in any event. However, by doing them in a standardized way the reusability and sharing across the boundaries of a project and of the project-based organization is increased, but this topic lies outside the boundaries of this thesis.

The resulting requirements enabling an overarching integrative approach assume that M&S services need to be accessible via a knowledge repository in which they are described in a standardized way. The solution recommended in Section 5.2.3 is based on the ideas of Model Driven Architecture ™ (MDA) [6]. Here requirements are used to formally capture M&S models in descriptive artifacts to realize captured knowledge of used components and how they are contributing to the process builds the knowledge repository with valuable information. However, it should be pointed out that this does not imply that a technical MDA approach is mandatory as well.

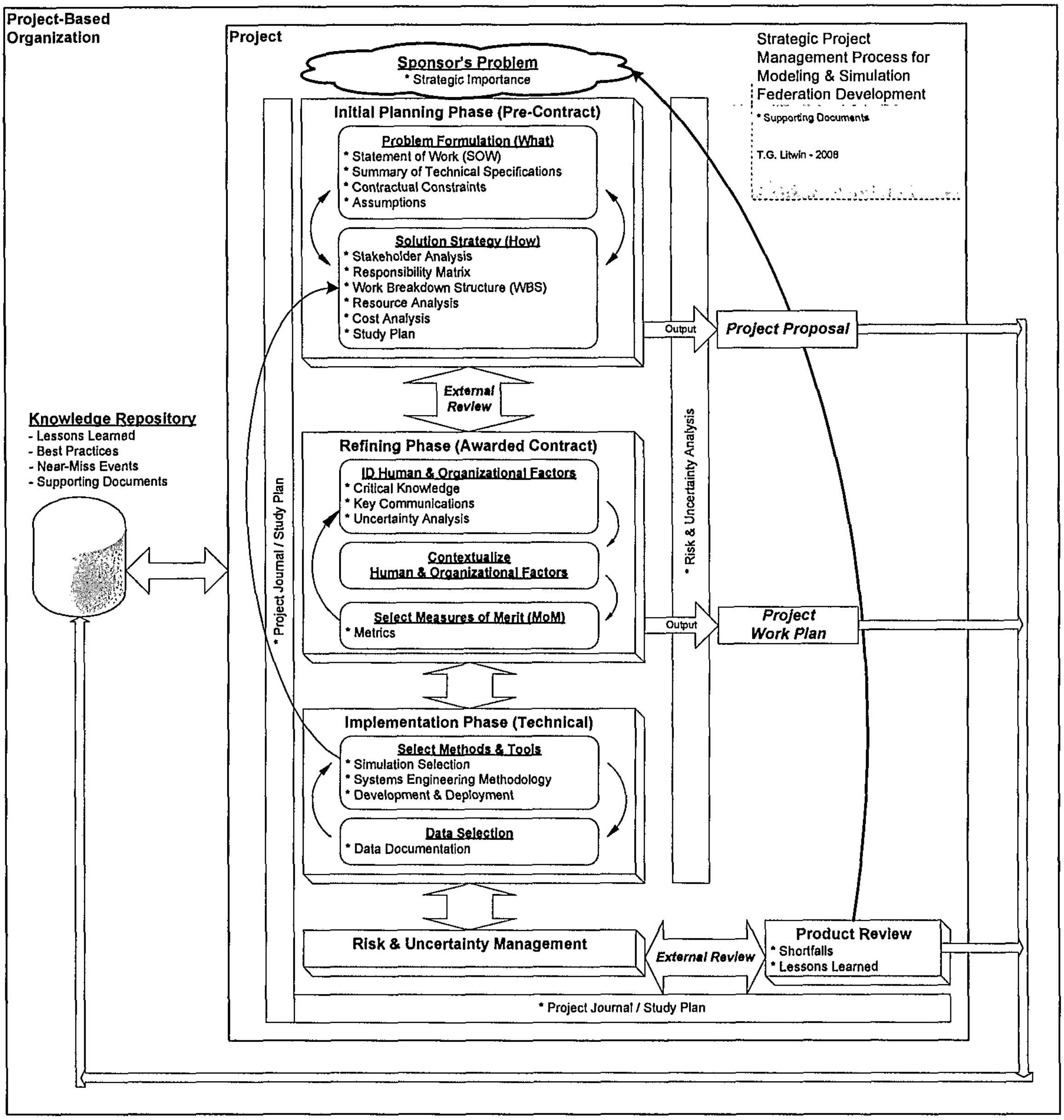

Figure 3. Strategic Project Management Process (SPMP) for M&S Federation Development

The proposed SPMP illustrated in Figure 3 may be utilized as a management tool for M&S federation development; however, it can be adapted for any project requiring dynamic development of software or simulation models. It contains three core phases: *Initial Planning, Refining,* and *Implementation* with each providing a different product: *Project Proposal, Project Work Plan,* and *Final Product* respectively.

From Figure 3 it can be noted that there are two domains which the SPMP functions in – the overall domain, *Project-Based Organization*, and the inner domain, the *Project.* These boundaries define where individual projects are part of a collective project-based organization. It is imperative to utilize a reusable *Knowledge Repository* during a development cycle in order to capitalize on previous project outcomes. Queries may be called to retrieve data and submissions should be made to a repository to ensure feedback (e.g. L/L, best practices, near-miss events, and supporting documentation) throughout the project i.e. every sub-process. This practice allows overarching project-based organizations to expand critical knowledge and become more efficient over time.

For a project to be initiated, a sponsor must present a problem by explicitly annotating the strategic importance of the problem to be solved. Only then, upon completion of the strategic importance documentation, the SPMP can commence. The first phase of the SPMP – ***Initial Planning*** – contains two sub-processes: *Problem Formulation* (What?) and *Solution Strategy* (How?). These two sub-processes will aid in developing and refining supporting documentation to evaluate what the system will do in support of which missions, Table 4, ultimately leading to a *Project Proposal.* It should be noted that several reiterations may be needed to resolve any outstanding issues and to close the gaps of any missing requirements in order to provide a robust and complete project proposal.

Table 4. Initial Planning Supporting Documentation

Supporting Documentation
Statement of Work (SOW)
Summary of Technical Specifications
Contractual Constraints
Assumptions
Stakeholder Analysis
Responsibility Matrix
Work Breakdown Structure (WBS)
Resource Analysis
Cost Analysis
Study Plan

The second phase of SPMP – ***Refining*** – begins after a contract has been awarded and refining spatial and contractual elements is required. There are three sub-processes: *Indentify Human and Organizational Factors* (evaluating where they are now and how they operate), *Contextualize Human and Organizational Factors* (placing them into the overall scenario), and *Select Measures of Merit* (MoM) (identifying the important concepts and processes, their role, and how to measure success or failure). These develop additional supporting documentation, as shown in Table 5, and ultimately deliver a *Project Work Plan.* During the contextualization sub-process several supporting documents (e.g. responsibility matrix, resource analysis) from the previous phase must be revised to add/change information pertaining to the awarded contractual constraints.

Table 5. Refining Supporting Documentation

Supporting Documentation
Critical Knowledge
Key Communications
Uncertainty Analysis
Metrics

To produce results, MoM is undoubtedly required. The need for MoM – explicit or not – is to classify a result (e.g. states, events) by the assignment of success or failure. Applying formal MoMs, provide a better understanding of the project and allow the results to be compared against each other and with other projects within the project-based organization. Also, the use of formal standardized MoMs, provides the knowledge repository with feedback and input for future projects.

The final phase of SPMP – ***Implementation*** – starts immediately after the project work plan is complete and the project development work begins. There are two sub-processes: *Select Methods and Tools* and *Data Selection* which develop additional supporting documentation for the project, as shown in Table 6, and delivers a *Product* to the sponsor for review. Again several iterations of the sub-processes may be required to rectify any missing data requirements identified in the data selection. It should be noted that during the selection of methods and tools sub-process, revisits may be required to the solution strategy sub-process to update previous supporting documentation (e.g. WBS, resource analysis, study plan) to maintain a consistent and complete SPMP solution.

Table 6. Implementation Supporting Documentation

Supporting Documentation
Simulation Selection
Systems Engineering Methodology
Development & Deployment
Data Documentation

Before a product is released to the sponsor, a final *Product Review* is required. During the review, the product is tested and compared to the previously selected MoMs and requirements set forth by the sponsor. During the review, key information about the project should be filed in supporting documentation, as shown in Table 7. Beside the supporting documentation other key information (e.g. major findings, recommendations) should be annotated and communicated to the teams and the sponsor.

Table 7. Product Review Supporting Documentation

Supporting Documentation
Shortfalls
Lessons Learned (L/L)

Risk and Uncertainty Analysis is an ongoing progression as a project moves through the SPMP. Every phase of the SPMP introduces new forms risk and uncertainty pertaining to the project. A project manager needs to take all aspects of risk into consideration and document the process along the way. Proper analysis of risk and uncertainty provides invaluable supporting documentation to top-level management and all stakeholders. With proper documentation risk and uncertainty management may provide insight and knowledge ultimately delivering a product on time and as described by the specifications.

There are two critical points – called *External Reviews*, aka stage/stop gates – within the SPMP flow where the teams/stakeholders should review all available supporting documentation and/or products. These reviews should occur between the initial planning and refining phase and between the implementation and product review phase. External review promotes team cohesiveness, cross-functional communication, and provides an avenue for decision makers to become informed about the process and project status.

As Figure 3 depicts several transition points to previous processes, it should be noted that depending on the project, process, PM, etc. additional decision points may be required to "revisit" previous stages or to refine supporting documentation. For example, if a project is midway through its development cycle and the PM determines a change to the proposal and/or contract is warranted – due to technical limitations – a review of and changes to supporting documentation may be required. Therefore, the labeling of Initial Planning Phase (*Pre-Contract*) and Refining Phase (*Awarded Contract*) may be deceiving to the reader.

The final two elements of the SPMP that are noteworthy are the *Project Journal* and *Study Plan*. A project journal is a chronological continuous document of key events containing information (e.g. meeting time and location, who attended, agenda, what was accomplished, what was outstanding, L/L by those who attended). The project journal should commence with the first event in the first phase – initial planning. A study plan is considered a "playbook". It contains problem formulation and solution strategy plans for all stakeholders and especially for the PM [5]. This study plan is a management tool which provides detailed guidance with a time phased execution plan linking all of the supporting documentation (e.g. SOW, WBS, etc.) together promoting a smooth flow for the solution strategy.

The above recommended SPMP provides a reusable project specific process flow for PMs to develop an intelligent strategy and a "plan-of-attack" to solve complex M&S federation problems based on past experiences. This allows project-based organizations to become more effective and efficient over time and expand their critical knowledge.

2. DEFINITION OF THE SPONSOR'S PROBLEM

Within project environments there are sponsors and customers. Sponsors normally provide the majority of the resources (e.g. financial) and set constraints for those resources for a given project. Customers normally provide technical specifications for a given project. However, the sponsor and customer are often one-in-the-same. The term "sponsor" used in this thesis is considered both the sponsor and the customer.

Typically a sponsor's problem may be linked to a specific project – however, there are other instances. Kerzner defines a project: "as an undertaking that has a scheduled beginning and end, and that normally involves some primary purpose" [8]. Projects are normally maintained under the programs of an organization. Several characteristics of projects should be noted when compiling information about a sponsor's problem – e.g. objectives, scope, product/services, problems/needs, resources, etc.

A sponsor must provide the initial articulation of the project and establish the conditions under which it must take place [5]. Additionally, a sponsor must determine how the assessment of the solution will be interpreted and calculated. It is important that the sponsor stay involved throughout the project and maintain a consistent focus on the problem-at-hand. A relationship between the sponsor and PM needs to be established and an understanding developed in order to comprehend resulting risks and determine actions to mitigate when necessary – this relationship leads to trust. It is important to maintain and build trust throughout a project, because there are times when decisions and unspecified matters may need action without deferring to the other.

There are many proven methods to capture a sponsor's problem. Depending on the PM he or she will choose which method is most suitable for the situation. This thesis utilizes two methods, *Strategic Importance* (Section 2.1) and *Systems Analysis and Design* (Section 2.2), to capture the sponsor's problem for PEO Soldier.

2.1 Strategic Importance

M&S projects selected for development should be selected deliberately. Preferably organizations need to select projects that have a strategic fit within the organization and have an appealing value proposition. Strategic fit can be described as: "where we are now" and "where do we want to be tomorrow" by aligning the project to the organization's strategy – moreover, does it answer the question: "does this project make sense?"

Value proposition is the overall value (measured by direct and/or indirect benefits and economic value) aligned with strategic goals of an organization that is added to an organization by executing a project at a particular cost. It should be noted that the value proposition can be negative. For example, a sponsor is looking for a long term solution and would like to start a working relationship with a developing team; therefore, a "starter project" is requested in order to gain confidence and/or experience knowing that money will be lost up front but in the long run added value will be gained. Value proposition can go both ways – which is best for the developing team and the sponsor. If the project does not have an ideal value proposition that aligns with the organization's missions and goals, the project may terminate due to lack of support.

Strategic importance documentation, at a minimum, should address the following criteria: what is the problem, why is it a problem, what is the vision/mission of the sponsor's organization, what is the organization's culture, what is the organization's organizational structure, who has the problem, who can use the solution, are similar solutions already available, how important is the solution to the sponsor, what resources will be made available, are there limitations to the project, etc. It is vital that the above criteria be identified, quantified, and captured into a strategic importance document and then communicated throughout the project organization. It should be noted that this document may need to be re-addressed as the project evolves and new personnel join the project organization. Below are the results from the strategic importance analysis conducted on PEO Soldier's task.

> PEO Soldier's strategic plan recently changed to spend less money and make smarter decisions on new acquisitions of equipment and supplies. A recent requirement is to acquire a new type of Body Armor (BA) for the entire force. This acquisition will cost billions of dollars, therefore, requires prudent research to determine which type of BA will be the most cost efficient and beneficial to the force. With the advancement of computers and simulation models, PEO Soldier wishes to use simulation models to support this and future procurement processes.
>
> The Army uses a wide-array of simulation models for various tasks and different objectives. The problem is no one model can currently support PEO Soldier's BA procurement task. However, if an integrated approach is considered using two or more pre-existing simulation models tied together, they could produce the desired results.
>
> Two of the models, if used in conjunction with each other, can feasibly provide the desired metrics for PEO Soldier. OneSAF and IWARS are two simulation models used by the Army to simulate tactical battle-space management (mid resolution) and infantry force-on-force (high resolution). An R&D initiative was established by PEO Soldier to integrate these two heterogeneous simulation models. This initial integration will act as a test platform for future tasks.
>
> The project value proposition for the customer (U.S. Army) is to spend less money buying better quality goods that will better serve the force. The project value proposition for the company (PEO Soldier) is to spend money investigating ways to utilize computer simulation models to solve complex R&D problems more efficiently.

The strategic importance statement should be developed in the pre-stages of the project, in collaboration with the sponsor and the PM. Information gathered in this document is the foundation of a project thus it is important that the finished product is complete and comprehensive.

2.2 Systems Analysis & Design Concepts

Speaking in general terms, Kendall proposes that: "*Systems Analysis and Design* seeks to understand what humans need to analyze data input or data flow systematically, process or transform data, store data, and output information in the context of a particular business" [10]. Adapting this business methodology for M&S development provides a gateway to an improved process and promotes a better understanding of the organization and the stated problem. Without proper planning, sponsor dissatisfaction can occur due to models becoming obsolete and/or falling into disuse.

In recent years software development tools have evolved and have become an integral part of the development process. For example, packages that utilize Unified Modeling Language (UML) support the analysis, design, and implementation of systems by taking into account user requirements and functions of an organization. Performing a systematic analysis comprising *enterprise modeling* (Section 2.2.1) and *information system infrastructure analysis* (Section 2.2.2) of a problem reduces development time and costs and lends to a robust solution.

2.2.1 Enterprise Modeling

For organizations to be aggressive in M&S federation development, they must be agile and able to integrate with all available functions including inside and outside of the project-based organization. *Enterprise Modeling* plays a crucial role in integration by enabling improved designs, analysis of performance, and management of operations [9]. According to Fox and Gruninger: "an enterprise model is a computational representation of the structure, activities, processes, information, resources, people, behavior, goals, and constraints of a business, government, or other enterprise" [9]. This type of modeling is easily adaptable for M&S and provides a language for one to be descriptive and define an enterprise, i.e. the organization. An enterprise model realizes MDA (in the simplest terms) for design, analysis, and operation; therefore it plays a key role in the SPMP.

Enterprise modeling may be used by a sponsor when conveying the problem-at-hand and/or by the PM during the initial planning phase known as problem formulation. Working with such models helps determine the impacts of the proposed system, representation of the conceptual design, an overview for top-level management, and supplies information and knowledge to keep a well-informed team.

Enterprise models are constructed in layers. The most basic high-level diagram is known as the *Context Level Diagram*. It represents the overall context of a system and the operating environment and illustrates the basic elements and relationships of a particular design. Exploding, which allows the context level diagram to show more detail of the system being modeled, leads to sub-level diagrams (e.g. Level 0, Level 1) which display supplementary details the more further the diagram is exploded.

Choosing the correct level diagram depends on the target audience. For example, the PM should have no interest in a Level 1 diagram which shows detailed information about how a system is interconnected and the functions that are required to make it work – that should be left to the technical team. The use of enterprise models is recommended to help organizations become agile and increase their ability to integrate with others.

2.2.2 Information System Infrastructure Analysis

Detailed analysis of the basic information system infrastructure provides insight into what needs to be accomplished. Discussions between the PM and the sponsor should lead to an understanding of the M&S problem presented. Detailed knowledge of the system is not of importance but the basic layout is. Basic elements should be identified and their relationships connected to provide a bird's-eye view of the mechanisms in the system to be designed. The context level diagram will provide the most general and broad conceptualization of the system. The diagram should be accompanied with documentation describing the process. The results from the information system infrastructure analysis conducted on PEO Soldier's task are below.

> During a federation execution, data must be captured into multiple databases. These databases must be suitable for analysts to categorize data and retrieve reports based on the current tasking. Depending on the task, the data requirements can be very dynamic. For example, researching BA requires a very large database because of the amount of information required. Examples include: every soldier (to include six (6) body parts, health, mobility, position, configuration, status, communications, etc.), every weapon (to include type, ammunition, position, status, etc.), every motor-vehicle (to include type, position, configuration, status, communication, etc.), and any other important entity within the federation. Depending on the federation configuration and logging requirements, every instance must capture the above data requirements into a database for further review, in effect requiring very large databases.
>
> Federating OneSAF and IWARS requires at least four (4) computer platforms (OneSAF, IWARS, Runtime Infrastructure (RTI), and data storage) and a very fast local network infrastructure. Due to current technology, wide-area and remote networking cannot be utilized for this type of simulation as they pose problems with time latency and low bandwidth.

Federating OneSAF and IWARS adds an element of difficulty to the information system infrastructure. The federation process, depicted in Figure 4, requires additional software (RTI) and hardware in order for the federation to operate properly. The RTI also requires both OneSAF and IWARS to add code to their respective simulation model. This alone can and will cause additional problems to both OneSAF and IWARS requiring modifications to the original code – which is not an ideal situation for an existing program. Another concern using the RTI methodology is that it requires expertise and experience. Both OneSAF and IWARS program teams have minimal exposure to this type of programming and implementation; therefore, this can lead to problems and delays during the integrating phase.

Figure 4 depicts a top-view of the federation with OneSAF and IWARS. The process federation starts off by receiving Objective Task(s) from PEO Soldier (describing what is to be accomplished by the simulation i.e. Figure 5, Operational Scenario). The federation then performs a Reference Lookup using the Mission Essential Task List to match tasking with military standards. The federation then arranges tasking and sends Program Tasks to each of the Federates – OneSAF and IWARS. Upon completion of the simulation execution, Program Results from both Federates are fed to the federation for processing. Results from the Federates are complied in the form of reports (called Objective Results) and sent to PEO Soldier for evaluation.

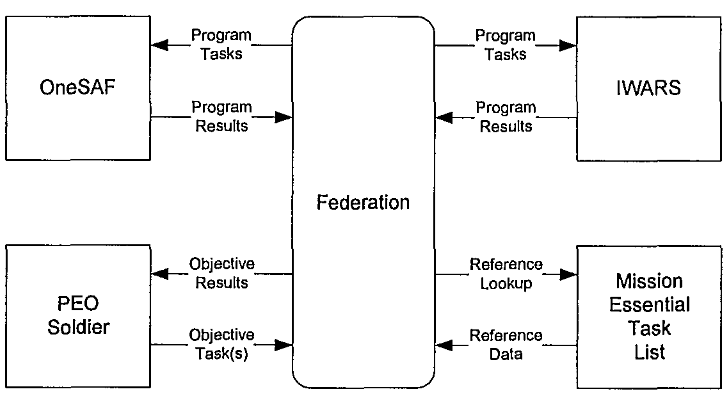

Figure 4. PEO Soldier Federation Context Level Diagram

By providing a simple context level diagram and a detailed description of the process, no question should go unanswered as to what the sponsor expects to see upon execution of the delivered M&S federation. Once formulated, this diagram and description should be passed to all stakeholders to ensure the problem-at-hand is communicated uniformly.

2.3 Identification of Key Points, Issues, Data Requirements

When defining a sponsor's M&S problem it is important to gather, articulate, and communicate key points, issues, and data requirements pertaining to the problem. In addition to this, specific requirements pertaining to metrics (discussed in Section 3.4) also need to be incorporated in this research. Several meetings between the sponsor and the PM may be required to capture adequate information about the future project. It may be beneficial for the PM to conduct brainstorming sessions with the sponsor and the sponsor's organization. By inviting a number of individuals from the organization, different perspectives of the problem may be promoted.

Other supporting documentation may be required – other than the strategic importance and information system infrastructure analysis – to define further details of a sponsor's problem. Requests from the project team and/or stakeholders may be passed on the PM to request such documentation. Information contained in this additional documentation may be of no importance to the sponsor or the PM but it could be critical to the development team(s).

3. ANALYSIS OF EMPIRICAL DATA

3.1 Assumptions

No matter the size or number of stakeholders within a project, assumptions must be communicated to everyone. If gone unspoken, assumptions made by individuals or entities without regard to others can lead to setbacks and/or errors that may or may not be recoverable. Assumptions may be valid, but the best way to deal with them is to gather, organize, and communicate them to all stakeholders within an organization.

Assumptions can be made during any part of a project, starting with the sponsor's problem all the way through the project solution. Working with multiple stakeholders and multiple organizations can complicate the assumptions problem – for example, PEO Soldier's challenge of stakeholders located in different parts of the U.S. and each having dissimilar cultures.

Beside the lack of absolute information, assumptions may be useful when different organizational cultures come together to provide a solution. It may be said that most individuals and cultures have different personal beliefs and/or views about how a solution should be carried out. A task built on incorrect assumptions can lead to (a) catastrophe and/or huge losses. For example, NASA lost a Mars orbiter in 1999 because Lockheed Martin's engineers mistakenly used English units for measurement when in fact NASA uses the metric system. The orbiter crashed into Mars and the Agency lost $125 million. This error could have been avoided during planning phases if *all* assumptions were communicated by NASA and Lockheed Martin.

Addressing general assumptions, technical assumptions, basic risk assumptions, confidence assumptions, lead time, impacts, etc. provides good information for the assumption documentation. Even after assumptions are addressed within a project's organization, it can be good practice to revisit and re-communicate them every so often to re-familiarize all stakeholders of the outstanding assumptions. Below are the results from the assumption analysis – which excludes technical assumptions – conducted on PEO Soldier's task.

> Meetings, travel, external research (VMASC) and billable hours (from OneSAF and IWARS) are funded by PEO Soldier. It is assumed all work will be accomplished by each stakeholder without any outsourcing. During sessions where integration efforts are being carried out, OneSAF and IWARS are required to provide management and technicians, preferably personnel who are well versed with the systems in use.
>
> The Final Demonstration (May 2, 2008) is not firm and may be changed by PEO Solider in the event of delay. However, every effort should be made to complete the project on time.

Even though the above assumption analysis revealed little information, a more in-depth analysis will be required both on the technical and non-technical sides of the project to make this project complete. Considering M&S federation development, a focus on technical assumptions should be considered a high priority due to the nature of multiple heterogeneous organizations, each having their own methods of solving M&S problems.

3.2 Contractual Constraints

Supporting documentation such as *Statement of Work* (SOW), *Summary of Technical Specifications*, *Project Constraints*, *Stakeholder Analysis*, and the *Responsibility Matrix* can be categorized under *contractual constraints* with respect to a project. These documents provide management tools and plans for execution given by a set of contractual constraints.

3.2.1 Statement of Work (SOW)

The *Statement of Work* (SOW) is very important to a project organization – it provides a narrative description of a project. A SOW explicitly states what the output product(s) and/or service(s) is going to be and, at a minimum, addresses elements in Table 8.

Table 8. Elements of SOW

Elements
General objectives of the project
Who are the stakeholders and what are their general roles
Who is going to accomplish what for the project in general terms
Funding resources; including funding amount, available assets, etc.
Brief description of project tasks
Dates and milestones of the project e.g. start date, end date, demonstration, etc.
What each stakeholder will provide to the project with respect to resources, etc.
Defines the scope of the project
Contract type e.g. time and materials

Writing a SOW in *active voice* prevents any ambiguity and provides a clear understanding what is to be done, by whom, and when. Another important purpose for the SOW is to place the project risk onto the stakeholders vice the sponsor – this can be done by placing performance measures on those goals listed in the SOW. Below are the results from the SOW analysis conducted on PEO Soldier's task.

> U.S. Army's Program Executive Office (PEO) Soldier has obligations to analyze the unit-level effectiveness of alternative soldier architectures – that is soldier's entire ensemble of equipment, to include future situation awareness and command and control (C2) systems. The latest requirement is to acquire a new type of body armor (BA) for the entire force. This acquisition will cost billions of dollars;

therefore it requires prudent research to determine which type of BA will be the most cost efficient and beneficial to the force. With the advancement of computers and simulation models, PEO Soldier desires to use a simulation model to support the procurement process. An integrated approach is exploited by using two pre-existing simulation models tied together.

One Semi-Automated Forces (OneSAF) and Infantry Warrior Simulation (IWARS) are two simulation models used by the Army to simulate the battle-space management (mid resolution), the former, and infantry force-on-force (high resolution), the latter. On November 1, 2007 a research and development (R&D) initiative was funded ($750K) and established by PEO Soldier to integrate these two heterogeneous simulation models together.

Old Dominion University's (ODU) Virginia Modeling, Analysis and Simulation Center (VMASC) was awarded a contract to conduct research on how (1) the two simulation models should be integrated and (2) oversee the integration efforts by two independent project groups (OneSAF and IWARS). VMASC will be responsible for delivering a Formal Research Report to all stakeholders by February 28, 2008 and deliver captured events and results of the integration to PEO Soldier by May 2, 2008.

OneSAF and IWARS programs are directly responsible for software engineering, program management, etc. with respect to their corresponding simulation models during the integration phase. All stakeholders are required to attend regular TELCONs, meetings, and/or working groups during the entire project to maintain consistency throughout and timely completion of the project. On May 2, 2008, a final demonstration of a fully functional federation using OneSAF and IWARS will be executed for PEO Soldier.

The above SOW analysis was constructed for academic purposes only and the actual SOW was very different. Government SOWs are very different in nature than typical commercial SOWs; therefore, results may vary depending on the sponsor(s) e.g. government, commercial, etc.

3.2.2 Summary of Technical Specifications

Summary of Technical Specifications provides expected characteristics of a final product and/or service in the form of quality attributes. For example, "the supplied M&S scenario must execute four phases under 10 minutes." Technical specifications are normally captured in a separate document and are discussed in the SOW. These specifications are normally utilized by technical personnel to gain an understanding of the real problem and what the sponsor expects to see in a final product. The technical specifications should contain enough information to allow stakeholders and PMs to properly plan a project and rule out any uncertainties of sponsor's technical expectations.

Project supporting documentation and technical specifications can be constructed in a manner so they may be changed during a development cycle. For example, a M&S federation project requires research on utilizing a new technology. It might be in the best interest of the project to allow changes to the technical specifications to "redirect" the project objectives depending on the findings of the initial research. However, this type of management style requires special attention to ensure a solid plan is put into place when changes to technical specifications occur. History has shown that small unexpected changes to technical specifications midway through a project can cause large cost overruns [8].

For example, when the U.S. Navy desires to build a new ship class it provides technical specifications. Then bids are estimated on the specifications, which are stated up-front. However, it takes numerous years for ship designers and builders to deliver the final product – normally five to seven years. With the ever changing threats around the world, the Navy often has to modify its original specifications to match the current threats. Costs have been noted to rise dramatically due to the late additions and/or changes to technical requirements causing "rework" of the project and project plan when these new specifications are introduced [11]. Below are the results from the technical specifications analysis conducted on PEO Soldier's task.

> Goals of the Federation: A fully functional federation must be demonstrated using OneSAF and IWARS as federates. The federation must execute five (5) milestones during one simulation cycle – soldier movement (mounted and dismounted), fire engagements (direct and in-direct), and command and control which all takes place inside an urban environment. An Operational Scenario has been provided by PEO Soldier, Figure 5.

Situation. Based on intelligence from a local source, a US squad engaged in counter-insurgency operations has planned a raid to **capture an insurgent leader** in the **town of Shugart-Gordon**. Multiple sources of intelligence have confirmed the location of the leader at location 31.1057N 91.1193W. Additionally, they have reported that his cell members have stationed themselves on rooftops within the town to identify potential Coalition forces and provide early warning to their leader. They also have mortar support. The citizens of Shugart-Gordon have fled the village, and it is primarily used as an insurgent planning and training center.

Mission. 1/1/A/1-5CAV conducts raid at **011500MAY08** at **31.1057N 91.1193W** in order to **capture local insurgent leader** and deny the use of Shugart-Gordon as a training sanctuary.

Execution. The purpose of this operation is to capture the local insurgent leader in order to gain further intelligence about insurgent operations. At the end of this operation, we would like to have the insurgent leader alive and in Coalition custody with no Coalition casualties. Because the citizens of Shugart-Gordon have fled the area, collateral damage is of little concern. **1st squad will conduct the raid with direct support from the mortar section**. They will **conduct the raid in three phases, mounted movement, dismounted movement, and clearing the objective**. During the operation, one fire team will provide overwatch while a second fire team enters the objective building to capture the insurgent leader and clear it of enemy fighters. Mortar fires will be used to help clear rooftops of enemy fighters.

Execution Matrix				
Unit	Phase I - Mounted Movement	Phase II - Dismounted Movement	Phase III - Clearing the Objective	Phase IV - Egress
A Fire Team	Mounted in lead vehicle	Move to Dismounted SBF and provide overwatch to B TM's movement	From Dismounted SBF, provide overwatch to B TM's actions on Objective. Lift fires when B TM begins breach of door.	Provide overwatch to B TM's egress, then remount lead vehicle.
B Fire Team	Mounted in trail vehicle	Move along Dismounted Route to position near objective	Breach objective to capture insurgent leader and clear enemy fighters	Egress along dismounted route and remount trail vehcile
HMMWV Section	Move along RT Blue and drop teams at Mounted SBF	Provide overwatch from Mounted SBF	Provide overwatch from Mounted SBF	Upon mounting soldiers, egress along RT Blue
Mortars	Priority of fires to 1st Squad	Priority of fires to 1st Squad	Priority of fires to 1st Squad	Priority of fires to 1st Squad

Figure 5. Technical Specifications – The Operational Scenario

The above analysis provided enough information for the project organization to develop a working model for the final product. This was the first attempt at building a federation of heterogeneous models; therefore, the sponsor did not want to provide too many detailed technical specifications as they wanted the development teams to "think outside the box" for this initial attempt at federating. A more detailed technical specifications document may be required as a project evolves over time and/or the complexity increases.

3.2.3 Project Constraints

Project managers constantly balance performance of projects with constraints. *Constraints* can be defined from resources (money, assets, people), physical (locations, equipment), technical (technology), capability (existing assets), performance (schedule, quality), etc. A *study plan* (Section 5.2) can be utilized to steer a project to completion by previous set forth constraints. Developing a solid study plan for a project requires prudent investigation by PMs and stakeholders of the problem-at-hand. This includes analyzing all possible constraints a project may incur during a development cycle. It should be noted that identifying all constraints is practically impossible as there are unforeseeable circumstances that can occur.

Identifying constraints takes teamwork. Group meetings – that begin at the start of a project and continue all the way through to the end – are the best way to identify constraints. Once captured, constraints should be addressed to key stakeholders within the entire project organization. Keeping a well informed project organization allows organizations to be agile and react quickly to new constraints. For example, if funding on a project was cut, a project organization might have to perform an *Earned Value Analysis* to adapt cost cutting measures to set new performance constraints – that is "we are willing to sacrifice quality for quantity".

The results from the constraint analysis conducted on PEO Soldier's task are below.

Constraints that can and will delay advancements and target completion dates:

- Resources: Due to the U.S. economic situation, PEO Soldier has a limited budget and very little room for "creep" – inflation of budget costs.
- Man-power: Each program (OneSAF and IWARS) has a limited number of hired employees. Each program must maintain current readiness and support the new initiative to integrate the models together.
- Technical Knowledge: Integrating simulation models – known as federating – is a fairly new concept and very few technical personnel are aware of current efforts to design and implement a federation of heterogeneous simulation models.
- Technology Advancement: Limited availability of software tools that aid programmers in developing a federations.
- Systems' Interoperability: Each simulation model (OneSAF and IWARS) used in the federation must be interoperable with each other i.e. compatible to work together. Extra time and resources may be needed to modify the current models of OneSAF and IWARS. A long term effect could be that it may be harder to maintain source code.
- The Unknown: Developing a new simulation model adds an element of difficulty to planning and estimating resources to accomplish the task as well as estimating the completion date.

3.2.4 Stakeholder Analysis

A *stakeholder* can be a person, group, or organization within a project organization that has interest in or is actively involved with a project. Stakeholders may include: PM, sponsor, technical group, teams, top-level management, etc. Kerzner notes that stakeholders sometimes have different values and interests pertaining to a particular project, thus creating a competition over these differences [8]. One way to overcome this rivalry effect is to identify, analyze, develop a plan, and communicate that plan to all stakeholders.

As new project organizations form, it is crucial for the PM to conduct an assessment of the stakeholders. The primary goal of *Stakeholder Analysis* is to develop an understanding of the dynamics between the stakeholders and the organization. Table 9 lists some recommended objectives to consider during stakeholder analysis. These objectives are not exclusive; however, they do provide a starting point for most PMs. The results from the stakeholder analysis conducted on PEO Soldier's task are below.

Table 9. Stakeholder Analysis Objectives

Stakeholder Analysis Objectives
Who has interest in the project and how are those interests aligned with the project
How are the stakeholders formally linked to the project
What kind of power does each stakeholder have over the execution, deliverables, etc.
What kind of past performance of each stakeholder is important to project
How to approach the alignments and/or misalignments between stakeholders and the project
How will the approaches will be implemented into the project
How will the satisfaction of each stakeholder be measured for the project
How will the performance of each stakeholder be measured throughout the project

For PEO Soldier M&S Project there are five (5) key stakeholders:

1. PEO Soldier: U.S. Army's Program Executive Office for Soldiers is a group in charge of improving Soldiers' fighting capabilities.

2. COTR: Contracting Officer Technical Representative is an individual who is a senior technical representative and subject matter expert (SME) in the M&S field for the U.S. Army.

3. VMASC: Virginia Modeling, Analysis, and Simulation Center is a group of academic professors and research scientists who specialize in M&S.

4. OneSAF: One Semi-Automated Forces is a group of individuals who own and maintain the OneSAF Program.

5. IWARS: Infantry Warrior Simulation is a group of individuals who own and maintain the IWARS program.

The Table 10 and Table 11 describe the relationships and approaches for the stakeholders related to the project.

Table 10 represents stakeholders' relationships and expounds on how their interests are aligned with the interest of the project, how formally they are linked to the project, the power they have over the execution of the project, and how their past performance is important to the project.

Table 11 represents stakeholders' approaches and expounds on approaches to deal with alignment with the project, how those approaches will be implemented, how satisfaction will be measured, and how performance will be measured throughout the project.

Table 10. Stakeholder Analysis – Relationships

Stakeholder	Alignment of Their Interests with Those of the Project	Formally Linked to the Project	Power Over of the Execution of the Project	Past Performance a Factor to the Project
PEO Soldier	Aligns with Strategic Goals	Owner of Project and Funding Source	Ultimate Authority of Funding for Travel, Meetings, etc.	Yes, Decision Making on Funding Resources
COTR	Advancement in M&S for the U.S. Army	Authority over Critical Technical Decisions	Final Authority for Technical Requirements	Yes, Formal Education and Practical Knowledge of the U.S. Army
VMASC	Advancement in Federating Heterogeneous Simulation Models	Academic Authority on M&S Methods	Final Authority for MDA & HLA usage in the Federation	Yes, Academic Knowledge of Developing Federations
OneSAF	Improve OneSAF Simulation Model and Interfacing Capabilities	Owner of OneSAF Program	Final Authority for OneSAF Changes and Implementation into the Federation	None
IWARS	Improve IWARS Simulation Model and Interfacing Capabilities	Owner of IWARS Program	Final Authority for IWARS Changes and Implementation into the Federation	None

Table 11. Stakeholder Analysis – Approaches

Stakeholder	Approach to Alignment	Implementation of the Approach	Satisfaction Measure	Performance Measure
PEO Soldier	Frequently Convey Importance of the Project	Join TELECONS and Meetings at Least Monthly	Fully Functional Federation and Under Budget	BA Procurement Question Answered
COTR	Constant Communication with all Stakeholders	Hold Bi-weekly TELECONS, Meetings, or Working Groups	Federation Meets Technical Specifications	Project Completed without Major Problems or Outstanding Issues
VMASC	Work Closely with COTR, OneSAF, and IWARS	Communicate Findings and Inquiries Multiple Times a Week	Federation Built using HLA & MDA	Formal Report Usefulness to OneSAF and IWARS
OneSAF	Work Closely with VMASC to Understand HLA & MDA	Realize the Formal Report and Communicate to VMASC	Successful Execution of OneSAF within the Federation	OneSAF Functionality within the Federation
IWARS	Work Closely with VMASC to Understand HLA & MDA	Realize the Formal Report and Communicate to VMASC	Successful Execution of IWARS within the Federation	IWARS Functionality within the Federation

Stakeholder analysis is extremely important to develop and implement especially when working with M&S federation projects. It was observed during the PEO Soldier project that OneSAF and IWARS often competed against each other and available technologies because each had their own beliefs and methods for developing M&S models.

This competition can be healthy (finding new ways to develop something) and also can cause delays (power struggles over model dominance) for a project.

3.2.5 Responsibility Matrix

Managing human resources can be difficult without a plan. The *Responsibility Matrix* is a planning tool that can be utilized by project organizations to remove conflict with regard to responsibilities between stakeholders and set expectations upfront. This tool uses organized tasks to establish expectations and relationships by aligning stakeholders with responsibilities to the tasks, and identifying relationships and roles of the stakeholders. A well designed responsibility matrix presents a clear picture to all stakeholders and leaves no questions about tasks and responsibilities.

PMs are ultimately responsible for developing a responsibility matrix; however, key leadership (e.g. top-level management, team leaders) should be part of the development process. If a responsibility matrix is designed without consulting all of the stakeholders, conflicts can arise due to poor communication. Below are the results from the responsibility matrix analysis conducted on PEO Soldier's task.

> The responsibility matrix, Figure 6, holds key information about the project – Work Breakdown Structure (WBS) IDs, Activities, and Stakeholder Responsibilities – that can be visualized. Utilizing the information below, all stakeholders are made aware of who is directly responsible, who needs to be consulted, who needs to be notified, and who must approve an activity. With assignments clearly annotated in the responsibility matrix, all possible communication lanes must be exploited to ensure proper flow of information. There are four (4) responsibility categories:
>
> 1. Must Approve (A): The stakeholder who must approve the completed activity.

2. Must be Consulted (C): The stakeholder(s) who must be consulted during the activity.

3. Must be Notified (N): The stakeholder(s) who must be notified (weekly and at completion) of actions taken during the activity.

4. Directly Responsible (R): The stakeholder(s) who are directly responsible for the completion of the activity or their portion of the activity.

PEO Soldier M&S project does not have a dedicated PM; however, the COTR and the sponsor (PEO Soldier) will combine efforts to serve as the PM. Most PM communications – updates, questions, requests, etc. – should be directed to the COTR. However, funding questions can be addressed directly with PEO Soldier followed up with a notification to the COTR about the correspondence.

		Stakeholders							
		Project		Teams					PEO
WBS-ID	Activity	Manager	COTR	VMASC	OneSAF	IWARS	Combat XXI	Dahlgren	Soldier
1	**PEO Soldier M&S Roadmap**								
1.1	**Initial Research**								
1.1.1	Research MDA Methodology			R					
1.1.2	Research FEDEP Methodology			R					
1.1.3	Research Merging MDA & FEDEP Methodologies			R					
1.1.4	Research OneSAF Program		C	R	C				
1.1.5	Research IWARS Program		C	R		C			
1.1.6	Apply MDA & FEDEP to OneSAF & IWARS		C	R					
1.2	**Research Report**								
1.2.1	Formalize Findings			R					
1.2.2	Generate Formal Report		N	R	N	N	N	N	N
1.3	**Conceptual Representation**								
1.3.1	Design HLA Federation		C	C	R	R			
1.3.2	Design Federation Object Model		C	C	R	R			
1.4	**Integration & Mapping**								
1.4.1	Build HLA Federation Framework		N	N	R	R			
1.4.2	Build Federation Object Model		N	N	R	R			
1.4.3	Integrate OneSAF into Federation		N	N	R	N			
1.4.4	Integrate IWARS into Federation		N	N	N	R			
1.5	**Verification & Validation**								
1.5.1	Verify HLA Federation		N		R	R			
1.5.2	Verify Federation Object Model		N		R	R			
1.5.3	Conduct Dry Run of Federation		N		R	R			
1.5.4	Validate Federation Simulation		A		R	R	N	C	
1.6	**Analysis**								
1.6.1	Conduct Simulation Runs				R	R	R	C	C
1.6.2	Validate Simulation Data		N		C	C	C	R	C
1.6.3	Conduct Data Analysis						N	R	N
1.7	**Final Demonstration**								
1.7.1	Conduct Final Demonstration		R		R	R	R	R	A

Legend	
A	Must Approve
C	Must Be Consulted
N	Must Be Notified
R	Direct Responsibility

Figure 6. Responsibility Matrix

A project with many stakeholders, e.g. a M&S federation project, can be considered a complex scenario/environment with respect to responsibilities. A well prepared PM managing a complex environment requires a well designed responsibility matrix that is communicated to all stakeholders. Without a responsibility matrix, conflicts between stakeholders may hamper project results.

3.3 Resource Constraints

Supporting documentation such as *Work Breakdown Structure* (WBS), *Resource Analysis*, *Cost Analysis*, *Critical Knowledge*, and *Key Communications* can be categorized under resource constraints with respect to a project. These documents provide management tools and plans for execution given by a set of resource constraints.

3.3.1 Work Breakdown Structure (WBS)

The Project Management Body of Knowledge (PMBOK) defines *Work Breakdown Structure* (WBS) as "a deliverable-oriented grouping of project elements that organizes and defines the total work scope of a project. Each descending level represents an increasingly detailed definition of the project work" [14].

One of the added benefits of WBS is that they can be reused as templates within a project-base organization – because similar projects within an organization often resemble one another and have similar development cycles. This reuse allows project-base organizations to benefit from previous projects allowing them to refine the process.

M&S federation projects can be very different at the detailed level; however, they are fundamentally similar when it comes to the development cycle. For example, when federating M&S federates, there are some "core" processes such as initial research, conceptual representation, integration & mapping, verification & validation, and analysis. Therefore, WBS can be a proven tool for M&S federation project-based organizations.

There are two ways to represent a WBS: textual indent or graphical. Graphical representation is a great way to provide a visual picture of the tasks; however, it can be difficult to develop when working with numerous tasks as it requires a very large graphical workspace. Textual indent format provides an easy solution by displaying categorized tasks in a tabbed format. A complete WBS must include a WBS dictionary; it provides amplifying information of the major tasks described in the WBS. The results from the work breakdown structure analysis conducted on PEO Soldier's task are below.

1 **PEO Soldier M&S Roadmap**

1.1 Initial Research

1.1.1 Research MDA Methodology

1.1.2 Research FEDEP Methodology

1.1.3 Research Merging MDA & FEDEP Methodologies

1.1.4 Research OneSAF Program

1.1.5 Research IWARS Program

1.1.6 Apply MDA & FEDEP to OneSAF & IWARS

1.2 Research Report

1.2.1 Formalize Findings

1.2.2 Generate Formal Report

1.3 Conceptual Representation

1.3.1 Design HLA Federation

1.3.2 Design Federation Object Model

1.4 Integration & Mapping

1.4.1 Build HLA Federation Framework

1.4.2 Build Federation Object Model

1.4.3 Integrate OneSAF into Federation

1.4.4 Integrate IWARS into Federation

1.5 Verification & Validation

1.5.1 Verify HLA Federation

1.5.2 Verify Federation Object Model

1.5.3 Conduct Dry Run of Federation

1.5.4 Validate Federation Simulation

1.6 Analysis

1.6.1 Conduct Simulation Runs

1.6.2 Validate Simulation Data

1.6.3 Conduct Data Analysis

1.7 Final Demonstration

1.7.1 Conduct Final Demonstration

Figure 7. Work Breakdown Structure (WBS)

Table 12. Work Breakdown Structure (WBS) Dictionary

WBS Element IDs	Description
WBS Element 1.1. – Initial Research	This element includes the effort of identifying methods, procedures, and practices of integrating heterogeneous simulation models.
WBS Element 1.2. – Research Report	This element includes the effort of generating a complete report (to include corporate, management, and technical sections) of the findings in element 1.1.
WBS Element 1.3. – Conceptual Representation	This element includes the effort of conceptual designing of a federation using MDA and HLA.
WBS Element 1.4. – Integration and Mapping	This element includes the effort of building the federation using OneSAF and IWARS as federates.
WBS Element 1.5. – Verification & Validation	This element includes the effort of verifying the methods and validating the code used to build the federation.
WBS Element 1.6. – Analysis	This element includes the effort of conducting simulation runs, validating the data, and performing formal data analysis.
WBS Element 1.7. – Final Demonstration	This element includes the effort of performing a formal demonstration for the sponsor (PEO Soldier).

Experience has shown – as well as known M&S management practices – that there are core processes (e.g. like the ones listed above) associated with M&S development cycles. These core processes can be beneficial to project-based organizations as they may be refined and reused on future projects. The key to success is to capture past project performance and to use the knowledge gained to enhance future projects.

3.3.2 Activity Analysis

Activity Analysis is important to any organization that wishes to seek the best technique(s) to manage and control resources. Managing resources within complex organizations, such as M&S federation projects, requires proper tools and experienced management to use them. There are several proven methods/tools; however, this thesis will only focus on a few of them.

The *Program Evaluation and Review Technique* (PERT) method was developed for managing project performance trends and is now utilized by most organizations to manage project activities [8]. This tool provides analysis on the networking of tasks and reveals interdependencies and related problems of a project's schedule. Performing such analyses enables managers to make adjustments as required to obtain the "best" solution, with respect to taking a probabilistic approach to managing task resources. From this analysis and the resultant data, a *Probability of Completion* (date set by the sponsor) can then be computed.

The *Gantt chart* or bar chart was developed to graphically represent a project's schedule (e.g. start and finish times for the project as well as all tasks) plotted against time or costs [8]. However, the tool does not clearly depict precedence relationships and/or dependencies, hence the need for PERT. Therefore, these charts are commonly used for showing project progress to top-level management and/or leaders of a project organization without specific details.

Below are the results from the activity analysis (PERT diagrams, Probability of Completion, and the Gantt chart) conducted on PEO Soldier's task.

> PEO Soldier set a date for the Final Demonstration (WBS Element 1.7.1) to occur on May 2, 2008. From the Kick-Off meeting (November 1-2, 2007) to May 2, 2008 the project is negotiating a 24 week window. From interviews with all stakeholders Table 13 was assembled and an estimated completion time was computed for each activity. PERT Diagrams (Figure 8, Figure 9, and Figure 10) – using estimated completion times from Table 13 – were assembled and an estimated completion time of 34.5 weeks for the project was computed. Based on calculations (Table 14) the project has a 0% probability it will be completed by May 2, 2008 deadline.
>
> PEO Soldier was notified of this analysis and wishes to continue with the project as planned and will adjust the deadline as necessary because it is NOT a

mission or time sensitive project. It was noted from PEO Solider that a "good working" model is more important than a "partial working" model.

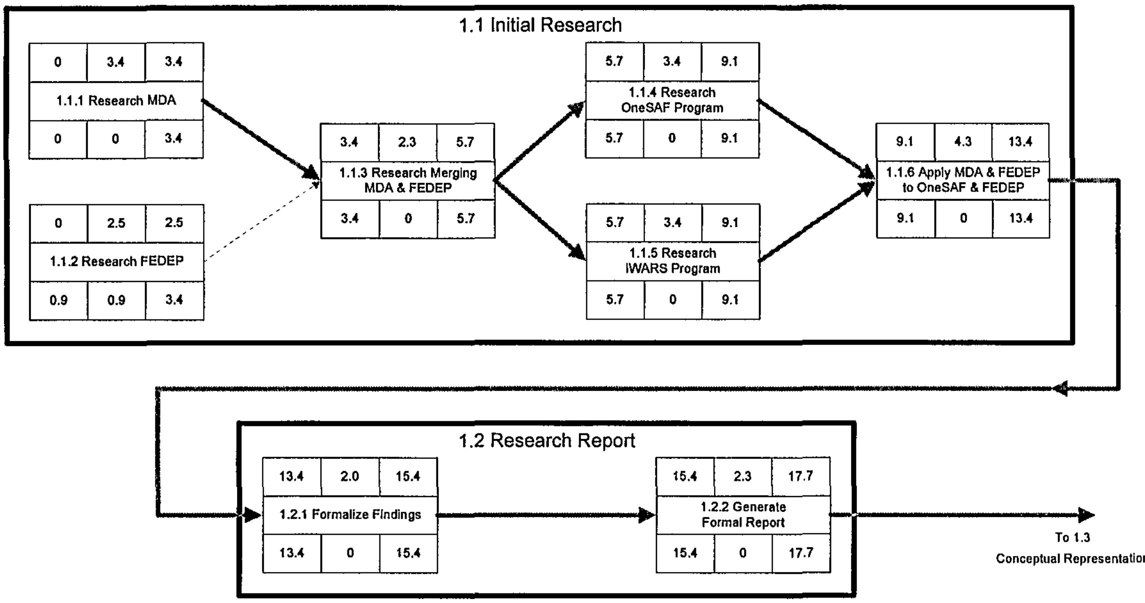

Figure 8. PERT Diagram – WBS Activities 1.1 - 1.2

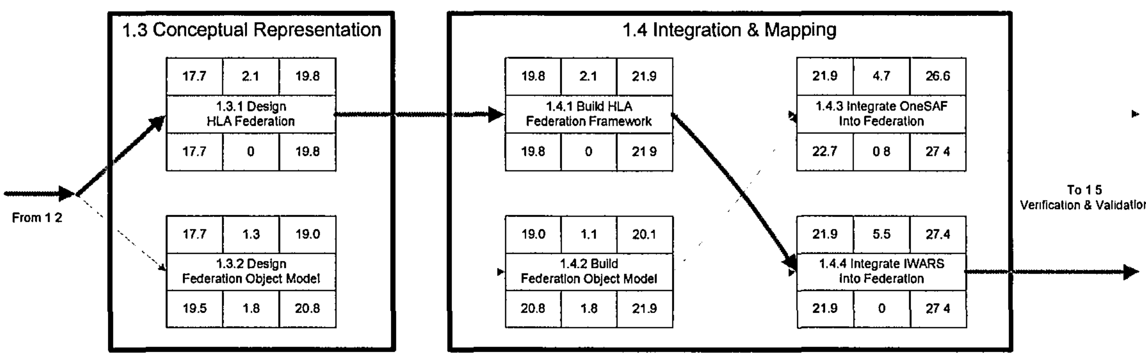

Figure 9. PERT Diagram – WBS Activities 1.3 - 1.4

*** Critical Path[4] noted in BOLD lines**

[4] Critical Path is the sequence of activities (that have the longest duration) that determines the shortest time possible to complete a project. A delay of any of the activities on the critical path impacts the project completion date.

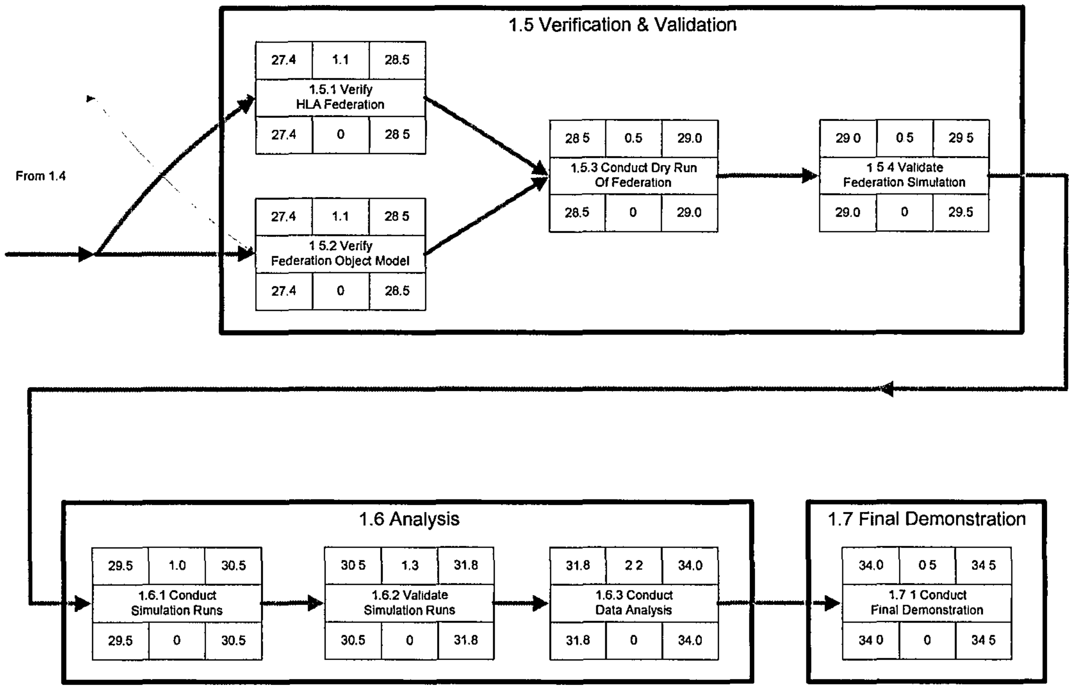

Figure 10. PERT Diagram – WBS Activities 1.5 - 1.7

Table 13. PERT – Completion Analysis Computations

WBS ID	Activity	Predecessor	Optimistic	Most Likely	Pessimistic	Estimate (O+4ML+P)/6	Std. Dev. (P O)/6
			Time in Weeks				
1.1	**Initial Research**						
1.1.1	Research MDA Methodology	-	1.5	3	7	3.4	0.9
1.1.2	Research FEDEP Methodology	-	1	2	6	2.5	0.8
1.1.3	Research Merging MDA & FEDEP Methodologies	1.1.1 , 1.1.2	0.5	2	5	2.3	0.8
1.1.4	Research OneSAF Program	1.1.3	1.5	3	7	3.4	0.9
1.1.5	Research IWARS Program	1.1.3	1.5	3	7	3.4	0.9
1.1.6	Apply MDA & FEDEP to OneSAF & IWARS	1.1.4 , 1.1.5	2	4	8	4.3	1.0
1.2	**Research Report**						
1.2.1	Formalize Findings	1.1.6	1	2	3	2.0	0.3
1.2.2	Generate Formal Report	1.2.1	1	2	5	2.3	0.7
1.3	**Conceptual Representation**						
1.3.1	Design HLA Federation	1.2.2	0.5	2	4	2.1	0.6
1.3.2	Design Federation Object Model	1.2.2	0.5	1	3	1.3	0.4
1.4	**Integration & Mapping**						
1.4.1	Build HLA Federation Framework	1.3.1	0.5	2	4	2.1	0.6
1.4.2	Build Federation Object Model	1.3.2	0.5	1	2	1.1	0.3
1.4.3	Integrate OneSAF into Federation	1.4.1 , 1.4.2	2	4	10	4.7	1.3
1.4.4	Integrate IWARS into Federation	1.4.1 , 1.4.3	2	5	11	5.5	1.5
1.5	**Verification & Validation**						
1.5.1	Verify HLA Federation	1.4.3 , 1.4.4	0.5	1	2	1.1	0.3
1.5.2	Verify Federation Object Model	1.4.3 , 1.4.5	0.5	1	2	1.1	0.3
1.5.3	Conduct Dry Run of Federation	1.5.1 , 1.5.2	0.25	0.5	1	0.5	0.1
1.5.4	Validate Federation Simulation	1.5.3	0.25	0 5	1	0.5	0.1
1.6	**Analysis**						
1.6.1	Conduct Simulation Runs	1.5.4	0.25	1	2	1.0	0 3
1.6.2	Validate Simulation Data	1.6.1	0.5	1	3	1.3	0.4
1.6.3	Conduct Data Analysis	1.6.2	1	2	4	2.2	0 5
1.7	**Final Demonstration**						
1.7.1	Conduct Final Demonstration	1.6.3	0.25	0.5	1	0.5	0.1

Table 14. Probability of Project Completion Analysis

WBS	Critical Path Activities		Completion Time (Weeks) Est.	Std. Dev
1.1.1	Research MDA Methodology		3.4	0.9
1.1.3	Research Merging MDA & FEDEP Methodologies		2.3	0.8
(1.1.4 , 1.1.5)	Research OneSAF & IWARS Programs		3.4	0.9
1.1.6	Apply MDA & FEDEP to OneSAF & IWARS		4.3	1.0
1.2.1	Formalize Findings		2.0	0.3
1.2.2	Generate Formal Report		2.3	0.7
1.3.1	Design HLA Federation		2.1	0.6
1.4.1	Build HLA Federation Framework		2.1	0.6
1.4.4	Integrate IWARS into Federation		5.5	1.5
(1.5.1 , 1.5.2)	Verify HLA Federation & Federation Object Model		1.1	0.3
1.5.3	Conduct Dry Run of Federation		0.5	0.1
1.5.4	Validate Federation Simulation		0.5	0.1
1.6.1	Conduct Simulation Runs		1.0	0.3
1.6.2	Validate Simulation Data		1.3	0.4
1.6.3	Conduct Data Analysis		2.2	0.5
1.7.1	Conduct Final Demonstration		0.5	0.1
	Project Estimated Completion Time		**34.5**	
	Project Standard Deviation			**2.7**

ID	Task Name	Start	Finish	Duration
1	**1.1 Initial Research**	11/1/2007	2/1/2008	13.4w
2	1.1.1 Research MDA Methodology	11/1/2007	11/23/2007	3.4w
3	1.1.2 Research FEDEP	11/7/2007	11/23/2007	2.5w
4	1.1.3 Research Merging MDA & FEDEP	11/26/2007	12/11/2007	2.3w
5	1.1.4 Research OneSAF Program	12/11/2007	1/3/2008	3.4w
6	1.1.5 Research IWARS Program	12/11/2007	1/3/2008	3.4w
7	1.1.6 Apply MDA & FEDEP to OneSAF & IWARS	1/3/2008	2/1/2008	4.3w
8	**1.2 Research Report**	2/1/2008	3/3/2008	4.3w
9	1.2.1 Formalize Report	2/4/2008	2/15/2008	2w
10	1.2.2 Generate Formal Report	2/18/2008	3/4/2008	2.3w
11	**1.3 Conceptual Representation**	3/3/2008	3/17/2008	2.1w
12	1.3.1 Design HLA Federation	3/4/2008	3/18/2008	2.1w
13	1.3.2 Design Federation Object Model	3/4/2008	3/12/2008	1.3w
14	**1.4 Integration & Mapping**	3/18/2008	5/8/2008	7.6w
15	1.4.1 Build HLA Federation Framework	3/19/2008	4/2/2008	2.1w
16	1.4.2 Build Federation Object Model	3/18/2008	3/25/2008	1.1w
17	1.4.3 Integrate OneSAF Into Federation	4/2/2008	5/5/2008	4.7w
18	1.4.4 Integrate IWARS Into Federation	4/2/2008	5/9/2008	5.5w
19	**1.5 Verification & Validation**	5/12/2008	5/26/2008	2.1w
20	1.5.1 Verify HLA Federation	5/12/2008	5/19/2008	1.1w
21	1.5.2 Verify Federation Object Model	5/12/2008	5/19/2008	1.1w
22	1.5.3 Conduct Dry Run of Federation	5/19/2008	5/21/2008	.5w
23	1.5.4 Validate Federation Simulation	5/22/2008	5/26/2008	.5w
24	**1.6 Analysis**	5/27/2008	6/26/2008	4.5w
25	1.6.1 Conduct Simulation Runs	5/26/2008	6/2/2008	1w
26	1.6.2 Validate Simulation Runs	6/2/2008	6/10/2008	1.3w
27	1.6.3 Conduct Data Analysis	6/11/2008	6/25/2008	2.2w
28	**1.7 Final Demostration**	6/26/2008	6/30/2008	.5w
29	1.7.1 Conduct Final Demostration	6/26/2008	6/30/2008	.5w

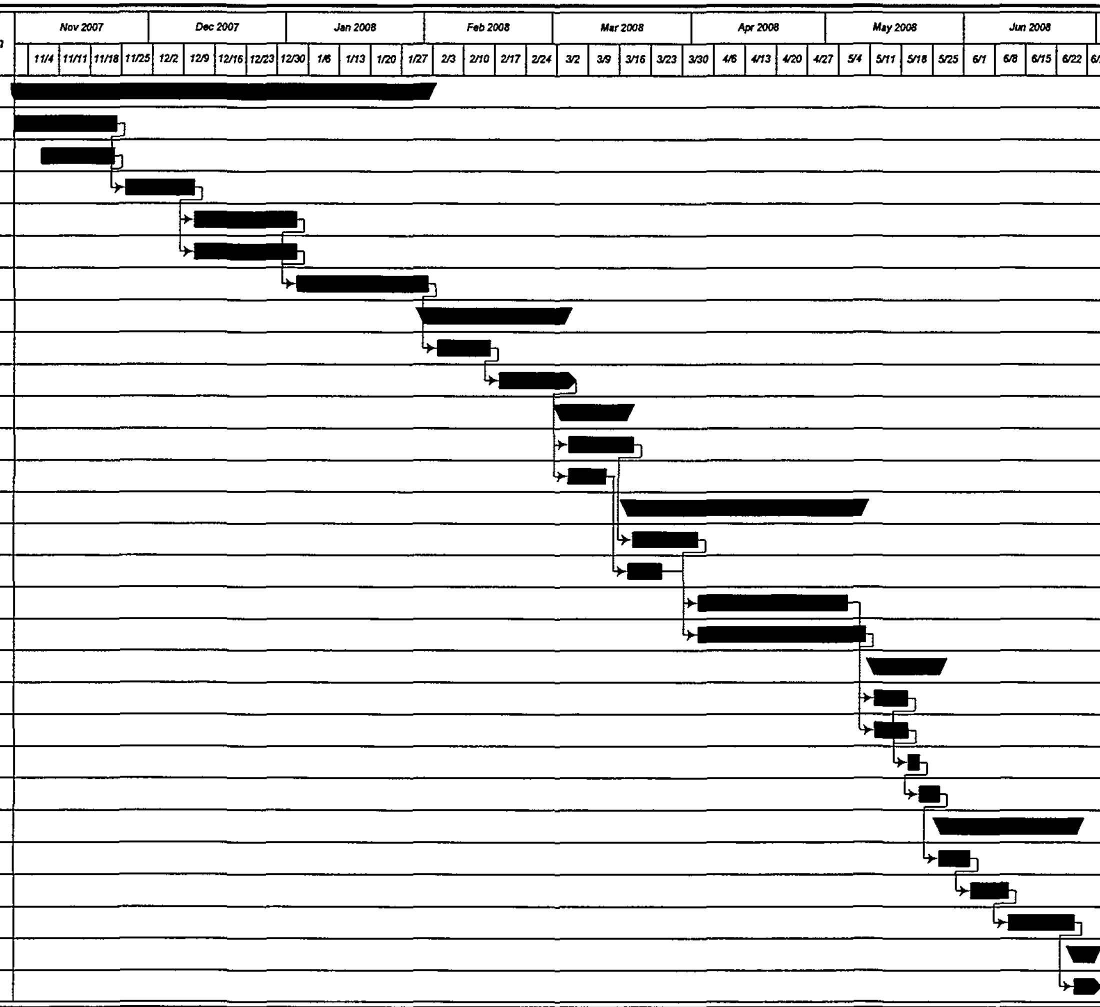

Figure 11. Gantt Chart

3.3.3 Human Resource Loading Analysis

Executing a project efficiently and effectively requires a balance of load of human resources. *Resource Loading* is planning tool that enables managers to determine the "right resources" at the "right time" at the "right cost" for the "right task". A resource loading chart depicts the flow of resources through a project's development and/or life cycle (LC). Properly developed human resource loading charts allow managers to allocate human resources by shifting working hours of personnel from week to week or day by day depending on the project. The charts can also determine estimated total resource hours required to complete a project.

The results from the human resource loading analysis conducted on PEO Soldier's task are below.

> Table 15 depicts the human resources (work hours) required by each working group by week. The Critical Path of the project contains about 90% of the activities; therefore, resource shifting cannot be capitalized. Since most of the project is handled in a "serial" matter, only a few activities (parallel ones) can shift resources to minimize resource loading. It should be noted that when "serial" activities occur at the same time, such as 1.1.3 and 1.1.4, human resources per week becomes heavily loaded and managers could be faced with human resource shortages – annotated by shaded blocks.
>
> The total amount of work hours for the entire project is 1938. Despite the project being a one-of-a-kind in nature i.e. more "serial" activities than "parallel" and most activities fall within the Critical Path, careful planning by each stakeholders' management is important and should be considered.

Due to the nature of developing M&S federations, there tends to be core processes (e.g. initial research, conceptual representations, integration & mapping, verification & validation, and analysis) that cause the critical path to fall within 90% of the activities – due to the serial activities. Therefore, this creates difficultly for managers trying to minimizing resources during the resource loading analysis.

Table 15. Human Resource Loading

WBS ID	Activity	Working Group(s)	Predecessor	Estimate Time in Weeks	Estimate Time in Hours	Work Hours/Week																																		Total Work Hours
1.1	**Initial Research**					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
1.1.1	Research MDA Methodology	VMASC	-	3.4	136 7	40	40	40	17																															136.7
1.1.2	Research FEDEP Methodology	VMASC	-	2 5	100.0	25	25	25	25																															100.0
1.1.3	Research Merging MDA & FEDEP Methodologies	VMASC	1.1.1 , 1.1.2	2.3	90.0				20	40	30																													90.0
1.1.4	Research OneSAF Program	VMASC	1.1 3	3.4	136.7							40	40	40	17																									136.7
1.1.5	Research IWARS Program	VMASC	1.1.3	3.4	136.7							40	40	40	17																									136.7
1.1.6	Apply MDA & FEDEP to OneSAF & IWARS	VMASC	1.1.4 , 1 1.5	4.3	173 3										13	40	40	40	40																					173.3
1.2	**Research Report**																																							
1.2.1	Formalize Findings	VMASC	1.1 6	2.0	80 0															40	40																			80 0
1.2.2	Generate Formal Report	VMASC	1.2.1	2 3	93.3																	40	40	13																93.3
1.3	**Conceptual Representation**																																							
1.3.1	Design HLA Federation	OneSAF, IWARS	1.2.2	2.1	83.3																			40	43															83.3
1.3.2	Design Federation Object Model	OneSAF, IWARS	1.2.2	1.3	50.0																			25	25															50.0
1.4	**Integration & Mapping**																																							
1.4.1	Build HLA Federation Framework	OneSAF, IWARS	1 3.1	2.1	83.3																					43	40													83 3
1.4.2	Build Federation Object Model	OneSAF, IWARS	1.3.2	1.1	43.3																					13	30													43.3
1.4 3	Integrate OneSAF into Federation	OneSAF	1.4.1 , 1.4.2	4.7	186.7																							35	35	35	35	20	27							186.7
1.4.4	Integrate IWARS into Federation	IWARS	1.4.1 , 1.4.3	5.5	220.0																							40	40	40	40	40	20							220.0
1.5	**Verification & Validation**																																							
1.5.1	Verify HLA Federation	OneSAF, IWARS	1.4.3 , 1.4.4	1 1	43.3																												3.3	40						43.3
1.5.2	Verify Federation Object Model	OneSAF, IWARS	1.4.3 , 1.4.5	1 1	43.3																												3.3	40						43.3
1.5.3	Conduct Dry Run of Federation	OneSAF, IWARS	1.5.1 , 1.5.2	0.5	21 7																														20					20.0
1.5.4	Validate Federation Simulation	OneSAF, IWARS	1.5.3	0.5	21.7																														20					20.0
1.6	**Analysis**																																							
1.6.1	Conduct Simulation Runs	OneSAF, IWARS	1 5.4	1.0	41.7																															40				40.0
1.6.2	Validate Simulation Data	Dahlgren	1.6.1	1.3	50.0																																50			50.0
1.6.3	Conduct Data Analysis	Dahlgren	1.6 2	2.2	86.7																																	60	27	86.7
1.7	**Final Demonstration**																																							
1.7.1	Conduct Final Demonstration	ALL	1.6.3	0.5	21.7																																		22	21 7
					Total Week Work Hours	65	65	65	62	40	30	80	80	80	47	40	40	40	40	40	40	40	40	78	68	57	70	75	75	75	75	60	53	80	40	40	50	60	48	***1938.3***

Part of Critical Path

Critical Work Week (Heavy Load)

3.3.4 Cost Analysis

Cost Analysis can be considered the most important study of a project. Without proper funding a project may not produce a useable product. Therefore, investigating and determining the approximate costs of a project is vital in determining the viability of project success. Typically the amount of funding is determined by a sponsor when a project is conceptualized. Without a proper plan in place, a project organization can exceed that predetermined level prior to completion – thus leading to project failure.

Expanding the human resource loading documentation from the previous section, variable costs (e.g. human resources – billable hours) and fixed costs (e.g. borrowed tools, software, travel, meetings) are added to approximate the total project cost. This technique produces a *Time-Phased Budget.* If the amount is larger than the granted amount, the project organization should address the issue with the sponsor to discuss further options – such as additional funding, reducing requirements, etc.

Below are the results from the cost analysis conducted on PEO Soldier's task. It should be noted that the following analysis contains *notional data* and should not be considered for actual budgetary use.

> The Budget for PEO Soldier M&S project is non-traditional and complex. As with most government related projects, funding originates from a sponsored program. That program will then pay for all or part of the expenses associated with the project. PEO Soldier, OneSAF and IWARS are all U.S. Army programs however; they are paid from different sources of money.
>
> PEO Soldier is funding the M&S project and is paying for research, software, travel, meetings, and billable hours. The following are expected costs related to the project but, not an exclusive list:
>
> - Research Grant (VMASC)
> - Unified Modeling Language (UML) Software

- TDY Costs (Travel related: transportation, hotel, per diem, etc)
- Meetings (rental fees, food, etc)
- Billable Hours (OneSAF and IWARS)

Table 16 is a Time-Phased Budget built on the human resource loading documentation. Totals are calculated by the week (fixed and variable costs) and by the stakeholder/group. PEO Soldier allotted $750K for the project. The project plan estimates the total cost at $261K, which is well under the allotted amount. However, if technical limitations occur during the project, it is very likely the project will shift to the right causing the billable hours to increase dramatically. PEO Soldier awarded VMASC a research grant for $70K. It should be noted that the estimated amount calculated for VMASC is at $76K. Fixed and variable costs were estimated by hourly rates, expected travel (to include number of personnel traveling, destinations, etc), expected meeting locations, and software needed.

Table 16. Time-Phased Budget

WBS ID	Activity	Working Group(s)	Predecessor	Estimate Time in Weeks	Estimate Time in Hours	Work Hours/Week																																		Total Work Hours
						1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	
1.1	**Initial Research**																																							
1.1.1	Research MDA Methodology	VMASC	-	3.4	136.7	40	40	40	17																															136.7
1.1.2	Research FEDEP Methodology	VMASC	-	2.5	100.0	25	25	25	25																															100.0
1.1.3	Research Merging MDA & FEDEP Methodologies	VMASC	1.1.1 , 1.1.2	2.3	90.0				20	40	30																													90.0
1.1.4	Research OneSAF Program	VMASC	1.1.3	3.4	136.7							40	40	40	17																									136.7
1.1.5	Research IWARS Program	VMASC	1.1.3	3.4	136.7							40	40	40	17																									136.7
1.1.6	Apply MDA & FEDEP to OneSAF & IWARS	VMASC	1.1.4 , 1.1.5	4.3	173.3										13	40	40	40	40																					173.3
1.2	**Research Report**																																							
1.2.1	Formalize Findings	VMASC	1.1.6	2.0	80.0															40	40																			80.0
1.2.2	Generate Formal Report	VMASC	1.2.1	2.3	93.3																	40	40	13																93.3
1.3	**Conceptual Representation**																																							
1.3.1	Design HLA Federation	OneSAF, IWARS	1.2.2	2.1	83.3																			40	43															83.3
1.3.2	Design Federation Object Model	OneSAF, IWARS	1.2.2	1.3	50.0																			25	25															50.0
1.4	**Integration & Mapping**																																							
1.4.1	Build HLA Federation Framework	OneSAF, IWARS	1.3.1	2.1	83.3																					43	40													83.3
1.4.2	Build Federation Object Model	OneSAF, IWARS	1.3.2	1.1	43.3																					13	30													43.3
1.4.3	Integrate OneSAF into Federation	OneSAF	1.4.1 , 1.4.2	4.7	186.7																							35	35	35	35	20	27							186.7
1.4.4	Integrate IWARS into Federation	IWARS	1.4.1 , 1.4.3	5.5	220.0																							40	40	40	40	40	20							220.0
1.5	**Verification & Validation**																																							
1.5.1	Verify HLA Federation	OneSAF, IWARS	1.4.3 , 1.4.4	1.1	43.3																												3.3	40						43.3
1.5.2	Verify Federation Object Model	OneSAF, IWARS	1.4.3 , 1.4.5	1.1	43.3																												3.3	40						43.3
1.5.3	Conduct Dry Run of Federation	OneSAF, IWARS	1.5.1 , 1.5.2	0.5	21.7																														20					20.0
1.5.4	Validate Federation Simulation	OneSAF, IWARS	1.5.3	0.5	21.7																														20					20.0
1.6	**Analysis**																																							
1.6.1	Conduct Simulation Runs	OneSAF, IWARS	1.5.4	1.0	41.7																															40				40.0
1.6.2	Validate Simulation Data	Dahlgren	1.6.1	1.3	50.0																																50			50.0
1.6.3	Conduct Data Analysis	Dahlgren	1.6.2	2.2	86.7																																	60	27	86.7
1.7	**Final Demonstration**																																							
1.7.1	Conduct Final Demonstration	ALL	1.6.3	0.5	21.7																																		22	21.7
					Total Week Work Hours	65	65	65	62	40	30	80	80	80	47	40	40	40	40	40	40	40	40	78	68	57	70	75	75	75	75	60	53	80	40	40	50	60	48	1938.3

Part of Critical Path

Critical Work Week (Heavy Load)

		Billing Rate/hr																																			Total Variable Costs
Variable Costs	VMASC	$80	$5,200	$5,200	$5,200	$4,936	$3,200	$2,400	$6,400	$6,400	$6,400	$3,736	$3,200	$3,200	$3,200	$3,200	$3,200	$3,200	$3,200	$3,200	$1,064																$75,736
	OneSAF & IWARS	$120																			$7,800	$8,196	$6,792	$8,400	$9,000	$9,000	$9,000	$9,000	$7,200	$6,396	$9,600	$4,800	$4,800	$6,000	$7,200	$5,808	$118,992
	Dahlgren	$120																																$8,000	$7,200	$3,204	$18,404

																																				Total Fixed Costs
Fixed Costs	Kick-Off Meeting at VMASC - Nov. 1-2, 2007	$12,500																																		$12,500
	UML Software - Dec. 10, 2007	$500																																		$500
	Working Group at Natick Army Depot - Jan. 7-8, 2008							$7,500																												$7,500
	Working Group at OneSAF (Orlando) - Mar. 3 -7, 2008													$5,500																						$5,500
	Working Group at OneSAF (Orlando) - Apr. 7-11, 2008																		$8,500																	$8,500
	Final Demostration at OneSAF (Orlando) - TBD																																		$15,000	$15,000
	Total Weekly Costs	$18,200	$5,200	$5,200	$4,936	$3,200	$2,400	$13,900	$6,400	$6,400	$3,736	$3,200	$3,200	$8,700	$3,200	$3,200	$3,200	$3,200	$11,700	$8,864	$8,196	$6,792	$8,400	$9,000	$9,000	$9,000	$9,000	$7,200	$6,396	$9,600	$4,800	$4,800	$12,000	$14,400	$24,012	$260,632

3.3.5 Critical Knowledge Analysis

It has been identified that there are four areas of knowledge that impact a project's performance: knowledge of an industry, knowledge about an organization, knowledge about a project, and knowledge about a project team [16]. This transformation from a broad domain (industry knowledge) to a narrow domain (project team knowledge) lends to the term known as *Critical Knowledge* and can be viewed in levels. These levels then can be mapped directly to M&S federation organizations – for example, industry knowledge → M&S community, organization knowledge → project-based organization, and so on.

Understanding the areas of critical knowledge can help managers of project-based organizations identify critical knowledge gaps and develop a plan to close those gaps – thus maximizing project performance. One method of identifying those gaps is to perform a *Critical Knowledge Analysis* on a project. This non-automated tool identifies and explains critical knowledge, identifies sources of critical knowledge, and develops a plan to transfer critical knowledge from one source to another.

The results from the critical knowledge analysis conducted on PEO Soldier's task are below.

> Knowledge is very important for any given task. It is vital to identify Critical Knowledge – knowledge associated with technical know-how, problem solving, task improvement, etc. – related to a project up front. Since the PEO Soldier M&S project is dealing with newer technology, most of the Critical Knowledge must be obtained from outside sources. Therefore, all of the stakeholders must understand what is expected of them related to particular knowledge, such as being the source or to who needs to be consulted.
>
> Table 17 assists with the identification of Critical Knowledge and how it should be used and transferred to others. The COTR and VMASC are the considered the SMEs on MDA and HLA when integrating federations. Therefore,

they should be the primary contacts when dealing with questions about federating federates. OneSAF and IWARS are highly encouraged to document in detail the process of integrating their M&S model into the federation. Following these simple guidelines will allow the project to remain on track and end with success as well as be beneficial in the future as more and more standalone M&S models will be integrated into federations to solve complex tasks.

The field of M&S is relativity new; therefore, *knowledge* achieved on previous work is invaluable to subsequent work. Furthermore, M&S federation development is a newer concept than M&S. The U.S. Army is just now conceptualizing and testing M&S federation projects; PEO Soldier is one of the first. Therefore, capturing, organizing, and storing knowledge gained from previous M&S projects is crucial to project-based organizations – this will be discussed in Section 5.2.3. A project lacking in critical knowledge and that does not have a plan in place places a project at risk.

Table 17. Critical Knowledge Analysis

Elements	Areas of Critical Knowledge			
	Industry's	Organization's	Project's	Project Teams'
What to Understand?	***External Enablers & Barriers***	***Power in the Organization***	***Project Capabilities***	***Strengths and Weaknesses of Teams***
Why is the Knowledge Critical?	To develop a Federation quickly and effectively using the latest technology	Working with the Military & Government can be difficult if one does not understand the structure	To ensure all requirements are captured, documented, communicated, and implemented within the Federation	The project deals with new technology and not all of the stakeholders fully understand how to implement a Federation
Source(s) of Critical Knowledge?	M&S Body of Knowledge, M&S Forums, etc	COTR, Senior Management, Prior Military Personnel	PEO Soldier, COTR (primary contact)	COTR, VMASC
Method of Critical Knowledge Transfer?	Communicate with people within the Body of Knowledge and attend M&S Forums	One-on-One Meetings, Involvement with Senior Management	Requirements Documentation Meeting with all Stakeholders present	Working Groups with COTR, VMASC, OneSAF, and IWARS
Method of Critical Knowledge Creation?	Assemble research knowledge and generate a Formal Report	Management Knowledge Documentation	Assemble Working Documents and Models capturing requirements	Assemble Documentation of work done, Lessons Learned, Project Journals, After Action Reviews

3.3.6 Key Communications Analysis

Identifying key communication activities, lanes, and a schedule of those events provides a project organization with a plan that ensures proper flow of information. Kerzner identifies barriers in communication such as perceptions, personality and interest conflicts, emotions, etc. [8]. A project organization with a well designed communication plan can minimize the above mentioned barriers and increase project performance.

Communication Analysis conducted on a project provides an organization with a communications plan to have information such as: sources/recipients, descriptions of and required information, frequency, media/channels and the possible interferences of the communications. Below are the results from the key communication analysis conducted on PEO Soldier's task.

> Communication is crucial; all stakeholders must communicate vertically and horizontally within the project. Successful communications lead to an effective and efficient solution. There are four (4) Key Communication Activities for the PEO Soldier M&S project. These activities are tied to WBS IDs: 1.2 Final Report, 1.4 Integrating & Mapping, 1.7 Final Demonstration, and Bi-Weekly Updates.
>
> Communications should not be limited to the above mentioned; if communication is needed, then simply make contact via email, telephone, video-teleconference, etc. Distance will be the biggest factor for communication break-down during the project as most stakeholders are no closer than 300 miles apart. Bi-weekly meetings are very important as they are informal and are meant to bring together all teams to answer and/or work out problems encountered during an activity. It is important that at a minimum ALL stakeholder managers be present during the bi-weekly meetings; everyone else is highly encouraged to attend. The COTR will coordinate the bi-weekly meetings; however, most will be via TELECON. Table 18 represents the four (4) Key Communication Activities and the expectations of them.

Table 18. Key Communication Activities

Elements	Key Communication Activities			
	Formal Report (WBS 1.2)	Integrating & Mapping (WBS 1.4)	Final Demonstration (WBS 1.7)	Bi-Weekly TELECON
Source	VMASC	OneSAF & IWARS	PEO Soldier, OneSAF, IWARS	COTR
Recipient	All Stakeholders	COTR, VMASC	All Stakeholders	All Stakeholders
Purpose	To deliver Formal Report on research on Federating OneSAF & IWARS using MDA & HLA	To provide the results/findings of Federating OneSAF & IWARS into a Federation	To provide the results/findings of the PEO Soldier M&S Roadmap Project	To maintain communications between all stakeholders and resolve current issues
Needed Information & Data	Formal Report, UML Supporting Documents, Slide Show	Status of Integration	Final Outbrief, Final Reports, Demonstration Results	As needed
Frequency	Once	Once	Once	Bi-Weekly
Channel	Report, Presentation	Presentation	Reports, Presentation	Preliminary Emails
Noise Source	Academia Preferences, Time Restrictions	Time Restrictions, Group Preferences, Politics	Politics, Management Preferences	Management Preferences
Noise Elimination	VMASC to communicate findings on a regular basis before delivering Final Report	OneSAF & IWARS to use specifications during the building of the Federation and to keep open minds and not resist changes	Management must first listen to all stakeholders before making a ruling or judgment call	Keep an open mind and listen to recommendations
Feedback	Instant feedback during the presentation	Instant feedback during the presentation	Instant feedback during the Presentation and Final De-brief of each stakeholder	Instant feedback during the presentation
ID/Title	*FR*	*I&M*	*FD*	*Bi-W*

3.4 Measures of Merit (MoM)

Project performance can be measured by *technical performance* and *human performance.* Technical performance can be measured from compliance to budgetary constraints, deadline attainments, quality of products (e.g. success of verification and validation of a M&S project), etc. Human performance can be measured from stakeholder satisfaction by means of surveys questioning results and operations of PMs, team members, sponsor(s), management, etc. Another aspect of human performance is learning. Was there knowledge and experiences documented and cataloged (knowledge repository) for future use? These performance measures can be accomplished by means of *metrics.*

To carry out strategic project management, it is implied that the performance of projects are measured at the project level, by means of *Measures of Merit* (MoM), and at the organizational level, by means of more comprehensive measures. These measures – also known as *metrics* – aggregated together within the project-base organization provides a method of comparing projects to each other and allowing management to make informed decisions. The need for MoMs is to classify results from states, events, tasks, etc. by the assignment of success or failure. Also, standardized MoMs align metric results and the knowledge repository so that results may be stored in an organized matter for future use.

The outcome of a M&S project solution and/or intermediate task needs to be evaluated – with the use of scenarios – by the impact of the results to the sponsor's policy and objectives and specific qualities relevant to those objectives [5]. Scenarios are used to define elements, relationships, and the dynamics of a model or task. Evaluating these scenarios by using selected metrics can provide insight to that particular study. Due to the complexity of M&S federations, no one measure or methodology exists to satisfactorily assess the overall effectiveness of a model's output; therefore, a multifaceted approach is necessary.

NATO COBP defines MoM as a generic term to encompass different classes of measures [5]. MoM enables an organization to evaluate interim states, final states, and/or particular events throughout a project. These measures provide a mechanism to deliver data needed to answer the sponsor's question. MoMs should be directly linked to objectives with thresholds and constraints and have a determined confidence level associated with each. MoMs are employed to compare multiple alternatives on equal terms as well as [5]:

- Establishing a standard or expectation of performance.
- Establishing the bounds of performance of a system as well as the effects of imposed constraints.
- Comparing and selecting alternative systems that may be very dissimilar but are designed to achieve a similar purpose.
- Assessing the utilization of a system in application domains or missions.
- Identifying potential weaknesses in specific areas of a system.
- Analyzing the impacts of organizational changes.
- Analyzing training effectiveness.
- Determining the most cost effective approach to achieve desired objectives.
- Comparing a replacement system, or components of a system, against predecessors.
- Assisting in generating and validating requirements and deriving specific requirements from broad statements of objectives.
- Evaluating the effectiveness of human decision making.
- Determining the degree of mission success or failure.
- Determining the return on normality.

Reliable and valid MoM selection is critical – if not-there is a risk of generating false conclusions. Reliable MoMs take into account expected variations in repeated measurements, accuracy of the measurements, and phenomenon occurrences with real effects and measurement effects. Valid MoMs take into account causal relationships between variables, measure only target objectives, and judge robust results with sufficient sensitivity. Then these results can be generalized and accepted by field experts.

NATO COBP utilizes a hierarchical level approach for selecting MoMs related to C^2 projects; however, concepts can be drawn from this section and employed for M&S federation development. Table 19 depicts five (5) classes of MoMs along with their intended purposes and Figure 12 illustrates those relationships:

Table 19. NATO COBP MoM Classes

MoM Class	Purpose
DP - Dimensional Parameters	Properties or characteristics in physical entities
MoP – Measures of Performance	Measures attributes of internal system behavior
MoCE - Measures of C2 Effectiveness	Measures impact of C2 systems
MoFE - Measures of Force Effectiveness	Measures force accomplishment of mission objectives
MoPE – Measures of Policy Effectiveness	Measures impacts in policy environments

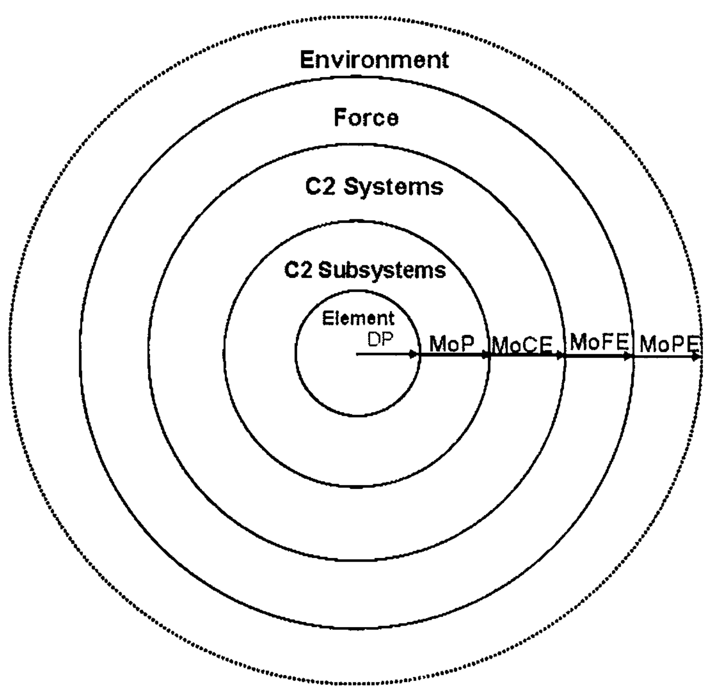

Figure 12. NATO COBP MoM Relationships

Evaluations of tasks provide insight to activities – decomposing a development cycle, identifying all tasks of the system, and determining proper data measurements of those tasks is imperative for project success. NATO COBP recommends two primary measures (Table 20): *time-based* (quantitative) and *accuracy* (quantitative or qualitative). These measures can be used separately or in combination, depending on the situation. It is important that the subject matter experts (SME) be part of the process and be consulted when determining which method should used and where.

Table 20. NATO COBP Measurement Categories

Time-Based	Accuracy
Time to react to an event	Precision of the observed system(s) performance
Time to perform a task	Reliability of the observed system(s) performance
Time horizon for future for predictive analysis	Completeness
Rate of performing tasks	Errors
	Quality of information produced

MoMs are used to measure the merit of an action or activity; however, the NCOBP does not specify the context of measuring, "what"? This can be accomplished by the use of a framework of four elements (4FE), Figure 13: The mission element (defines what needs to be done on the strategic level), the system element (defines what needs to be done on the system level in order to support the ideas), the evaluation element (defines what the metric is part of MoM), and the data element (captures the measurement(s)).

The main contribution of the 4FE is to compare and transfer metrics between different phases and systems. For example, making sure a project metric is used to decide which system to procure and reuse when the real system needs to be tested later; this is of high value for project-based organizations. Next we will discuss an application of the 4FE supported by U.S. DoD and Department of Homeland Security that provides a means to capture elements into a context for analysis.

ODU and VMASC are supporting a variety of organizations working in the domains of acquisition, development, testing, training, and operational support [7]. All of these organizations use M&S in one way or the other to support measuring effects and capabilities. However, there is no sufficient framework established to ensure the alignment of assumptions and constraints.

While developing a metric based framework, Platform Independent Models[5] (PIM) can be a significant management help. The following example of the metrics will demonstrate this potential. Here metrics are defined in the context of four elements – mission, system, evaluation, and data – as shown in Figure 13:

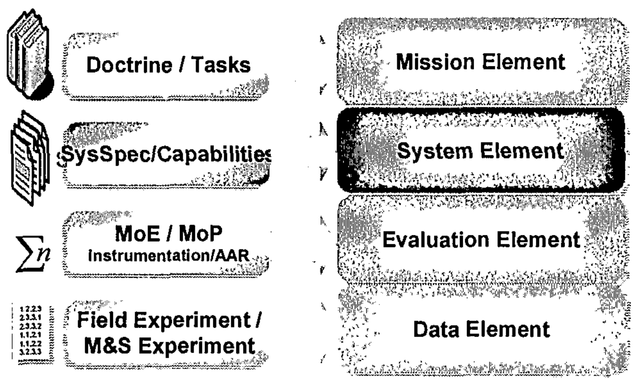

Figure 13. An Application for Metrics

The overall framework will now be explained. The *mission and means* framework sets the operational context for the mission essential task that is measured by a metric; this defines what and why something has to be accomplished. The *system* to be evaluated (or the system under test) is the system and its capability currently delivering the functionality needed to conduct the mission essential task; this defines who is doing the task and how.

---

[5] PIMs are used to model mission essential tasks and compose them into vignettes and scenarios.

The evaluation element is the *formula* used to compute a value for the metrics and is an element on its own. The final element is the collected *data* belonging to the metrics context as well.

This form of metrics was first recommended by Jack Sheehan and Dr. Paul Dietz for the U.S. Army Test and Evaluation activities [7]. The idea is not limited to testing but is applicable in all domains. For example, it would make no sense if metrics used in the operational testing of systems are different from those used to decide which system to procure. Furthermore, if a new metric is successfully used in real world operations, it should be used for future procurements and testing as well. The same is true for the PIMs derived from the METL as well as for the PIMs describing scenarios and vignettes. It makes no sense to have different "business views" in different domains with respect to the same mission essential tasks.

When adapting NATO's COBP MoM recommendations to project management in the domain of M&S federation development, a process may be developed to provide effective measurements to determine success or failure of a project or task. Top-level management can also utilize this tool in conjunction with comprehensive metrics (e.g. balanced scorecards) to manage a project-based organization. This topic is beyond the scope of this thesis and left to the reader for further research.

For complex projects (one with many employed MoMs) one might consider adding central performance monitoring functionality to the SPMP. By adding this functionality a PM can easily track/follow a project by performance through the different stages. It also provides top-level management the ability to manage resources by comparing MoM results instantly. For example, if a project is designed with milestone incentives and reaches a point with above average results, reports can be generated on-the-fly with pre-programmed tools. Further research and testing will be required before exploiting this option.

PEO Soldier did not emphasize MoMs within this project due to the nature of the problem and it being the first attempt at federating heterogeneous M&S models together; the focus was more towards a working model and not so much prescribed results. However, subsequent projects by PEO Soldier will phase-in MoMs. Therefore, this thesis does not contain an actual MoM analysis.

3.5 Uncertainty, Risks, and Knowledge Analysis

All projects encounter some kind of *risk,* and those risks have causes. Kerzner defines risk as "a measure of the probability and consequence of not achieving a defined project goal" [8]. It can be said that risk has two components: probability of occurrence (likelihood) and impact of the occurrence (amount at stake) [8]. Risks can be rewarding and/or have consequences associated with them. To avoid consequences one needs to understand the knowledge and/or lack of, uncertainty, and ambiguity related to a project. *Risk Analysis* and management (discussed in Section 5.3) is a five step process: *identify, evaluate, plan, track, and tackle.* Failure to properly analyze and manage risks continuously through a project increases the probability of project failure and/or sponsor dissatisfaction.

Risk analysis begins with the identification of possible risks. Managers of a project organization should work together to identify risks by asking questions (e.g. what can go wrong during this process, what kind of impact will it have on the project, what can we do to mitigate that problem?), interviewing SMEs, and examining the existing supporting documentation (e.g. WBS, plans). The indentified risks then need to be organized and transformed into supporting documentation for evaluation. Upon completion of evaluation, a plan is devised to mitigate each risk. Track and tackle will be explained in Section 5.3.

The results from the uncertainty, risks, and knowledge analysis conducted on PEO Soldier's task are below.

> It was determined that there are four (4) key risks associated to the PEO Soldier M&S project: Maturity of Technology (MDA and HLA), Complexity of Developing a federation, Dependency of each others System (OneSAF and IWARS), and Resultant Data for Analysis.
>
> Table 21 describes factors to help mitigate Project Risk.

Table 22 denotes Probability of Occurrence of Risk (Po) and defines the scale used to measure of risk (a numerical value between 0 and 1). Table 23 denotes Risk Impact (Ri) of those occurrences and defines the scale. Table 24 denotes the calculations to determine the Overall Project Risk Factor (OPRF).

The OPRF is 0.71 and can be considered a "Moderate to High Risk" project.

Table 21. Risk Mitigation

Risk Mitigation

Risk	Strategy	Indicators	Actions
Maturity of Technology (MDA and HLA)	Reduce	Bi-weekly meetings with VMACS and the Formal Report results	Work closely with M&S groups and other academia
Complexity of Developing a Federation	Reduce	Bi-weekly meeting outcomes and design reviews	Utilize modeling software tools to develop the federation architecture
Dependency of each others System (OneSAF and IWARS)	Reduce	Bi-weekly meeting outcomes and design reviews	OneSAF and IWARS work closely and disclose all problems and concerns to all
Resultant Data for Analysis	Reduce	Data result reviews with Data Analyst	Refine the Operational Scenario and Federation configuration to obatin correct results

Table 22. Probability of Occurrence of Risk (Po)

Probability of Occurrence of Risk (Po)				
Po	**Maturity**	**Complexity**	**Dependency**	**Resultant**
Low (0.1)	Existing technology	Simple design	OneSAF and IWARS completely compatible with each other	Federation Data 100% useful
Moderate (0.5)	Change needed	Moderate change	OneSAF and IWARS somewhat compatible with each other	Federation Data is somewhat useful
Major (0.9)	Research needed	Very complex	OneSAF and IWARS not compatible with each other	Federation Data is not useful

Table 23. Risk Impact (Ri)

Risk Impact (Ri)				
Ri	**Cost**	**Schedule**	**Requirements**	**Quality**
Low (0.1)	Budget not exceeded	No impact on Critical Path	Exceeds requirements	100% Repeatable results
Moderate (0.5)	Costs exceed budget by less than 25%	Small impact on Critical Path (<= 8wks)	Meets requirements	50% Repeatable results
Major (0.9)	Costs exceed budget by less than 60%	Large impact on Critical Path (> 8wks)	Requirements cannot be meet due technology	0% Repeatable results

Table 24. Overall Project Risk Factor (OPRF)

Overall Project Risk Factor (OPRF)							
Risk	Assessment	Probability of Risk	Impact on Cost	Impact on Schedule	Impact on Requirements	Impact on Quality	Overall Impact
Maturity of Technology (MDA and HLA)	Moderate	0.5	0.5	0.5	0.9	0.5	**0.6**
Complexity of Developing a Federation	Moderate-High	0.7	0.7	0.8	0.7	0.5	**0.7**
Dependency of each others System (OneSAF and IWARS)	Low-Moderate	0.3	0.3	0.3	0.1	0.4	**0.3**
Resultant Data for Analysis	Low-Moderate	0.3	0.3	0.4	0.1	0.5	**0.3**

Probability of Occurrence	0.45	
Project Risk Impact		0.6

Project Risk Factor	*0.71*

4. IMPLEMENTATION – METHODS & TOOLS

The *Implementation* phase of the SPMP is where the project becomes more technical in nature than managerial. Even though it is more technically orientated, general project management should not be lessened during this process. Project organizations have to continuously monitor all the events in the implementation phase and readjust the project plan as needed. For example, a PM may have to readjust the project's schedule and/or budget to accommodate new development challenges because technical teams discovered they cannot use pre-existing models.

Even though the implementation phase is placed lower on the SPMP chart, Figure 3, it does not infer that technical work must wait until all other management tasks and supporting documentation is complete. Depending upon the situation and the project task, the project organization and/or PM may determine that technical work must begin as soon as a contract has been awarded. Therefore, careful planning and consideration may be needed to plan and execute a project that has parallel tasks (management and technical) running simultaneously.

The idea of "reusable artifacts" is pivotal for the success of implementation. As one of the themes presented in this thesis, it is stated that "reusing" supporting documentation, project products/services, and knowledge gained from previous projects lends "know how" and actual artifacts to future projects. This is especially critical for implementation. If components of an existing M&S model can be reused in another project, it can drastically reduce development time and the cost of a project. Utilizing concepts and methodologies such as Model Driven Architecture (MDA), High Level Architectures (HLA), Federation

Object Model (FOM), Runtime Infrastructure (RTI), etc. can assist project-based organizations by using existing solutions for a new M&S federation project.

The most important factor of reusability is the formalized way of documenting, storing, and retrieving information when needed. Without a formalized way of documenting their processes, project-based organizations cannot properly utilize their knowledge repository to retrieve and apply knowledge and reusable products to new project tasks. The formalized documenting system must be powerful and flexible enough to express all data requirements to support the technical mapping process.

Tolk suggested a concept, for organizations that develop federations, to assemble federation integration knowledge called Pathfinder Integration Environment (PIE) [27]. This web-portal concept provides a way to share localized expertise (with respect to federation development) and knowledge of all possible federate candidates, so that organizations can effectively select the correct federates and develop federations more efficiently.

Figure 14 depicts the PIE concept with three sections. The first section, *Knowledge*, is where knowledge resources are described and applied to support the current process. The second section, *Resource Description*, is where M&S resources (e.g. models, federates, tools, software, lessons learned, best practices) are described. The final section, *Resources*, is the locations those resources identified. The goal of this concept is to provide a method of "sharing" information among project organizations and inside project-based organizations via the web. The web was chosen as a medium for this information because it may be easily accessed by everyone and presented to find solutions quickly.

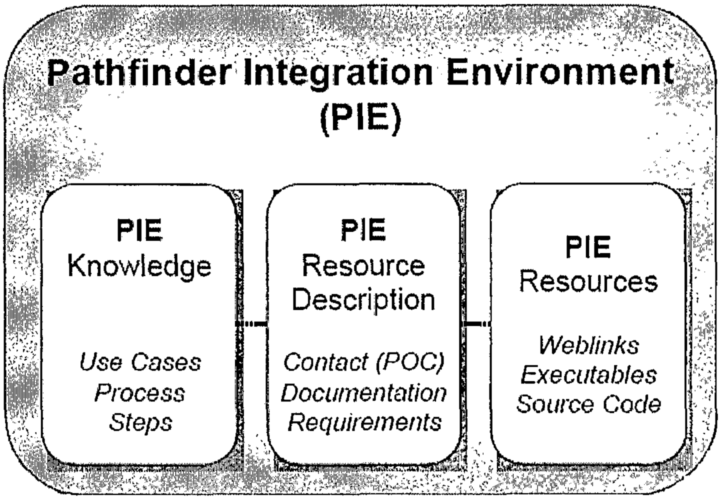

Figure 14. Pathfinder Integration Environment Concept

The implementation phase explained in this thesis contains four main ideas: *Simulation Selection* (Section 4.1), *Data Selection* (Section 4.2), *M&S Federation Systems Engineering Approach* (Section 4.3), and *Developing & Deploying Plans* (Section 4.4). These ideas can be neither complete nor exclusive. Due to constraints within the PEO Soldier project, the simulation and data selection sections are discussed briefly and contain minimal information. However, they are worth mentioning because they are necessary for any federation development project.

4.1 Simulation Selection

Simulation Selection may be considered the first step of the M&S development process. Before any planning can occur, it must be determined what kind of model(s) would best fit the simulation system. There are many types of M&S methodologies and paradigms to chose from such as distributed simulation, parallel simulation, agent based modeling, federation modeling, etc. Therefore, it may require M&S subject matter experts (SME) to determine which method is best suited for the task.

One example of simulation selection is a task requiring a model to simulate a transportation management system which has satellite offices in different geographic locations. Developing a federation of distributed simulation systems interconnected by the internet might be the best choice for that particular project. Meetings with the sponsor, SME, technical leads, PM, etc. is critical in the beginning stages to determine which methodology would be ideal for the project.

Other important factors related to simulation selection that should be considered are listed below. These may seem closely related to model selection however they are just as important when selecting the simulation system:

- Integration Necessities: Does the model(s) in question support HLA, a standardized FOM, compatible with a RTI, etc.

- Transformable: Can the candidate model support a transformation from its legacy system to an infrastructure that supports MDA or automatic code generation?

- Compatibility and Composability: Are the models compatible (i.e. can they talk to each other – are they interoperable)? Can the models be composed with components from the other model (i.e. foundation classes, etc.)?

- Reuse: Are there any pre-existing simulation systems already developed and in use today with the same capabilities?

- Fidelity and Resolution: Will the candidate model(s) provide the correct data/information needed to answer the task (i.e. do we have confidence in the data provided and will it contain enough information to answer our questions)?

Even though simulation selection and data selection are mentioned in two different sections, it should be noted that simulation and data selection go hand-and-hand. For example, data requirements need to be identified before selecting a simulation system to ensure those data requirements can be met with the selected system.

4.2 Data Selection

The output data of a M&S model generally represents the dynamic response of the system for a given scenario and initial set of constraints. This data is then often delivered to analysts to perform formal mathematical procedures to evaluate and determine the outcome of the simulation. During these analysis procedures, the data has to be transformed into usable formats to answer the questions motivated by the project's task. A M&S federation typically produces massive amounts of data and therefore requires experienced personnel to handle such data.

For example, Figure 15 depicts a system of systems. Note that the intra-data (communications between S_1 and S_2) is identified by **{ x, y, z }** and system's output data is a function of the system indentified by **f(x,y,z) = (X,Y,Z)**. One might consider the outputs X, Y, and Z to be the only data required by analysts. However, that is not always true. Often analysts need a comprehensive data set (including the intra-data) to determine why an output of X, Y, and Z was produced.

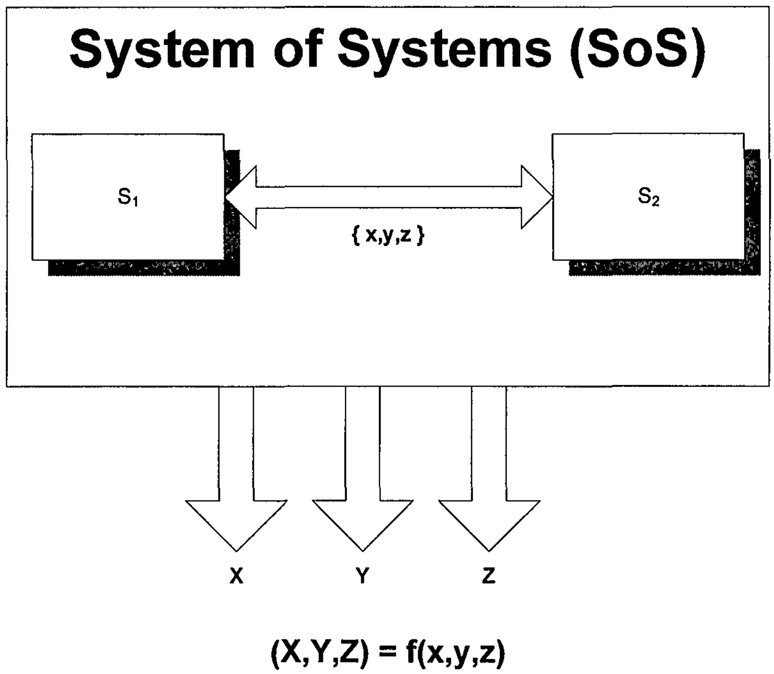

Figure 15. System of Systems Data

Therefore, it is essential during *Data Selection* to correctly identify the kind and type of data required for analysis, data sources within the M&S model, data administration (i.e. how to document the metadata), and data attributes (e.g. fidelity, accuracy, resolution) needed to answer the sponsor's question(s) – this process often requires input from authoritative groups, SME, etc. Below are typical guidelines to follow during the selection process:

- Locate the Requirements: What process(s) are you trying to support? For example, the effectiveness of the BA for a soldier.

- Identification of Elements: Identify the data elements that will provide you the results for effectiveness measurements.

- Identification of Systems: Identify the system(s) that will provide you that information. For example, IWARS can compute the six body parts of a body and allows BA to be placed on a soldier within the model.

4.3 M&S Federation Systems Engineering Approach

Federating M&S heterogeneous federates with an engineering solution has been a well received topic in recent years, thus producing several new methodologies. Applying and merging *Federation Development and Execution Plan* (FEDEP) and *Model Driven Architecture* (MDA) methodologies can feasibly provide another top-down engineering approach to assist in constructing federations – vs. typical straight implementation that may cause development difficulties [2].

Research during the PEO Soldier project showed the benefits of using a top-down engineering solution to match current capabilities (OneSAF and IWARS) with operational requirements (required metrics for procurement). Federating these two heterogeneous simulation models required merged ideas from FEDEP and MDA methodologies. This systems engineering approach also allows organizations to align requirements to M&S model(s) during development.

The top-down engineering approach proposed below merges FEDEP and MDA methodologies allowing organizations to provide faster and cleaner implementation of federations. Though performing straight implementation may provide a one-time solution, it normally does not allow replication for future projects – therefore, providing no value to the project-based organization. Using a systems engineering methodology allows organizations to better understand how something functions and apply that knowledge to future projects – ultimately becoming more efficient. This process is a key requirement for strategic project management.

4.3.1 Federation Development and Execution Plan (FEDEP)

A *federation* is defined as two or more physically distributed simulation systems integrated together into a unified simulation environment to accomplish a complex task [20]. It became clear in the early stages of federation development that a methodology was needed as various communities – such as government and commercial organizations – were taking several different approaches often developing along same line. Many of those organizations used M&S as the key enabler to generate general functions within the federation. However, those approaches were considered proprietary and straight forward implementations without an engineered solution.

Since the mid-1990s several M&S communities noticed this growing problem and developed and proposed a recommended practice to the IEEE in 1999 that described a generalized process for building and executing a federation. In March 2003, the IEEE approved and released guidance – IEEE 1516.3 *Recommended Practice for High-Level Architecture* (HLA) *Federation Development and Execution Process* (FEDEP) – to orient developers to a specific set of tasks and activities needed to develop and execute federations.

FEDEP is a generic common sense systems engineering methodology that uses defined steps (activity inputs, recommend tasks and activity outputs) to take a federation through a development cycle – from idea and conceptual model to the evaluation of the results [21]. This basic framework allows developers to tailor it to their needs while maintaining an engineering solution. The FEDEP process is broken down into seven hierarchical activity steps, or levels, with feedback loops between each as shown in Figure 16. Each of the seven steps can be described in great detail however; for the purpose of this thesis we are only focusing on steps one (1) through four (4).

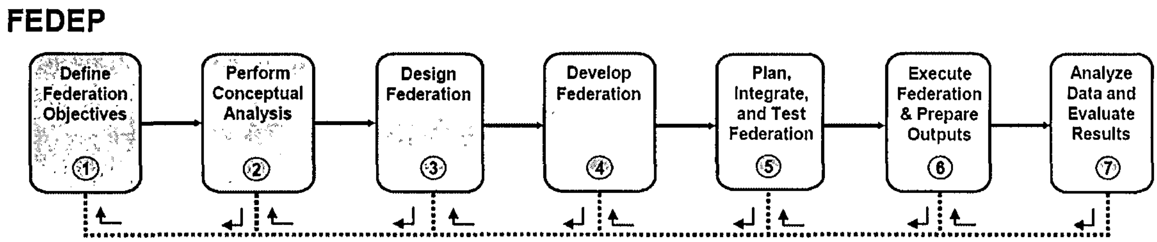

Figure 16. Federation Development and Execution Process (FEDEP)

- Step one (1) *Define Federation Objectives*, all available resources are identified in advance as well as user requirements, objectives, and desired outcomes. The developed and refined information is then captured in an *Initial Planning Document* which is passed to the input of step three (3).

- Step two (2) *Perform Conceptual Analysis* starts the development process of a federation by developing the federation Scenario, Conceptual Model, Test Criteria, and Requirements. Federation Test Criteria and Requirements are products which provide inputs to step seven (7) Analyze Data and Evaluate Results and will not be discussed further. Federation Scenario[6] and Conceptual Model[7] are key inputs for steps three (3) and four (4).

- Step three (3) *Design Federation* continues the development process by producing the Federate & Federation Designs, Federation Development and Execution Plan, and List of Selected Federates. All three products are then supplied to step four (4).

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[6] Federation Scenario contains types and numbers of entities/objects used in the federation; description of entities/object capabilities, behaviors, and relationships; event timelines; geographic regions; natural environmental conditions; initial and termination conditions; vignettes; etc. [21].

[7] Conceptual Model is the transformation of the federation objectives/requirements into implementation-independent functional and behavioral descriptions [21].

- Step four (4) *Develop Federation* is the last step of the planning stage and before starting the integration of the federation. Expected outputs of step four (4) are extensive and should contain: Federation Agreements, New/Modified Federates, Implemented Federation Infrastructure, Runtime Infrastructure (RTI) Initialization Data, Federation Object Model (FOM), Federation Execution Data (FED), FOM Document Data (FDD), Scenario Instances, and Supporting Databases.

FEDEP provides general guidelines and a process flow for developing and generating core components of a federation. Each of the previous steps should be revisited if changes occur downstream as there is a possibly those changes will impact prior work. It is also critical that those changes are captured, well documented and communicated to all stakeholders to ensure a proper engineered solution is maintained throughout the federation model.

4.3.2 Model Driven Architecture (MDA)

Object Management Group's (OMG) Model Driven Architecture (MDA™) was developed by technical representatives from a diverse body of vendors, suppliers, and end-users aiming to improve overall project development with the benefits of: faster development time, architectural advantages (scalability), improved code consistencies (security) and maintainability, and increased portability (interoperability and composability) [22]. The main objective of the MDA framework is to insulate business logic from technology advancement or lack thereof. To put it another way, it is a standardization of divorcing implementation details from business functions unifying the business model with technology – another key element required for strategic project management.

MDA takes a top-down approach vs. the typical bottom-up – where technology normally drives corporate desires and requirements. Utilizing MDA methodology for example, let's say a corporation wants to add a new function to its online services. The request for change originates from corporate management and is captured using Unified Modeling Language (UML) tools even before the IT department is given a "go" for implementation. MDA ensures consistency is maintained throughout the business model, and any additions introduced are verified – to eliminate potential compatibility issues – against other components within the entire framework. This leads to codifying and standardizing steps from the conceptual model to the final product [23].

The MDA approach can be viewed similarly to the traditional software development life cycle. However, MDA offers three key levels of models and is technology-independent at its core [23], see Figure 17. Documents and diagrams are produced within the three levels and are in the form of requirement descriptions (text and pictures) and everything else is in UML – use cases, class diagrams, interaction diagrams, activity diagrams, sequence diagrams, etc. [24].

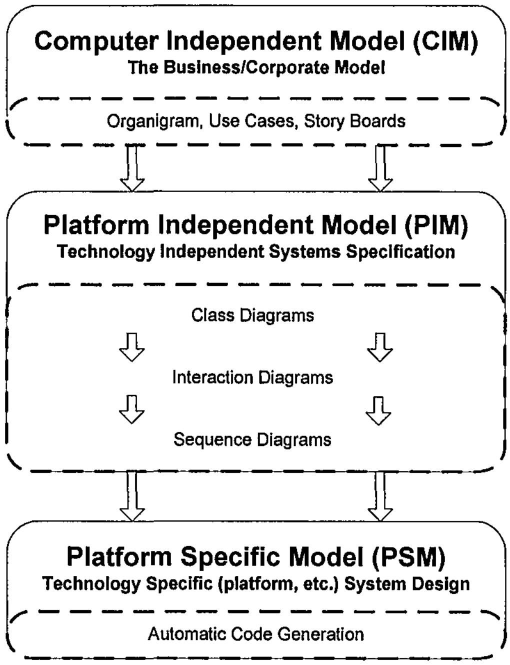

Figure 17. Model Driven Architecture (MDA) Levels

The *Computational Independent Model* (CIM) describes the corporate vision – conceptual view – of the system and is often called the domain model or business model. The *Platform Independent Model* (PIM) describes more specifically the core business components and services, to include functionality and behavior, independent of any technology to be used. Finally, the *Platform Specific Model* (PSM) describes technical implementation. Here IT subject matter experts (SME) work out the details on how components and services should be implemented using a particular technology.

As one moves down through the models, technology takes over the business realm. The completed PSM, if captured in UML correctly, contains enough information so that automatic code generation tools may be utilized to generate specific code. The generated code is not a 100% solution; minimal work may be required to complete a fully functional application.

The OMG's vision is to allow organizations – possibly causing realignment in the process – to utilize the MDA methodology and to enable them to be more agile and efficient during times of shifting infrastructures, changing requirements, new technology, etc. This ultimately leads to an economical and more rapidly deployed solution [23]. Taking the time to correctly model a proposed system leads to easier implementation – i.e. automating the construction – integration, maintainability, testing and simulation all along providing valuable information to the project-based organization for future projects [25].

4.3.3 Merging FEDEP and MDA Methodologies

FEDEP (assists in creation of federations) and MDA (assists creation of software models) share similarities, as shown in Figure 18. Essentially FEDEP steps two (2) through four (4) are the core components of MDA. FEDEP step two (2) produces a CIM from products of the Federation Scenario and Conceptual Model. FEDEP step three (3) produces a PIM from the products of Federate & Federation Designs, Federation Development and Execution Plan, and List of Selected Federates. FEDEP step four (4) produces a PSM from the products of Federation Agreements, New/Modified Federates, Implemented Federation Infrastructure, RTI Initialization Data, FOM, FED, FDD, Scenario Instances, and Supporting Databases.

By uniting these two methodologies an engineered federation solution can be produced more rapidly while maintaining scalability, code consistency (for security reasons and maintainability), and portability (for interoperability and composability) [23].

Steps/Levels	Outputs/Products		
	FEDEP	MDA	
2	Federation Scenario, Conceptual Model	CIM	Organigram, Use Cases, Story Boards
3	Federate & Federation Designs, Federation Development & Execution Plan, List of Selected Federates	PIM	Class Diagrams, Interaction Diagrams, Sequence Diagrams, etc
4	Federation Agreements, New/Modified Federates, Implemented Federation Infrastructure, RTI Initialization Data, FOM, FED, FDD, Scenario Instances, Supporting Databases	PSM	Automatic Code Generation/Coding

Figure 18. FEDEP and MDA Similarities

4.3.4 Applying the Systems Engineering Process

Way to MDA – for the PEO Soldier's project we aligned existing simulation models by mapping operational requirements with implied capabilities. By using MDA it provided us with an exceptional way to align dissimilar architectures using a common language – UML – so that misalignments may be easily identified. Mapping to MDA may be carried out in five phases as shown in Figure 19.

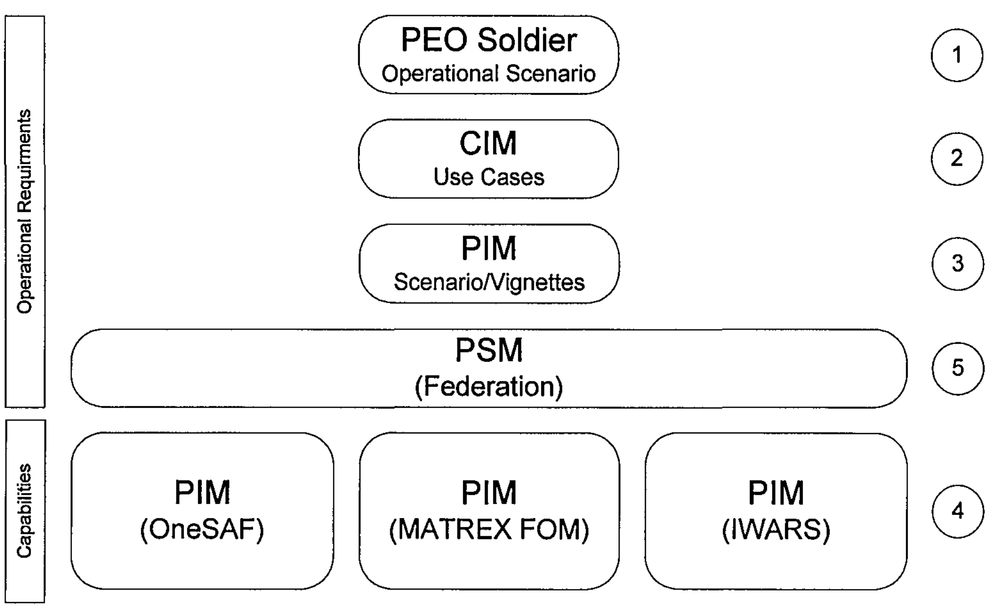

Figure 19. Way to MDA Phases

- Phase 1 (*Identification*): Identify resources and which tasks need to be accomplished.

- Phase 2 (*Description*): Describe the operational picture as a CIM using Use Cases.

- Phase 3 (*Context*): Refine the details for players, results, metrics, etc. as a PIM using Class Diagrams, Interaction Diagrams, Sequence Diagrams, etc.

- Phase 4 (*Identification & Context*): Identify and refine the details of potential federates as PIMs using Class Diagrams, Interaction Diagrams, Sequence Diagrams, etc.

- Phase 5 (*Orchestration*): Design the federation – utilizing HLA and FOM standards – by mapping all PIMs together into a PSM and then generate code.

The Operational Scenario – the primary task of the PEO Soldier federation is to generate proper data for in-depth analysis. Metrics will be used on the data and in the end the U.S. Army will attempt to make an intelligent decision on which type of body armor (BA) to procure. PEO Soldier – corporate management – has provided specific guidance for the operational scenario. In order for the correct data to be generated several battle situations and phases have to be predetermined to cover all aspects of battle for any given soldier.

The model has to execute – in one federation cycle – five milestones which include soldier movement (mounted and dismounted), fire engagements (direct and in-direct), and command and control – all taking place within an urban environment. The Operational Scenario may be captured and viewed from a high-level using an Activity Diagram in UML, Figure 20. The combination of the above milestones should produce enough data so that analysts can answer questions about soldiers' mobility, survivability and mission accomplishment associated with a new type of BA.

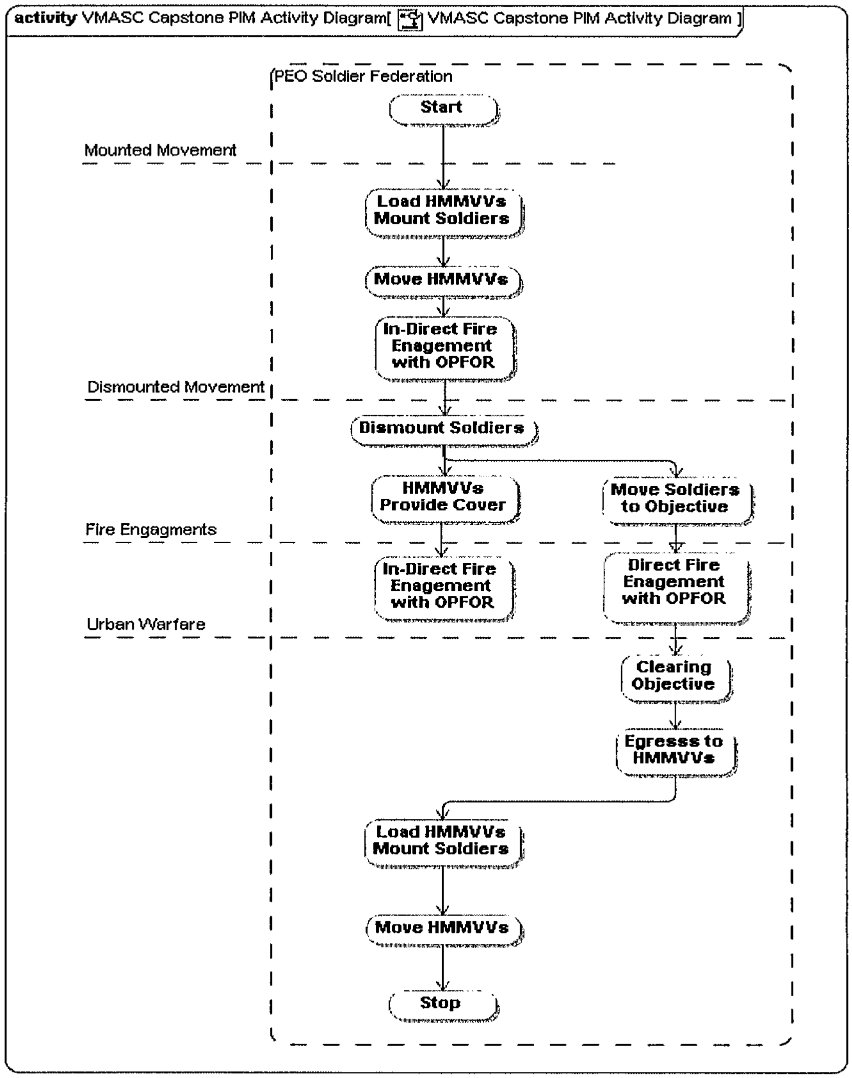

Figure 20. Operational Scenario in a UML Activity Diagram

Federate Selection – matching current capabilities (simulation models from the U.S. Army's inventory) with operational requirements may be accomplished by exploiting information from the Operational Scenario. From Figure 20 we can observe requirements of objects (HMMVVs, soldiers and mortars), movements (mounted and un-mounted), fire engagements (direct and in-direct), etc. We can now match those requirements to current capabilities by selecting potential federates.

- ❖ OneSAF – according to U.S. Army's description, One Semi-Automated Forces (OneSAF) is a composable entity-level computer generated forces simulation designed for brigade and below, combat and non-combat operations representing entities, units, and behaviors across the spectrum of military operations in a contemporary operating environment. In other words, OneSAF is a medium-resolution model handling everything from the battle-space, buildings, HMMVVs, mortars, tanks, etc.
- ❖ IWARS – according to U.S. Army's description, Infantry Warrior Simulation (IWARS) is a constructive, force-on-force simulation model for assessing the combat worth of systems and sub-systems for both individuals and small unit dismounted war fighters in a high-resolution combat environment.

Therefore, OneSAF will own the battle-space and major entities, and IWARS will own and simulate all soldiers within the PEO Soldier federation. To visualize the PEO Soldier federation model, imagine OneSAF owning the battlefield and all entities on it (other than soldiers) and IWARS owning the soldiers on that battlefield, see Figure 21. Localized Simulations, known as Hot Spots, will be active when IWARS is performing most of the simulation. Meanwhile OneSAF will continue simulating other events in the battle-space and responding to interactions from IWARS. This shifting of hot spots will be the key to the *orchestration* of the PEO Soldier federation as shown in Figure 22.

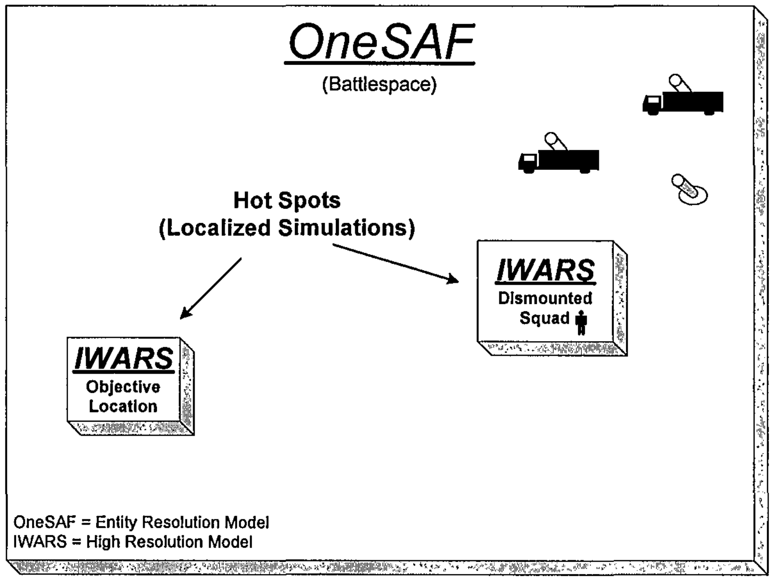

Figure 21. Visualization of the Federation Model Selection

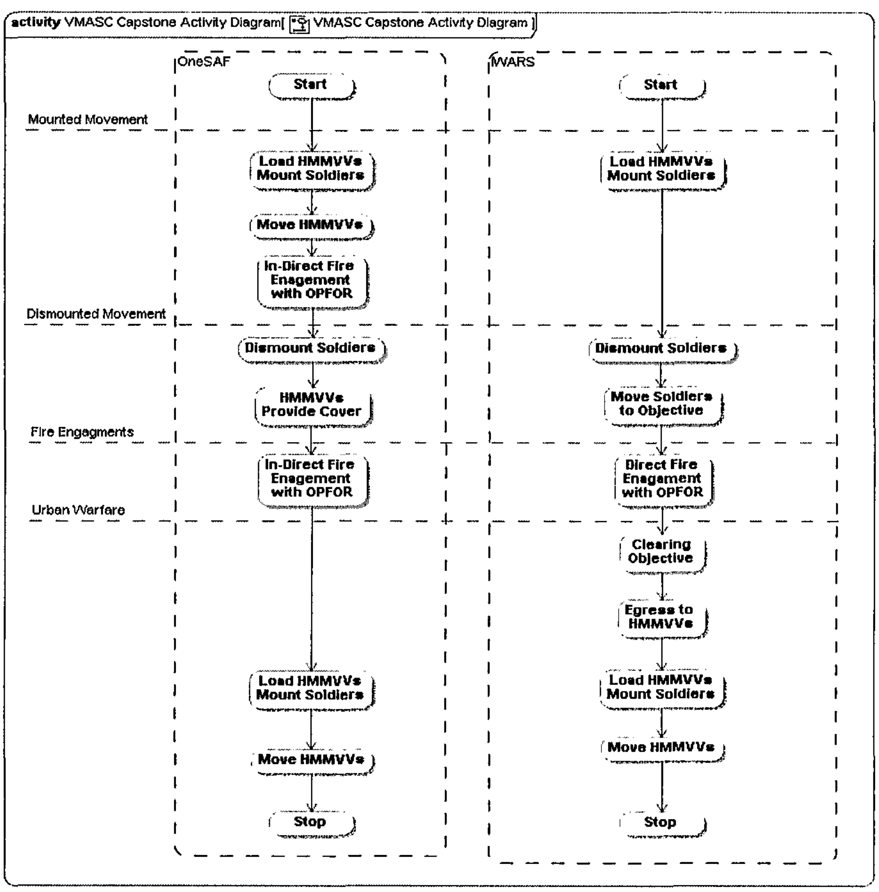

Figure 22. Operational Scenario Redefined with Federates

Mapping – now that we identified the two federates that will comprise of our federation and the mapping phases we must begin the process of mapping them together using FEDEP and MDA.

1) <u>CIM and the Use Case</u> – the first step is to develop the CIM using the Use Case in UML for the given operational scenario. The operational scenario states there will be soldiers, HMMVVs, and mortars. Each of the entities has functions associated to them. For example soldiers, HMMVVs, and mortars all move and require communications. From the operational scenario we can continue to build a complete Use Case for the federation as shown in Figure 23.

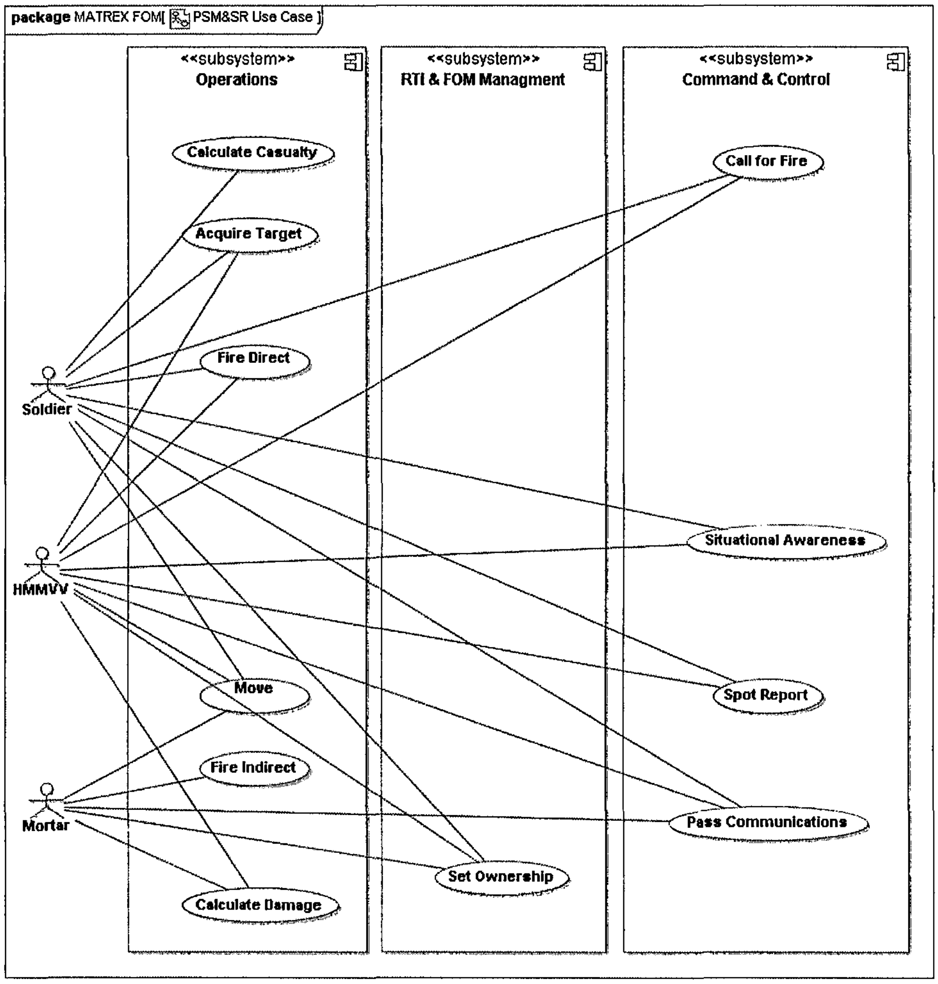

Figure 23. CIM and the UML Use Case

2) <u>PIM and the Sequence Diagram</u> – the next step is to develop the federation PIM for the operation evaluation. The solution is to take a "top view" of the key sequence of events and drill down into those events producing detailed messages, calls, interactions, etc. For example, In-Direct Fire, Figure 24, has 11 key events between the two federates. It is best to identify the key events and name them so that they can be broken down further with greater detail later on in the process. For example, event six (6) callforFire is a simplified description of the communication between IWARS and OneSAF. However, that interaction may be broken down into smaller elements and finer details.

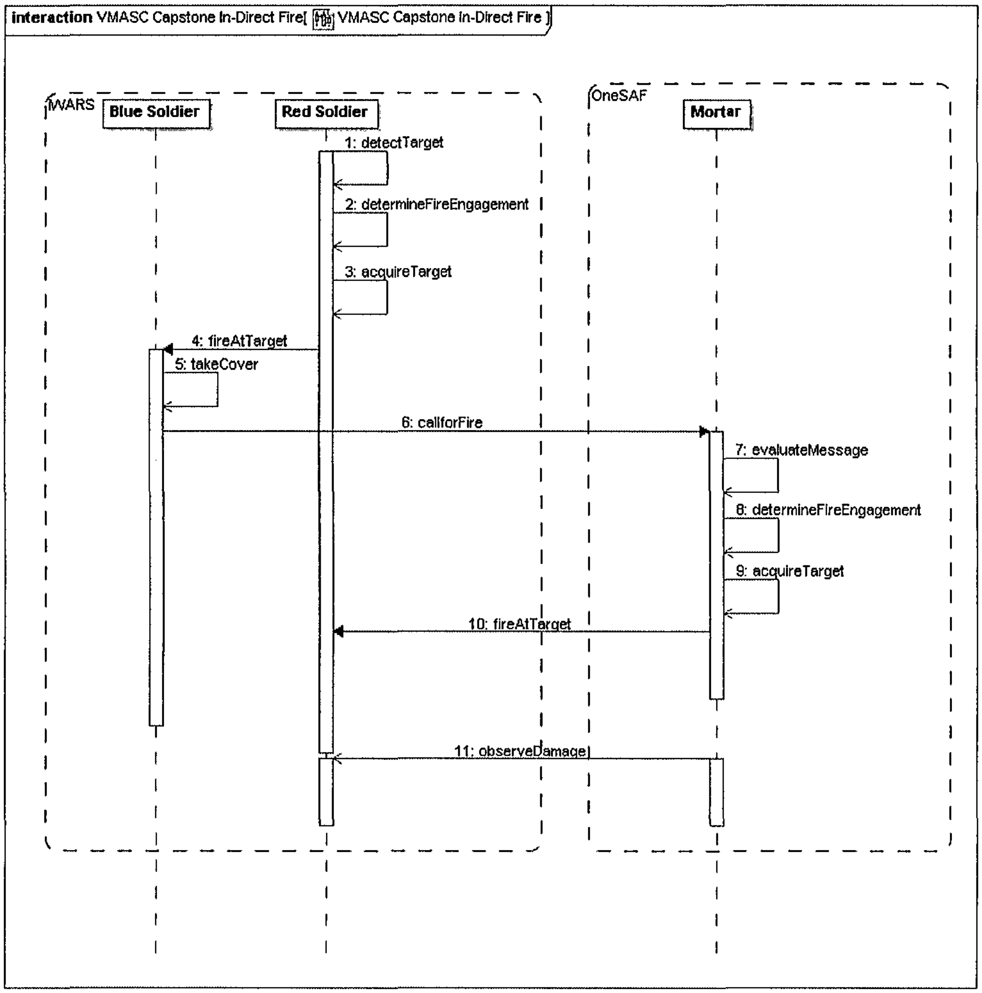

Figure 24. PIM and the UML Sequence Diagram

PIMs may be formally described by schemas. For example, event 10 may be formally written as: Tank → Shoot at → Soldier; notice there are no implementation details noted or discussed here. This schema is then broken down into finer detail and mapped to a specific use during the PSM phase. It is imperative that after all PIMs are developed, they are compared to the objectives (FEDEP step seven (7) *Analyze Data and Evaluate Results*). If the PIMs are not verified for correctness, data collection and metric analysis may lead to false or inconclusive results.

3) Mapping PIM Objects – using the key events from the top view sequence diagrams, one may easily determine the structure of the FOM. For example, callforFire is an interaction with six parameters: Originating and Receiving Component, Identification, Target Element, Requested Unit, and Munition Selection that describes the request callforFire.

4) Communications and Mapping FOM – in 2003 the U.S. Army started a program called Modeling Architecture for Technology and Research EXperimentation (MATREX) and developed a standard FOM to be used in all future and current standalone and federation simulations. The primary objective of FOM is to develop a reusable software component – a model that describes object classes, attributes, and interaction classes – that reduces development time and allows software engineers and programmers to easily understand another's object model without having an in-depth knowledge of the inner workings of the other simulation model. The FOM also provides information on the capabilities of a federate to exchange information and communicate inside a federation. A FOM is analogous to a domain model or ontology representing the business objects and interactions for a corporate software architecture.

The idea of a standardized FOM is extremely important for project-based organizations. This allows multiple M&S models within a project-based organization to be compatible with each other and theoretically require little time to develop a federation with each other – thus virtually reducing interoperability/composability conflicts. There are downsides associated with a standardized FOM; for instance, it is impossible to capture every possible object, attribute, and interaction inside one FOM, especially when the U.S. Army has over 20 major simulation tools each accomplishing different goals.

To further explain this problem, PEO Soldier observed this when attempting to connect several federates together when connecting a low and high resolution model together. This was the biggest hurdle to clear in an attempt to integrate OneSAF and IWARS. It is worth mentioning that when a FOM is specified, it becomes a PSM because decisions have been made on usage, but it may be implementation-independent.

The above systems engineering process is a key enabler for project-based organizations to build federations quickly and efficiently with minimal conflicts among federates. The repeatability of the process allows project-based organizations to improve their proficiency at implementation, understanding of the M&S models within the organization, and total development cycle times simply by reusing knowledge and artifacts from previous projects. These artifacts and knowledge gained should then be captured, organized, and documented in the knowledge repository of the project-based organization for future use.

4.4 Developing & Deploying Plans

Depending on the organization and the project, several options exist for *Developing & Deploying* a M&S federation project. Reviewing the term "modeling and simulation", we see that there are two elements: "modeling" and "simulation". *Modeling* is the practice of conceptualizing a sponsor's problem into simplified representations such as mathematical formulas and/or logical algorithms. *Simulation* is the practice of implementing those formulas and algorithms into computer code and executing the simulation model.

Modeling is a science and requires experienced personnel to develop accurate formulas and algorithms. During the modeling process, SMEs (within the scope of the project) should work close with M&S experts to apply domain specific details to M&S methodologies. Therefore, it should be noted that typical software engineering practices are not effective for modeling. However, simulation may utilize software engineering methodologies because this is the start of computer coding. But, special consideration must be given during the coding process to ensure the correct M&S framework (e.g. distributed simulation, discrete simulation) is utilized and implemented to correctly simulate the given problem.

Below are some options for deployment methodologies based on the analysis of PEO Soldier's task. These ideas and opinions of the author were not executed on the PEO Soldier project and/or verified; therefore, the author invites the interested reader to further investigate. During this study, a hypothetical question was asked: "What if we wanted to develop a new M&S model (called M&S2.0) to solve the problem instead of federating federates, what development methodology should we consider?" It is addressed below.

Federating OneSAF and IWARS:

The author recommends utilizing the *Rapid Application Development* (RAD) approach for Federating OneSAF and IWARS. RAD uses a four (4) phase Life Cycle (LC) approach utilizing the following techniques: Joint Application Development (JAD), Computer-Aided Software Engineering (CASE), Iterative Prototyping, and Time-Boxed approach. Each of the four (4) phases has key attributes: Requirement Planning, User Design, Construction, and Cutover.

Since there are multiple program organizations (OneSAF and IWARS) working together, JAD can assist with the integration. M&S relies on the use of Unified Modeling Language (UML) – a CASE tool –; therefore, it would be beneficial to the development of the federation. To summarize, using the RAD approach appears to be the best choice for federating OneSAF and IWARS, allowing the project to be completed on-time and on-budget.

Developing M&S2.0:

The author recommends utilizing the *Agile Modeling* approach during the development of M&S2.0. Agile Modeling is considered an extreme programming practice for software development. It is characterized as an interactive and incremental approach. Agile Modeling is designed for small core groups of programmers and should contain no more than at total of 12 personnel. There are four (4) core values Communication, Simplicity, Feedback, and Courage which makes software development rapid and efficient.

M&S2.0 project is considered a risky project; therefore, Agile Modeling can be used to hire fewer personnel and maintain a shorter than expected engineering LC. In order for Agile Modeling to be successful, programmers selected for the project must be experienced and knowledgeable in the latest advancements in the M&S field.

The above methodologies are options and opinions of the author based on observations made during the PEO Soldier project. Project-based organizations may have different proven deployment methodologies in place. No matter which method is utilized, project-based organizations need to promote their methodologies and provide guidance to newly formed project organizations to facilitate project success. As with all other project related results feedback, lessons learned, near-miss events, etc. should be captured, organized, and entered into the project-based knowledge repository for future use.

5. PROJECT MANAGEMENT

Project Management is a process that occurs throughout a project that requires careful planning and organization by a *Project Manager* (PM). A PM should approach all projects with forethought and be proactive so that they can effectively lead a project and the project organization to success. The management process starts off with analysis and development of supporting documentation, Chapters 2 and 3. When the supporting documentation is completed, the next phase of a M&S federation project is two part: implementation (Chapter 4) and project management (Chapter 5).

Project management is an ongoing process that requires PMs to constantly make decisions, plan for execution of events, manage risks, and review the product and/or services as a project progresses. The key component of project management is the *Study Plan*, Section 5.2. This study plan is considered a "playbook" for the PM and provides the stakeholders guidance on how a project is to be executed.

5.1 Decision Making – Analytical Hierarchy Process (AHP)

Typical M&S decisions are tightly coupled and complex in nature due to human and organizational factors [5]. Organizations are often faced with making these complex decisions. It is suggested using integrated tools to analyze and explore the relationships between human and organizational factors can lead to a smarter decisions. The idea of these tools is to make informed decisions by removing the "clutter" and concentrating on the important elements of a decision.

NATO COBP illustrates the paradigm of decision making drivers, Figure 25. It should be noted that the relationship between Time Available, Complexity, and Uncertainty determines the situations that organizations face. For example, if time is unlimited and complexity and uncertainty are minimal, then the most desirable situation can be achieved. However, it is known that is never the case – mainly because time is not unlimited. Therefore, decision makers need to compromise somewhere in the middle to achieve a "best" solution.

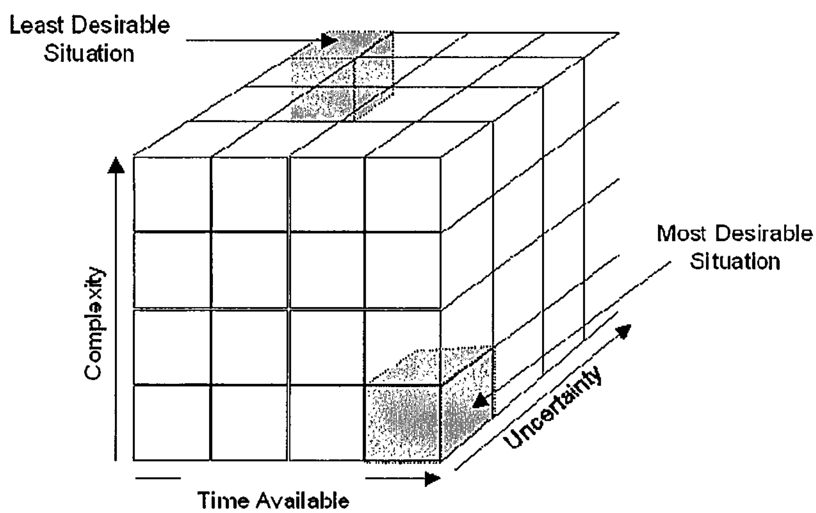

Figure 25. NATO COBP Decision Making Drivers

Making complex decisions on which model to chose, which method to use, etc. can be very difficult if not impossible for a single person to make. However, project and project-based organizations can employ a process that utilizes artifacts and inputs from stakeholders to obtain a "best solution" for a given problem – the process is called the *Analytical Hierarchy Process* (AHP).

An AHP is a structured technique to support complex decision making. Using mathematics and human psychology, AHP provides a comprehensive and rational framework for structuring a problem, representing, and quantifying elements relating to goals. After a process model has been assembled and calculated, the number one resultant is considered the "best choice" – based on the criteria and input variables.

Continuing the hypothetical question from Section 4.4 (Should PEO Soldier develop a new M&S model instead of federating OneSAF and IWARS?) an AHP was assembled and the results are below.

Information in Table 25 and Table 26 was assembled from interviews with all concerned parties, research by the author, and designated requirements as set forth by the U.S. Army and PEO Soldier.

Table 25 Definitions:

- Engineering Life Cycle (LC): time to develop (engineering and coding) the model
- Product LC: time from the start of the project until the model is removed from service
- Development Cost: costs incurred during the Engineering LC
- Maintenance Cost: costs of maintaining the model beyond the Engineering LC

Table 26 Notes:

- It should be noted that the objectives in the table are strictly opinions and not hard facts.
- The objectives were graded on a scale from 0 – 9 where 0 is considered least favorable and 9 is considered preferred.
- During interviews with PEO Soldier it was determined there are three (3) areas of concern and each has an assigned *Importance Factor* (or weight) and is represented in %.

Recommendation:

To provide a well informed decision as to which approach (Federating OneSAF and IWARS or development a new M&S2.0 model) would be best, an AHP model (Table 26) was computed. On a scale of 10 developing M&S2.0 received a score of

8.79 and Federating OneSAF and IWARS received a score of *7.94*. Which means developing M&S2.0 received an 8.5% higher score than Federating OneSAF and IWARS. The author recommends developing M&S2.0

Table 25. AHP Artifacts

System	Engineering LC (YRS)	Product LC (YRS)	Development Cost ($K)	Maintenance Cost over Product LC ($K)
Federating OneSAF & IWARS	1	3	750	1,000
M&S2.0	2	5	3,000	1,500

Table 26. AHP Calculations

M&S Model	Corporate Objectives: Corporate Risk	Alignment to Corporate Objectives	Alignment to Strategic Plan	Useful Data for Other Decision Support	Acquisition Decision Support	Advancement in Army's M&S Knowledge	Ease of Use	Overall Quality of Product
Integrate OneSAF & IWARS	8	8	8	4	8	6	5	7
Develop M&S2.0	3	9	8	9	9	8	8	8
for Integration	2.67	0.89	1.00	0.44	0.89	0.75	0.63	0.88
for M&S2.0	0.38	1.13	1.00	2.25	1.13	1.33	1.60	1.14

M&S Model	Technical Objectives: Technical Risk	Proper Engineered Solution	Interoperable / Compatible	Composable	Complexity of Developing	Maturity of Technology	Engineering LC
Integrate OneSAF & IWARS	4	6	8	2	7	9	9
Develop M&S2.0	5	9	5	5	9	5	3
for Integration	0.80	0.67	1.60	0.40	0.78	1.80	3.00
for M&S2.0	1.25	1.50	0.63	2.50	1.29	0.56	0.33

M&S Model	Financial Objectives: Financial Risk	Development Cost	Maintenance Cost	Product Life Cycle
Integrate OneSAF & IWARS	8	9	2	3
Develop M&S2.0	3	4	8	8
for Integration	2.67	2.25	0.25	0.38
for M&S2.0	0.38	0.44	4.00	2 67

Total Sums	Weight	Weighted Sum
8.14 9.95	45%	3.66 4.48
9.04 8.05	35%	3.17 2.82
5.54 7.49	20%	1.11 1.50

Objective Scale: 0 (Least Favorable) - 9 (Preferred)

Importance Weight (%)	
Corporate Objectives	45%
Technical Objectives	35%
Financial Objectives	20%

Overall Results
(higher the better)

For Integration	[redacted]
For M&S2.0	8.79

5.2 Study Plan

NATO COBP defines a *Study Plan,* also known as a "playbook", as a tool that analyzes project related artifacts and prepares a solution strategy to solve a sponsor's problem [5]. A study plan has two interrelated parts: (1) a formulated problem (what) and (2) a solution strategy (how). Problem formulation provides an operating definition of what needs to be done in the context of events. The solution strategy provides an operating definition of how each event will be accomplished.

A study plan develops a feasible approach to solve a problem based on set forth specifications, MoM analysis, and risk analysis. Each event within a project must undergo this process to determine a solution strategy. It should be noted the event may have an impact on another; therefore, careful consideration must be given to resolve any conflicts between events.

Throughout a project, the study plan must undergo several reiterations to modify both the formulation and the solution strategy as events are completed, changed due to circumstances, and/or new challenges are presented to the project organization. Without a study plan, project organizations may encounter conflicts between events because they were not properly scoped, prioritized, scheduled, or resourced [5].

Project management and technical implementation success of a single project hinges on past experiences and the transfer of knowledge from preceding projects. Different artifacts are identified to promote this continuous improvement cycle: study plan, project journal, lessons learned, and knowledge management. Applying information, knowledge, and "know-how" from other management tools such as Project Journals (Section 5.2.1), Lessons Learned (Section 5.2.2), and the Knowledge Repository (Section 5.2.3) to a study plan may be beneficial to project organizations and promote project success.

5.2.1 Project Journal

Loo conducted a study on project journaling and proved it to be beneficial for project management. Loo concluded that "journaling can facilitate learning specific skills including interpersonal communication, conflict management, managing effective meetings, managing stress, and leadership skills" [18]. This learning is accomplished by "reflecting" thoughts in a project journal.

Reflecting is carried out in three stages: (1) self awareness of the stimulated learning situation (positive or negative and/or uncomfortable circumstances), (2) self criticizing of the situation, and (3) self development of new perspectives based on the above discoveries. Project Journaling is an excellent learning tool for all personnel within a project and/or project-based organization. Journaling may be used by organizations to build teams, improve management skills, and improve organizations overall [18].

Project Journals can be extended beyond personal use – they can be used to capture important events (e.g. bi-weekly meetings, technical reviews, brainstorming sessions) that take place during a project's development cycle. Table 27 denotes possible elements to capture within a project journal. These elements, combined with the above mentioned, should allow project and project-based organizations to study: how events occur, how the events were performed, why were the events performed in that way, etc. The knowledge gained during this process should then be captured in a knowledge repository and transferred across projects within a project-based organization. As Loo discovered with individuals, applying project journaling to projects should allow project-based organizations to improve their performance by reflecting on past experiences and applying those experiences to future projects.

Table 27. Project Journal Elements

Elements
What event happened?
When did the event happen?
How did the even happen?
Why did it happen in that way?
Who was involved?

5.2.2 Lessons Learned (L/L)

U.S. Army defines *Lessons Learned* (L/L) as "knowledge or an understanding gained by experience either by a negative or positive experience [17]. Before capturing L/L, it should be determined the L/L are noteworthy, valid, and relevant to a particular subject before they are officially documented. L/L are developed at the macro level (management) and the micro level (technical), each having their scope of detail (finer details of implementation go into technical L/L). L/L may enclose or address topics of interest, provide information of an event, etc. and not restate doctrine or policies.

Examples of L/L are: what should have been available, what was available, what current solutions could have helped to close the gap, etc. For example, during PEO Soldier's task, it was determined that the technical teams should have used Platform Independent Models (PIM) during the planning phase instead of theoretical Unified Modeling Language (UML) diagrams. The diagrams proved to be too voluminous for real-world use and caused delays. This example is an excellent point to be made for follow-on projects.

For strategic project management, project-based organizations must have a plan in place to capitalize on the full potential of L/L – they must accumulate, validate, store, disseminate, and reclaim L/L to achieve organizational goals and objectives. Accumulation of L/L should be garnered from sources internal and external to the project organization and contain *positive* and *negative* experiences. Established guidelines and standards permit a streamline process for validating L/L. During the validation process, key personnel and subject matter experts (SME) review and tailor the L/L preparing them for storage in the repository.

Captured L/L may be applied to a project-based organization via a knowledge repository. However, some standardization is required to ensure proper data matching is maintained within the repository and the organization. Without standards of validating, storing, and reclaiming those L/L cannot be effective.

Project-based organizations are responsible for organizing L/L and developing plans to disseminate and applying L/L to follow-on and/or recurring projects. New projects benefit from previous experiences by reducing the "learning" curve and ultimately reducing the development time of a project – especially those within the same project-based organization.

Collecting L/L is an ongoing process throughout the SPMP (and done for each sub-process within) and should not be left until the end of a project to begin capturing L/L. Every noteworthy event should be documented, organized, and stored for future use enabling project-based organizations to improve over time.

5.2.3 Knowledge Management & The Repository

Luthans defines *Knowledge Management* as "the development of tools, processes, systems, structures, and cultures explicitly to improve the creation, sharing, and use of knowledge critical for decision making" [1]. Knowledge management is a relativity new concept and researchers are working on methods and tools to acquire, store, and disseminate information and tangible and intangible knowledge throughout project-based organizations.

With the advancement of the internet, all of the military services have adapted a web portal – single point access from anywhere around the world – called *Knowledge Online*, for example the U.S. Navy's portal is called *Navy Knowledge Online.* This portal is used to train sailors on their duties, deployments, etc. It is also used for transferring a working knowledge of a person's job, their experiences, and education to another person who may or may not be replacing them within an organization.

No matter if a person is leaving an organization or not, knowledge management is important to the immediate organization (project organization) and the overarching organization (project-based organization); it benefits all. A knowledge management system allows personnel to reference information about a new position/task they are to assume, allowing them to prepare for the upcoming task.

Strategic project management relies on information (feedback) from previous projects executed within the project-based organization. Information such as supporting documentation, project journals, near-miss events, best practices, etc. all contribute to the knowledge base of a project-based organization. Executing projects in a standardized way increases the reusability and sharing across the boundaries of a project and of the project-based organization.

The resulting requirements enabling an overarching integrative approach assume that M&S services need to be accessible via a knowledge repository in which they are described in a standardized way; these ideas are based on Model Driven Architecture™ (MDA) [6]. Requirements to formally capture M&S models in descriptive artifacts realize the captured knowledge of used components and how they contributed to the process. This builds the knowledge repository with valuable information. However, it should be pointed out that this does not imply that a technical MDA approach is mandatory as well.

Sinclair suggested a *common data infrastructure*, Figure 26, which allows organizations to "reuse" knowledge within a project-based organization by utilizing a repository [19]. This infrastructure is not exclusive and is considered a static model. However, for MDA methodologies to be applied to this framework, a model needs to be modified and adapted to allow dynamic content. For example, not all M&S federation projects are the same (e.g. different requirements, ideas, data) and need to be handled in different ways. Therefore, the common data infrastructure may need to be modified to accommodate these differences.

It may be noted in Figure 26 that the NATO COBP ideas presented in 5.2 can be adapted to this model. For example, the Data Available element is correlated to the knowledge repository and the Study Data element is information from the current project – therefore transferring knowledge from the repository and applying it to the current project.

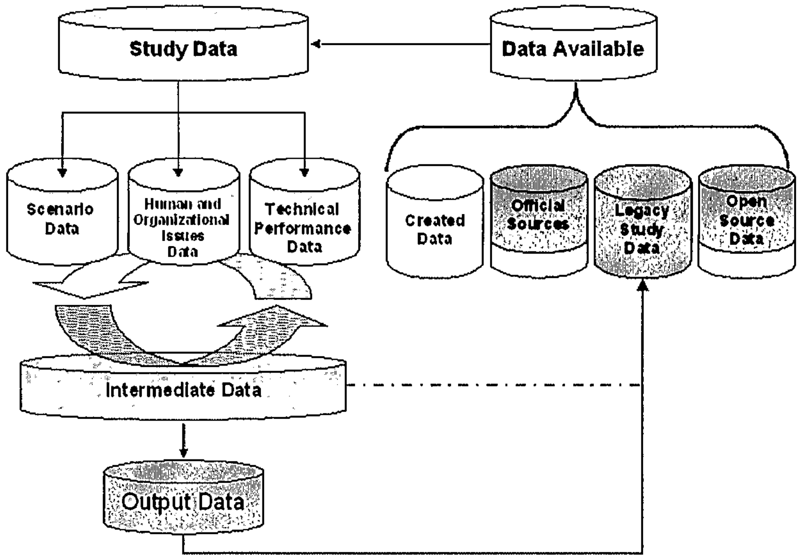

Figure 26. Common Data Infrastructure for Reuse of Knowledge

The U.S. DoD is currently moving towards net-centric organizations. In such a net-centric environment, services that are offered to the community have to be described exactly as recommended in [4] as well as: a service provider (or providing agency or organization) that describes its services, the necessary inputs, the resulting outputs, and how to access these services. This description is posted to a central – or potentially distributed – repository. Service consumers go to this repository and search for potential solutions to their problem. If they find a fit based on the description, they use the mechanisms described to access the service. The more agreement we achieve regarding the artifacts we use to describe the systems and services, the easier this communication will be.

5.3 Risk & Uncertainty Management

Risk Management is an ongoing process to mitigate undesirable results throughout a project's development cycle and beyond. It should also be mentioned that risk management occurs at two levels: at the project level and the project-based organization. Each of these levels requires different styles and methods to handle risks associated with projects and organizational factors. Therefore, top-level management and PMs may have to develop very different plans to prevent crisis within their associated organization.

Risk management is a five step process: Identify, Evaluate, Plan, Track, and Tackle. Upon completion of the initial *Risk Analysis* (Section 3.5), PMs and key managers of a project organization must *track* and *tackle* those risks and uncertainties previously identified to prevent a crisis. However, as a project evolves, new risks and uncertainties may emerge, and if so they need to be analyzed and documented as described in Section 3.5.

Crisis(es) can occur at the macro level (major milestones) or micro level (events) – each requiring attention and forethought to eliminate a potential crisis. Risk increases with hazards and difficulties and decreases with safeguards and risk mitigation plans. Depending on the situation or the event, management may want to take on more risk because it is known that there is a bigger benefit. However, if an organization wants to eliminate high risk and uncertainty, extra planning will be required; therefore, costing more in time and resources. There is a fine balance between the above mentioned; managers and top-level management need to set guidance so that an entire project organization understands what kind of "risk pain" is acceptable.

Risk management requires managers and the PM to communicate the current status of events and desired intentions on how to deal with encountered risks, i.e. make public the risk analysis supporting documentation. For example, PEO Soldier announced in the initial meetings that data results were not of utmost importance but a working model was. Therefore, stakeholders understood the risks upfront with respect to output data; in turn, they can place this at a lower priority than functionality of the federation.

PMs are typically accountable for project related risks. Therefore, the risks and uncertainties identified in the risk analysis should be constantly monitored by the PM. It is recommended that each of the risks have some kind of "triggers" associated with them. For example, the risk of "Complexity of Developing a Federation" might have a trigger during the mapping and integration phase – e.g. OneSAF and IWARS having data mismatching issues. If, at WBS 1.4, managers are recognizing this issue, because the two models are having difficulty communicating, then actions may be needed to resolve the situation before the project is delayed, possibly becoming a crisis.

PMs may be required to take actions to alleviate a crisis and may do so by assembling a crisis management team to resolve a current crisis, approaching the sponsor to provide updates and/or recommendations on how to move forward, diverting resources from other events to handle the current situation, etc. Managing risks is dynamic in nature because results from one event may affect the results of another. Therefore, PMs and key managers need to be proactive and constantly monitoring the project for risks and uncertainties.

Risk and uncertainty experiences and/or crisis should be captured, organized, and stored within the knowledge repository of a project-based organization for future use. Learning from a previous crisis and applying that knowledge to a current project allows managers to implement corrective actions to help guide a project to success.

5.4 Final Product Review

The final phase of a M&S project is the *Final Product Review*. Here, prior to its release, the final product and/or service(s) are tested and compared to the requirements set forth by the sponsor. Selected MoMs are utilized to measure results against the requirements, and if all are determined "good", then the project can be declared a success. MoMs may also be exploited to give a product and/or service a certification. For example, a project meeting predetermined certification criteria is given a certification based on the results and released for general use.

Identifying *shortfalls* is the most important aspect during the final review. Selected personnel must review MoM results and investigate for failures and/or partially effective results. If it is determined that a product has shortfalls, those shortfalls have to be captured, documented, and communicated early enough – before the final report is due. For example, if it has been determined that there is a mismatch in the project's capability and/or availability, the project organization should notify all stakeholders, especially the sponsor, immediately. If communicated early enough, cooperative efforts by all stakeholders and the sponsor may resolve the problem before the final due date. If not, sponsor dissatisfaction may occur.

Lessons Learned, *Near-Miss Events*, and *Best Practices* need to be finalized during this phase as they should have been ongoing during the entire project. As mentioned in Section 1.4.3 there are two levels when considering project management: macro (management) and micro (technical). As the project draws to a close, both management and technical personnel need to capture and finalize their lessons learned, near-miss events, and best practices for the project. These products are then added to the project-based organization and ultimately stored in the knowledge repository for future projects. These products may also be passed beyond the project-based organization such as academy, professional organizations, etc. For example, if a new M&S technique was discovered during the project, it would be beneficial to the M&S community if technical members publish their findings.

The report of the final product review serves three purposes: (1) communicate the results to all stakeholders and the sponsor(s), (2) provide a permanent record of what happened during the project, and (3) establish creditability within the M&S community [5]. Table 28 denotes typical elements that a final report should contain at a minimum; the final report may differ depending on the sponsor and the project-based organization's requirements.

Table 28. Final Report Elements

Elements
Objectives (sponsor's problem and the problem formulation)
Project scope and assumptions
Project solution strategy
Project findings and conclusions
Recommendations
Future challenges
Data – descriptions, collection techniques, raw data
References

6. CONCLUSIONS & RECOMMENDATIONS

The strategic project management process (SPMP) proposed in this thesis is a start of an investigation for M&S federation development. In particular the author recommends further studies be conducted on other M&S federation projects and apply the findings to this initial attempt. The data used in this thesis was a small subset consisting of one project and several academic and professional resources; this should be expanded to present a well investigated product.

This SPMP provides a systems engineering process that allows operational requirements and technical constraints to be integrated into an MDA based framework for supporting project managers, model developers, and sponsors for procurement. This process also allows for translation of the problem so managers and engineers can use the same framework to communicate their challenges and solutions without violating constraints and areas of responsibility of other team members.

Using strategic management practices improves project performances and project-based organizations by using prior experiences to improve on future projects. This is especially true for organizations that utilize and develops projects with similar methodologies and is done so by refining the process.

The recommended solution enables project management of simulation based acquisition and supports the alignment of procurement, development, test, and training by introducing a common view derived from operational needs, including a set of consistent metrics.

The author recommends some challenges for future research with respect to a SPMP for M&S federation development and procurement.

- Documentation Constraints: A need for necessary methods, tools, and data requirements to locate, organize, and apply to participating supporting documentation.

- Tools: Decision making flows charts, WBS shells, etc.

- Checklists: Checklists for the SPMP, checklist M&S federation events, etc.

- Standardized Mapping Processes: Automated process to map requirements to develop a base M&S model.

- Knowledge Repository: Automated service with an ontology for processing dynamic material as described in this thesis.

- Central Performance Measure: Investigate a solution to centrally monitor performance – managed by a Project Management Officer – by comparing MoMs of a project to that of the project-based organization.

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