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Application Of Modeling And Simulation To Reduce Costs Of Acquisition Within Triple Constraints

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APPLICATION OF MODELING AND SIMULATION TO REDUCE COSTS OF ACQUISITION WITHIN TRIPLE CONSTRAINTS

by

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ABSTRACT

A key component of defense acquisition programs operating using the Integrated Defense Acquisition, Technology, and Logistics Life Cycle Management System is the reliance on the triple constraints of cost, schedule, and performance. While the use of Modeling and Simulation tools and capabilities is prevalent and well established in the Research and Development, Analysis, and Training domains, acquisition programs have been reluctant to use Modeling and Simulation in any great depth due to inaccessibility of tools, Subject Matter Experts, and implications to cost and schedule. This presents a unique Simulation Management challenge which requires an in-depth understanding of the technical capabilities available within an organization, their applicability to support immediate needs, and the flexibility to utilize these capabilities within the programmatic environment to provide a value added service. The focus of this dissertation is to study the use of Modeling and Simulation in the Defense arena, and to review the applicability of Modeling and Simulation within programmatic acquisition environments which are constrained by cost, schedule, and performance.

This research draws comparisons between Modeling and Simulation to other Process Improvement initiatives, such as Lean and Six Sigma, and reviews case studies involving the application of Modeling and Simulation within triple constrained environments. The development of alternate scenarios allows cost benefit analysis to be conducted for each scenario and alternate scenario, developing a case for whether or not the application of Modeling and Simulation within the triple constrained environment delivered any consequential benefit to the acquisition process.

Observations are made regarding the level of Modeling and Simulation as applied within each case study, and generalized recommendations are made for the inclusion of cost benefit analysis methodologies for analyzing proposed Modeling and Simulation activities within acquisition programs. Limitations and shortcomings of the research activity are discussed, along with recommendations for potential future work in the Simulation Management field, both with respect to the specific case studies reviewed in this study and the general field.

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LIST OF ACRONYMS/ABBREVIATIONS

APG	Aberdeen Proving Ground
ATC	Aberdeen Test Center
AT&L	Acquisition, Technology, and Logistics
CAD	Computer-aided Design
CBA	Cost Benefit Analysis
CONUS	Continental United States
CSP	Cost, Schedule Performance
DFSS	Design for Six Sigma
DMAIC	Define, Measure, Analyze, Improve and Control
DOD	Department of Defense
FEA	Finite Element Analysis
ECP	Engineering Change Proposal
FSR	Field Service Representative
FTE	Full Time Equivalent
G&A	General and Administrative
IP	Intellectual Property
LSS	Lean Six-Sigma
MOD	Ministry of Defense
M&IE	Means and Incidental Expenses
M&S	Modeling and Simulation
OCONUS	Outside the Continental United States
OEM	Original Equipment Manufacturer
R&D	Research and Development
RDT&E	Research, Development, Test, and Evaluation
ROM	Rough Order of Magnitude
SME	Subject Matter Expert
TACOM	U.S. Army Tank-automotive and Armaments Command
TARDEC	Tank-automotive Research, Development and Engineering Center
TIR	Test Incident Report
TMBS	Turret Motion Based Simulator
TPS	Toyota Production System
VE	Value Engineering
V&V	Verification and Validation
VV&A	Verification, Validation, and Accreditation
YPG	Yuma Proving Ground
YTC	Yuma Test Center

CHAPTER ONE: INTRODUCTION

A key component of defense acquisition programs operating using the Integrated Defense Acquisition, Technology, and Logistics (AT&L) Life Cycle Management System is the reliance on the triple constraints of cost, schedule, and performance. While the use of Modeling and Simulation (M&S) tools and capabilities is prevalent and well established in the Research and Development (R&D), Analysis, and Training domains, acquisition programs have been reluctant to use M&S in any great depth due to inaccessibility of tools, Subject Matter Experts (SMEs), and implications to cost and schedule. This presents a unique Simulation Management challenge which requires an in-depth understanding of the technical capabilities available within an organization, their applicability to support immediate needs, and the flexibility to utilize these capabilities within the programmatic environment to provide a value added service. The focus of this dissertation is to study the use of M&S in the Defense arena, and to review the applicability of M&S within programmatic acquisition environments which are constrained by cost, schedule, and performance.

Several examples of large scale M&S exercises, and use of M&S tools, exist within the Defense arena. More notably, M&S is a key component in numerous training applications, where cost savings into the millions of dollars have been documented by use of virtual tools to deliver effective user training. In the R&D domain, M&S through virtual development is extensively used in early lifecycle phases of projects to provide proof of concepts and demonstrate ideas, also resulting in cost savings when compared to physical development. While certain proprietary M&S tools have significant costs associated with the products, resources, and personnel training and SME costs associated with their use within an organization, the overall cost of tool use is offset by the savings realized. These savings generally take multiple products or lifecycles to realize, however, the overall cost savings to the organization is greater than the initial and continued investments in the M&S tools, therefore management tends to promote the use of M&S capabilities as an overall cost reduction mechanism. It should also be noted that management and leadership of R&D oriented organizations generally tend to possess technical backgrounds, and therefore, have had experience or exposure to M&S to understand the value and applicability of the tools. This contributes to the investment R&D organizations make in M&S resources.

Triple-constrained acquisition environments, or programmatic organizations, generally tend to shy away from investment in M&S capabilities, as their primary functional areas are in program management, logistics support, and sustainment of currently in-use or fielded products. As such, the perceived need or interest to invest in M&S tools, which are generally associated with the R&D domain, remains minimal. This dissertation conducts case studies of M&S applications within triple-constrained environments, where M&S is used as an enabling tool to support decision making processes in support of programmatic activities. The premise of this research is to demonstrate cost savings and benefits through case studies of appropriate use of M&S in programmatic environments, and to devise a method through which to quantify these savings and benefits such that it can be factored into the decision making process of cost, schedule, and performance constrained environments.

One of the challenges of quantifying cost savings through use of M&S is the lack of a common shared process or paradigm through which consistent measurements can be taken in a variety of M&S application scenarios. While reviewing case studies of M&S applications, it is imperative to define a process by which M&S cost savings can be quantified to provide comparable results. While this is a unique challenge in the field of M&S, there has been significant work done in the field of Value Engineering (VE), Lean Six-Sigma (LSS), and other process improvement initiatives which seek to quantify benefits and savings through use of processes. Literature reviews conducted for this dissertation will also focus on reviewing how cost savings and benefits are quantified in various other fields in order to draw parallels with the application of M&S, while creating a unique novel process or paradigm that can be consistently applied to M&S.

The final aim of this dissertation is to lay the groundwork for future research in the area of M&S management, and in particular, the area of quantifying the value of M&S in various applications. Industry application of this research should promote the use of quantification of costs and benefits of M&S applications to influence decision making processes in triple constrained environments to ensure appropriate use of the capabilities where applicable, and conversely to avoid use of M&S in applications where quantification methods indicate lack of value. By being able to identify applications where M&S can reduce costs and add benefit or value will in turn reduce the overall cost of acquisition within triple constrained environments.

CHAPTER TWO: LITERATURE REVIEW

In order to quantify cost savings and benefits of M&S application, there must be a structured process to measure costs which can be applied consistently to unique case studies. There has been substantial work done to develop methodologies to measure cost effectiveness of efficiencies introduced process improvements. If viewed as a process improvement, the application of M&S can be directly compared to the fields of LSS and VE, and other process improvement practices which have been well established. Significant research exists and methodologies have been established to measure cost effectiveness of process improvement practices, and if parallels can be drawn between these practices and the application of M&S, then a framework for a systematic methodology for quantifying cost savings and benefits of applying M&S can be established.

The premise of this research assumes that (1) M&S can be viewed as a process improvement mechanism, generally defined as an activity which reduces costs or improves quality in a given application, and (2) a structured process for quantifying costs and benefits of process improvement mechanisms can be applied to M&S through close comparison of M&S to other similar mechanisms. To establish (1), the purpose of M&S application within a scenario needs to be determined; for example, if M&S is used in a design or engineering activity, the purpose may be to reduce cost or increase the efficiency of the design process through elimination of waste due to physical prototyping and testing. If M&S is used in a training scenario, then the purpose of this application may be to reduce cost through use of virtual, or a mix of live and virtual, training assets as opposed to purely live training systems. Although used for vastly different applications, the general premise for the use of M&S common to these and other applications is to serve as a process improvement mechanism. In order to establish (2), other process improvement mechanisms need to be studied, such as LSS and VE, and parallels need to be drawn to the application of M&S. For purposes of this research, the fields of LSS and VE are studied, and past and current literature in these fields is reviewed to determine how similar process improvement mechanisms quantify cost savings and benefits of application. A common theme in measuring costs and benefits is the use of an "alternative scenario," in which the costs of not using the prescribed process improvement mechanism are discussed, thereby attempting to quantify the savings and benefits. Through the literature survey, various process improvement mechanisms and applications are studied, including applications of M&S, and the methods used to quantify cost savings and benefits of the mechanisms are discussed.

Acquisition processes within triple constraints environments consist of many complexities, including "production processes, uncertain buy quantities, and numerous design changes" (Henninger). In a direct application of M&S as a process improvement mechanism, Amy Henninger describes the challenges of reducing weapons systems' lifecycle costs, and in particular, the reduction or control of downstream acquisition costs through use of M&S in upstream production facilities design. Each of the complexities add significant cost to the acquisition process, and conversely, and simplification of these processes can result in significant cost savings. In a scenario involving facilities redesign for the production of a weapons system, Henninger describes how process simulation is used to "improve performance of physical processes by examining the behavior of a model based on various inputs and situations." The application of M&S in the example given by Henninger involves multi-objective optimization, along various elements required within a facilities optimization problem; for example, time in system, production throughput, workcell costs, etc. The use of M&S in this case was able to directly impact the decision making process, and using a structured and repetitive process, changes were applied to facilities based on optimized values derived from M&S. The cost benefit of using M&S was "a reduction of life cycle costs" for the weapons system acquisition program.

Although Henninger does not quantify the reduction in cost, the general notion of savings is discussed through the alternative scenario had M&S not been used to support the facilities redesign process. The costs associated with the physical rework of a facility plan, followed by the physical redesign of a facility, were the major factors driving Henninger to use M&S to support the facilities planning and redesign process.

LSS methodologies, and Design for Six Sigma (DFSS), focus on process improvement through reduction of variability. With wide application in almost all industries, including defense and acquisition, LSS methodologies seek to standardize processes in order to reduce variations from all aspects. A survey conducted by Gerald J. Hahn and Necip Doganaksoy of GE Global Research Center reviews how DFSS, through statistical data collection, is employed in various fields of manufacturing, field support, pharmaceuticals, semiconductors, foodservice, communications, and broad service industries, and can be used to increase efficiency and realize cost savings and benefits. The benefit of applying LSS and DFSS methodologies in each of these areas is efficiency, or reliability, also referred to as "quality over time." The compounding effect of increase in quality is both a cost savings and a realized benefit to an organization through implementation of the methodology. The measurement of cost saving, again, is left to an alternative scenario, in which the lack of quality or deficiency in product of services is compounded as a loss had the LSS or DFSS methodology not been utilized to improve the process.

The foundations of Lean philosophy are well documented within the Toyota Production System (TPS). As a mechanism of "continuously making conscious choices to radically redefine and dynamically optimize strategy, systems, processes and services, and add value to clients, employees and shareholders," the pervasive application of LSS within TPS is perhaps the widest use of a process improvement mechanism within an organization reaching almost all aspects of business operation. In a survey conducted by Adil F. Dalal on the cost savings and benefits of applying LSS methodologies, the following savings were realized:

- Lead-time reductions of up to 75%.
- On-time delivery rates of up to 100%.
- Productivity improvements of over 80%.
- Scrap reductions of up to 95%.
- Space use improvements of more than 25%.
- Setup time reductions of more than 85%.
- Machine downtime reductions of 70%.
- Total project time reductions of 70 to 90%.
- Project rework reductions of 60 to 90%.
- Project costs reductions of 50 to 70%.

In times of economic crises, Dalal's research contends that investing in process improvement mechanisms, such as LSS and elements of TPS, can result in significant cost savings. Dalal does indicate that, as with many process improvement initiatives, application of Six Sigma methodologies within an organization may be a time-consuming pursuit, and as such there is an inherent cost of implementing such initiatives. Similarly, M&S as a process improvement initiative has a cost of implementation or use which must be taken into account when conducting an assessment of cost savings and benefits. Additionally, Dalal's work points out key requirements of implementing Lean, Six Sigma, or LSS methodologies, such as specialized software, training and qualification of personnel, and potentially culture change within an organization, each of which have implementation costs associated with them. While the cost of software and training may be easily quantified, the cost of implementing cultural change is rather complex to measure; similarly, the cost of acquiring M&S tools and training may be easily quantifiable, however, the cultural change necessary to encourage the use of M&S within an organization is much more complex.

Quantification of cost and benefits has been a core tenet of value creation when implementing Lean methodologies in TPS, as exemplified in research by Jeffrey Liker in The Toyota Way. To realize benefits, value curve analysis is utilized to determine the appropriate implementation of Lean practices, and correlating improvements to bottom-line performance measurements. The prescribed methodology within the practitioner community for comparing application cost of a process improvement methodology is to determine the cost of application and that of one or alternate scenarios void of process improvement; based on the literature review and repeat application of this analysis technique, the use of alternate scenarios is heavily relied on for assessing the impact of M&S in Case Studies reviewed for this research.

There have been several studies of the role of M&S within an organization. A study conducted by C. A. Murphy and T. Perera reviews the role of M&S within an aerospace company, and discusses the difficulties implementing M&S within a technical organization. Among the difficulties discussed by Murphy and Perera is the limited understanding of simulation, and its lack of acceptance within various organizations, indicating that cultural change is perhaps necessary within certain sectors to encourage the acceptance and recognition of the use of M&S tools to support design, development, and manufacturing. Prior to mid-1980's, the application of M&S was limited to discrete event simulation as used for very specific tasks by highly trained SMEs. With the availability of general purpose computing resources, emergence of 3D graphics technology, and other technical developments, M&S began to take a more diverse role in its application within technical organizations beyond discrete event simulation. In Murphy and Perera's assessment of M&S application within the aerospace industry, the use of M&S beyond its traditional role allowed organizations to use M&S capabilities for digital experimentation, product development, and other needs, while recognizing dramatic savings in cost and time. It is within this mode of wide application that M&S moves beyond a simple mathematical tool and can be viewed more of as a process improvement initiative similar to LSS or VE.

Prior to Murphy and Perera's research, a review of the application of M&S tools for the design and manufacture of airframes or any other industrial sector had not been conducted, and furthermore, a survey conducted at the Winter Simulation Conference (1999) had indicated that simulation was by and large not utilized throughout product development. While prior activity did indicate the use of M&S for facilities planning and other very specific application, the broad use of M&S in product development or in support of acquisition had not been studied or quantified. Consistent with the maturity timelines of M&S tools and capabilities, it can be inferred that while SMEs were familiar with the more mature applications (facilities planning, etc.), the acceptability of M&S in product design was low due to the immaturity of the capabilities and lack of early adaptation and investment by organizations. With advances in technologies supporting wider use of M&S capabilities, more organizations are now leaning forward through corporate investment, time and collaborative partnership with M&S tool vendors to support a broader use of M&S as a process improvement mechanism.

CHAPTER THREE: METHODOLOGY

As shown through literature review, parallels can clearly be drawn between quantification of costs and benefits of M&S, and the fields of Value Engineering, Lean Six-Sigma, Total Quality Management, and other paradigms which claim cost reduction and increased benefits through application. A common theme within each quantification paradigm is the emphasis placed on capturing accurate costs, and the development of an accurate and realistic alternative scenario in which the process is not used, so that a comparison can be made to determine whether the application of the process results in reasonable costs savings and benefits.

This research relies heavily on the development of an accurate quantification paradigm for M&S application, and as such, it is prudent to study established methods from which close parallels can be drawn to this activity. The first section of this chapter focuses on the methodologies currently established for cost benefit analysis (CBA) in comparable fields, and how these methodologies can contribute to the creation of a holistic method for capturing costs and benefits of M&S. The remainder of this chapter applies the quantification method to scenarios in programmatic environments to determine if any cost savings and benefits are realized through the application of M&S. For purposes of this research, three case studies were developed using specific programmatic scenarios over thirteen months (October 2008 through January 2010) which were executed within triple constraint acquisition environments. The application of the quantification method is demonstrated in the case studies and results and findings are discussed in the following chapter.

Data collection for each of the three case studies poses a unique challenge which requires polling several sources for cost information. For each Case Study, major metrics for cost are established, such as time and labor costs associated with SMEs, unique hardware or tool costs, facilities charges, etc. are identified. Cost data is retrieved from receiving organizations, cost and procurement analysts, SMEs, and management personnel.

Development of a Holistic Quantification Method for M&S Costs and Benefits

In order to assess the value of modeling and simulation within a programmatic environment of triple constraints, case studies of individual applications need to be examined through a structured process. To calculate the value of using M&S, accurate cost, schedule, and performance data must also be gathered for the alternative process.

A systematic approach to developing the quantification method was taken, which involved the development of high level models and the use of alternative scenarios which are further refined through decomposition. A simplified approach can be taken to determine the overall costs and benefits of various applications; for the application of M&S to an activity that does not currently apply it, the initial scenario can be viewed as the series of events associated with not using M&S, and the alternate scenario is the application of M&S. Within this model, multiple alternate scenarios can be developed and analyzed to determine the costs and benefits of various application scenarios to determine which approach could be appropriately applied within the triple constraints of cost, schedule, and performance. Conversely, for activities where M&S is applied at some level, the alternate scenarios can be used to determine cost savings and benefits, if any, realized to cost, schedule, and performance through the use of M&S vice non-M&S alternate scenarios.

To accurately capture the costs associated with alternate M&S scenarios, general guidelines need to be established of what cost factors are considered relevant in the realm of M&S application, such as tool costs, personnel, etc., to sufficient detail such that the same process guidelines could be applied to other alternate scenarios to allow for like comparisons.

Costs associated with M&S can be defined into three broad categories: one-time capability costs, recurring capability costs, and experimentation costs. These items can be described as follows:

- One-time Capability Costs - costs associated with acquiring the M&S capability for use within an organization, or the initial cost of acquiring the capability, such as the initial purchase costs, etc. These are generally high cost items / capital investments associated with bring various M&S capabilities to an organization.
- Recurring Capability Costs - costs associated with maintaining the M&S capability for use within an organization, such as recurring licensing fees, bench costs for personnel not directly supporting experimentation, continuous improvement/training costs not specifically tied to experimentation, etc.
- Experimentation Costs - costs associated with directly conducting an experiment, or "use cost," for utilizing the M&S capability, such as personnel labor costs, additional equipment use fees, transportation costs directly attributable to the experiment, etc.

As can be expected, the major cost driver for M&S capabilities is the initial acquisition of the facilities, capabilities, hardware/software, and associated trained SMEs or personnel. Once the capabilities are acquired by an organization, the recurring costs are comparatively lower and experimentation costs are reimbursable buy the user. For the case studies discussed below, data is gathered for the experimentation cost as well as the overall cost of the capability to the organization.

From a user's standpoint, the primary costs are that of experimentation alone; however, this cost may include amortization of the other major costs of acquiring the capability, as well as its recurring costs, so that the organization can recoup the initial investment in the capability and any costs associated with its upkeep.

M&S Application Case Studies

Data collection was conducted from program offices at the U.S. Army's Tank-automotive and Armaments Command (TACOM, Warren, MI). Additional test support was received from Tank-automotive Research, Development and Engineering Center (TARDEC, Warren, MI), Aberdeen Test Center (ATC) at Aberdeen Proving Ground (APG, Aberdeen, MD), and Yuma Test Center (YTC) at Yuma Proving Ground (YPG, Yuma, AZ). Names of specific program offices have been removed from the presented data to retain confidentiality.

Two scenarios involving use of M&S in programmatic environments were studied and developed into case studies for this research. Data was collected from each of the case studies to determine the overall cost of the M&S activity, and the perceived cost of the alternate scenario of not using M&S was also estimated. For both scenarios, the programmatic environment, or program office, did not own the facilities or resources to conduct the M&S activity, therefore the all simulation and related analysis activities were conducted by an external organization which maintained the M&S capability; this allowed for an accurate measure of the exact cost of the M&S scenarios based on the costs incurred by the program office. Additional resolution for detailed breakdown of costs was gathered from the M&S organization, to include any amortized costs not directly linked to the experiments.

Case Study 1: Durability Testing of External Vehicle Components

A program office was challenged to immediately produce and field a stand-off armor package for a tactical vehicle. The process of fielding new production items or components requires endurance and durability testing to ensure product reliability as it is fielded to an end-user, i.e. extensive testing needs to be conducted to ensure reliability of components over various terrain profiles, examination of failure points due to stress caused in dynamic environments, etc.

At minimum, 3,000 miles of endurance testing over various terrain profiles is conducted and Test Incident Reports (TIR's) are written to document any issues or failures seen during testing. Corrective action is taken based on the type of failure; if the failure directly involves the component under test, redesign of the component may be necessary and additional time and resources are allotted to rerun testing to ensure a successful design.

In this Case Study, the program office was presented the option of prototyping and building the stand-off armor component and immediately entering field testing at the proving grounds, or to conduct physical simulation testing prior to field testing which would require two additional weeks. The costs associated with the additional physical simulation testing were approximately $38,000 inclusive of personnel labor hours (including overtime); detailed cost breakdown is discussed in Chapter 4. The purpose of the physical simulation test was to induce approximately 1,500 miles of vibration profile to the vehicle and stand-off armor system to predict failure modes prior to entering field tests.

Figure 1 - Case Study 1 M&S Progression

The design of the stand-off armor system was completed primarily using virtual prototyping as shown to the left of Figure 1. Computer-aided design (CAD) software was used to render a model of the vehicle for which the armor system was to be designed, followed by

SMEs designing and integrating various armor components. The primary challenge associated with virtual prototyping was the availability of the base vehicle model due to intellectual property (IP) issues from the Original Equipment Manufacturer (OEM); this is a common issue seen across subsystem integration projects involving multiple competing parties. In order to overcome IP issues, a scanned model of the physical vehicle was used, however, resulting in loss of fidelity for precision tasks - this adds to the design verification process in which inaccuracies need to be rectified. For example, whole overall placement of major stand-off armor components is relatively accurate, attachment and interface points between the vehicle and the stand-off armor needs to be carefully verified to ensure that bolt-on points are accurately located on the physical system due to inaccuracies in the scanned vehicle model. Additional challenges in virtual prototyping were noted and are discussed in more detail in Chapter 4.

Upon completion of virtual prototyping design of the stand-off armor subsystem, an initial prototype kit was produced for fit-up and initial testing. Upon fit-up of the subsystem to the vehicle, the integrated system was ready for physical testing - an interim "physical simulation" step was added, as shown in the center of Figure 1, to perform an initial shakedown of the system prior to endurance and durability testing at a proving ground facility. The TARDEC physical simulation facility provides 4-post actuators capable of inducing terrain inputs onto a vehicle's suspension; the resulting motion simulates the terrain profile as recorded from a proving ground course. Approximately 1,500 virtual miles were induced on the vehicle's suspension while data was collected on failures of any components; test administrators and data collectors recorded all minor and major system failures, such as any broken linkages or components, as the test was conducted. The resulting incident reports were in turn used to take corrective action and modify the design of the failing subsystems, and the design changes were implemented into the virtual prototyping process to ensure that the technical data was up-to-date for manufacturing purposes. After completion of the virtual miles, the vehicle was released for physical testing. The costs associated with this interim process are documented and used when conducting the cost benefit analysis for physical prototyping.

Physical testing for the stand-off armor was conducted at YPG. Costs associated with physical testing include test personnel, vehicle OEM Field Service Representative (FSR) travel and time, instrumentation and data collection, repair costs, and other various costs which are discussed further in Chapter 4. Upon receiving the vehicle and initial inspection at YPG, a test regimen consisting of approximately 3,000 miles to prove endurance and durability of the stand-off armor subsystem and its integration on the vehicle was conducted by YTC personnel with the support of OEM FSR's. Any failures found during this process are documented in TIR's and corrective action is implemented by FSR's upon review and guidance from design engineers; this process may include fabrication of new components to replace any malfunctioning parts, for which the additional design and fabrication time needs to be considered.

Throughout this Case Study, cost metrics are collected for CBA calculations. While the cost of issues found and resolved during the virtual prototyping process can be easily ascertained, it is much more complicated to compute the downstream effects or potential savings during the field testing phases of implementing these fixes. In order to quantify potential costs of fixes downstream, detailed costs of FSR support and parts fabrication need to be analyzed, along with comparative costs of similar past efforts.

Case Study 2: Suspension System Redesign

The second Case Study reviews the development process of redesigning a vehicle suspension system. A program office was challenged to redesign the suspension system of an armored tactical vehicle, which included trade studies to determine appropriate suspension and component level application, physical fit-up, endurance and durability testing, and final down-select of a candidate suspension solution. Triple constraint prioritization was placed highest on performance, followed by schedule and cost.

M&S was employed significantly throughout the design process by SMEs to ensure appropriate application and sizing of hardware; from systems integration, to studying energy management within the suspension system, the design process was almost entirely virtual prior to procurement, integration, and test of any physical hardware. High fidelity models of both the vehicle system and suspension subsystem, and its associated components, were utilized throughout the design process. Finite element analysis (FEA) was also conducted at the subsystem level to study stress and strain on components to ensure durability of selected parts. Additionally, quarter suspension models were studied to ensure appropriate energy management within the integrated system for specified vehicle loading conditions and expected mobility performance (speed over given terrain profiles). Upon sufficient confidence of the virtual design, hardware was procured and integrated onto the vehicle system, replacing the existing suspension system, and tested on specifically designed test obstacles to study system performance as predicted by the M&S efforts conducted during the design process. Each of these efforts is described in more detail in the following section.

The initial systems integration was done entirely through virtual prototyping, in which a high fidelity model of the vehicle system was integrated with a suspension subsystem model acquired from the suspension manufacturer. This level of invasive integration can only be accomplished using high fidelity models as it requires interfacing multiple subsystems accurately; attachment points, such as welding and bolt-on points, need to accurately match, along with interface with other vehicle subsystems (transfer case, steering arms, etc.). Virtual integration also allowed the team to study full articulation of the suspension system and all associated moving parts to ensure non-interference between components. This process also allows the designer to replace components during design to study alternates, such as the effect of using a different size tire or wheel assembly.

Upon initial iteration of design, the system was studied in more detail by SMEs to ensure appropriate sizing of suspension subsystems, such as shocks and springs, to allow the vehicle to meet performance characteristic requirements. Two types of analyses were conducted; FEA on the design was conducted to study stress and strain on individual components, and a quarter vehicle suspension model was created to study energy management within the design and to ensure appropriate sizing of primary suspension components.

To conduct FEA on the suspension system, a high fidelity mesh model of the suspension system was utilized along with models of the attachment and interference points on the vehicle (shock mounts, bump stops, etc.). This process requires significant input from SMEs and designers to ensure accurate modeling, and is computationally expensive requiring several hours to complete on multiple processors. Therefore, iterations of design can add significant time in analysis and contributes significantly to the cost of the effort. Upon completing the FEA simulation, SMEs review the results and provide feedback on which components within the system are likely to fail under given load conditions - if any significant weak points are found, the system design is refined and the process is repeated.

In addition to FEA to determine component performance, a quarter vehicle suspension model was created to study energy management within the suspension system. Given various load conditions of the vehicle, worst case scenarios are studied - information regarding performance over expected terrain conditions (speed, obstacle height, etc.) is coupled with vehicle loading conditions at the suspension boundary, and the energy absorption characteristics of the suspension system are studied to ensure that the suspension behaves in a manner that maximizes ride quality while successfully managing the energy during jounce and rebound conditions. The results of this process allow the SMEs to recommend appropriate shock and spring characteristics allowing the vehicle to perform to the given specifications.

Upon successful iteration of FEA, quarter vehicle suspension modeling, and virtual prototyping, hardware was acquired and integrated onto the vehicle system. In order to verify and validate (V&V) results from the simulation effort, a unique repeatable test course consisting of a single concrete obstacle was designed which allowed the vehicle suspension subsystem to be tested in full jounce and rebound conditions at a given vehicle speed. Strain gauges are added to several points on the vehicle suspension system to validate results and to ensure that recommended stress and strain limits of components are not exceeded during operation. Upon completion of this test and ensuring that the suspension system is appropriately integrated, the complete design package is submitted back to the program office for potential acquisition.

Cost data for each individual M&S effort conducted throughout this design, integration, and test process is collected and analyzed, and is presented in Chapter 4.

Case Study 3: Armor and Blast Testing

One of the most significant challenges facing the military ground vehicles community is the ability to conduct armor and blast testing through use of M&S, and to use M&S as a predictive tool when analyzing proposed design of new vehicle systems or changes to existing vehicle systems. The implications to cost savings are quite significant as the use of M&S would reduce the need to destructively test production-representative assets. This Case Study reviews the current state of M&S used for armor and blast testing activities, and attempts to quantify some of the costs associated with this capability.

Due to the lack of fidelity of current capabilities, programmatic offices considering major design changes must budget significant cost and schedule implications to conduct destructive testing of assets; in the case of armor systems, coupon testing may be acceptable, however, there are still significant cost and schedule implications associated with acquiring subsystem materials, range time, etc. to conduct physical tests.

As described in the literature review, there are concerted efforts within DOD (United States) and MOD (United Kingdom) government R&D facilities, vehicle platform developers, and subcomponent suppliers to increase the level of fidelity of tools available to conduct armor and blast testing through M&S. Of the numerous challenges associated with achieving this capability, verification, validation, and accreditation (VV&A) of M&S tools requires significant physical destructive testing and correlation with results to ensure that M&S outputs are indicative of physical performance.

Details of costs associated with armor and blast M&S, including R&D investments, are analyzed in Chapter 4, along with comparisons with costs associated with physical destructive testing.

Data Collection

Cost data collection from multiple sources presents unique challenges for consolidation and comparison. Data for purposes of cost estimation for the Case Studies was sourced from SMEs, financial analysis, and contracting cells, and is further categorized by agency type and cost type. The standard form for collecting and consolidating cost information is shown in Figure 2. Once multi-source data is consolidated, it can be utilized to compute actual, rough order magnitude (ROM), or estimated costs of Case Studies or of alternate scenarios when conducting the CBA.

CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY):				
Cost Description:				
Source:				
Source Type:	SME [ ]	Finance [ ]	Contract [ ]	
Agency Type:	Government [ ]	Contractor [ ]		
Cost (US$):				
Cost Accuracy:	Actual [ ]	ROM [ ]	Estimate [ ]	
Cost Type:	Facility [ ]	Service/Labor [ ]	Hardware/Parts [ ]	License [ ]
	Transportation [ ]	Storage [ ]	Travel/Per Diem [ ]	Other Fee [ ]
Cost Unit:	Hourly [ ]	Monthly [ ]	Annual [ ]	One-Time/Fixed [ ]
Details/Comments:				

Figure 2 - Consolidated Cost Data Collection Form

Any additional information pertinent to individual cost data can also be denoted in the Details/Comments field. The intent of the form, while consolidating cost data, is to also allow flexibility in understanding the data from its original source, which would be convoluted with other cost information. This template also serves as a basis for future data collection and consolidation.

In order to compute total activity costs for Case Studies and CBA, standard calculators needed to be developed to minimize deviation between actual cost and calculated costs, and also to fully account for the total cost of activities as broken down into various categories. General categories for the Case Studies not involving travel are personnel and hardware (or facilities) cost; for Case Studies involving travel, such as testing conducted at remote sites, additional costs of travel (per-diem rates, airfare, etc.) need to be captured. Figure 3 captures activity costs for non-travel related activities (Case Study 3); specifically, it accounts for various costs associated with testing activities, in this case for multiple threats associated with destructive testing.

	A	B	C	D
1	**Armor Testing Cost Simulator**			
2				
3	# of Days:	0		
4	Work-day (hours)	0		
5				
6	Personnel Labor Costs			
7		# People	Utilization	Rate ($/hr)
8	SME	0	0	0
9	Support	0	0	0
10				
11	Total Hardware Costs			
12		Unit Cost	Quanitity	
13	Coupons or Hulk*	0	0	=C13*B13
14	^ Transportation	0	0	=C14*B14
15	Threat A	0	0	=C15*B15
16	Threat B	0	0	=C16*B16
17	Threat C	0	0	=C17*B17
18	Sub-totals			=SUM(D13:D17)
19				
20	Total Labor Cost Calculations			
21		Labor Hours	Labor Cost	
22	SME Cost	=B8*C8*(B3*B4)	=B8*C8*D8*(B3*B4)	
23	Support Cost	=B9*C9*(B3*B4)	=B9*C9*D9*(B3*B4)	
24	Sub-totals	=SUM(B22:B23)	=SUM(C22:C23)	
25				
26	Total Cost	=SUM(D18+C24)		
27				
28	Notes (assumptions for purposes of calculation)			
29	* If Hulk, use capitalized vehicle/hulk cost (as if testing new), set qty. to 1			
30	Transportation qty. for hulk should also be set to 1			

Figure 3 - Test Activity Cost Approximation

The test activity ROM cost is computed based on several factors, which are highlighted in Figure 3 and can be modified in the spreadsheet:

- Number of days the test experiment is expected to last. This can be approximated based on past performance of the test facility and other similar experiments which have been run.

- Number of hours worked per day; for standard experiments, this is set to eight working hours per day (40 hour work-week). There may be instances which require overtime, or experiments which are run continuously (24 hours per day); this field can be edited as needed to fit the testing circumstances.
- Number of subject matter experts supporting the experiment, their utilization (100% dedicated, or 50%, or whatever their task-loading may be), and their composite hourly rate. For ROM development purposes, the number of SME personnel required to conduct the experiment may be gauged based on past performance of similar activities. The composite hourly rate of the employee can be extracted from contract documentation, SME estimates, cost analysts, or any other source that can provide what the hourly rate of the employee is.
- Number of support personnel, similar to the number of SMEs, is provided as an additional cost category in instances where there are multiple employee types that are supporting the test activity; for example, there may be engineers, drivers, field service representatives, test data collectors, or other support staff with different task loading and different hourly composite rates, each of which can affect the overall ROM cost computation.
- Hardware costs need to be provided to capture costs associated with various non-personnel items; for purposes of this activity, cost of test assets (hulks), transportation, and test threats were added for ROM development.

The spreadsheet is designed to be extensible, allowing addition of fields as necessary; for example, if additional labor categories are required beyond SME and support staff, additional lines could be added in the spreadsheet. Similarly, additional hardware (or facility) costs can be added easily to the tool.

The total labor cost calculations follow standard methodologies used in cost estimation. SME cost is computed based on the number of days the resource will be used, hours worked per day, factored by task loading and composite hourly rate for the individual labor category. The labor cost for the other support personnel can be computed in a similar manner. The sum of the cost of each labor category provides the total labor cost for ROM development. This number is added to the total hardware resource cost to determine the total ROM cost.

While Figure 3 provides a tool for computing ROM costs for destructive testing in Case Study 3, additional sheets are created for other types of test activities. For Case Studies 1 and 2, the major expense of labor and travel costs could be used to develop the ROM. While additional hardware costs could be figured for the development of a more accurate cost model, the major cost driving factor is labor which is significantly higher than the prototype hardware (which, at least in Case Study 1, would be minimal). For Case Study 2, the cost of experimentation in either simulation or physical hardware testing does not require any additional hardware, therefore the cost model proved to provide accurate ROMs for the alternate scenarios in which only test costs were considered. Figure 4 depicts the ROM development tool for off-site personnel and travel cost approximation.

	A	B	C	D	E	F	G
1	**Off-Site Personnel and Travel Cost Simulator**						
2							
3	# of Days:	0					
4	Work-day (hours)	0					
5							
6	Personnel Labor Cost						
7		# People	Utilization	Rate ($/hr)	Traveling?*	Days Traveling**	
8	Field Service Rep	0	0	0	No	=IF(E8="Yes",FLOOR(C8*B3,1),0)	
9	Engineer	0	0	0	No	=IF(E9="Yes",FLOOR(C9*B3,1),0)	
10	Logistician	0	0	0	No	=IF(E10="Yes",FLOOR(C10*B3,1),0)	
11							
12	Per Diem Calculation						
13		Lodging	M&IE	Total	Airfare***	Car Rental****	
14	Proving Ground	0	0	=SUM(B14:C14)	0	0	
15							
16	Total Cost Calculatior						
17		Labor Hours	Labor Cost	Lodging	M&IE	Airfare	Car Rental
18	FSR Cost	=B8*C8*(B3*B4)	=B8*C8*D8*(B3*B4)	=IF(F8>1,(F8-1)*B14,0)*B8	=IF(F8>2,((F8-2)*C14)+(1.5*C14),F8*0.75*C14)*B8	=IF(F8>0,B8*E14,0)	=IF(F8>0,F14*$F8,0)
19	Engineer Cost	=B9*C9*(B3*B4)	=B9*C9*D9*(B3*B4)	=IF(F9>1,(F9-1)*B14,0)*B9	=IF(F9>2,((F9-2)*C14)+(1.5*C14),F9*0.75*C14)*B9	=IF(F9>0,B9*E14,0)	=IF(F9>0,F14*$F9,0)
20	Logistician Cost	=B10*C10*(B3*B4	=B10*C10*D10*(B3*B4)	=IF(F10>1,(F10-1)*B14,0)*B10	=IF(F10>2,((F10-2)*C14)+(1.5*C14),F10*0.75*C14)*B10	=IF(F10>0,B10*E14,0)	=IF(F10>0,F14*$F10,0)
21	Sub-totals	=SUM(B18:B20)	=SUM(C18:C20)	=SUM(D18:D20)	=SUM(E18:E20)	=SUM(F18:F20)	=SUM(G18:G20)
22							
23	Total Cost	=SUM(C21:G21)					
24							
25	Notes (assumptions for purposes of calculation)						
26	* If Yes, per-diem costs will be calculated for this labor category						
27	** Days are calculated based on utilization and Traveling flag						
28	*** Assumes one round-trip ticket per person for duration of stay						
29	**** Daily rate, assumes one shared vehicle per labor category						

Figure 4 - Off-Site Personnel and Travel Cost Approximation

Similar to the table shown in Figure 3, the Off-Site Personnel and Travel Cost Approximation ROM cost development tool depicted in Figure 4 computes the overall personnel costs associated with test activities based on various labor categories and detailed breakdown of travel expenses:

- Number of days the test experiment is expected to last.
- Number of hours worked per day; for standard experiments, this is set to eight working hours per day.
- Number of subject matter experts supporting the experiment, their utilization, composite hourly rate, and whether or not the individual labor category is expected to travel. Whether or not the individual labor category is traveling will significantly impact overall ROM cost; if there are groups of individuals within the same labor category that are not traveling, they can be entered on a separate line.
- Location per-diem rates can be entered based on standard published rates as used by Government and Industry. These rates are updated annually based on locality costs and other factors, and the data is widely available. The two components of per-diem rates are

lodging rates (hotel expenses) and the meals and incidental expenses (M&IE). Each component is factored differently based on the number of days the individual is traveling, which needs to be incorporated into the overall ROM calculation.

Personnel labor costs are computed based on the number of days worked, hours worked per day, number of people per labor category, their utilization and their composite hourly rate. This is computed the same way as was done for the table in Figure 3.

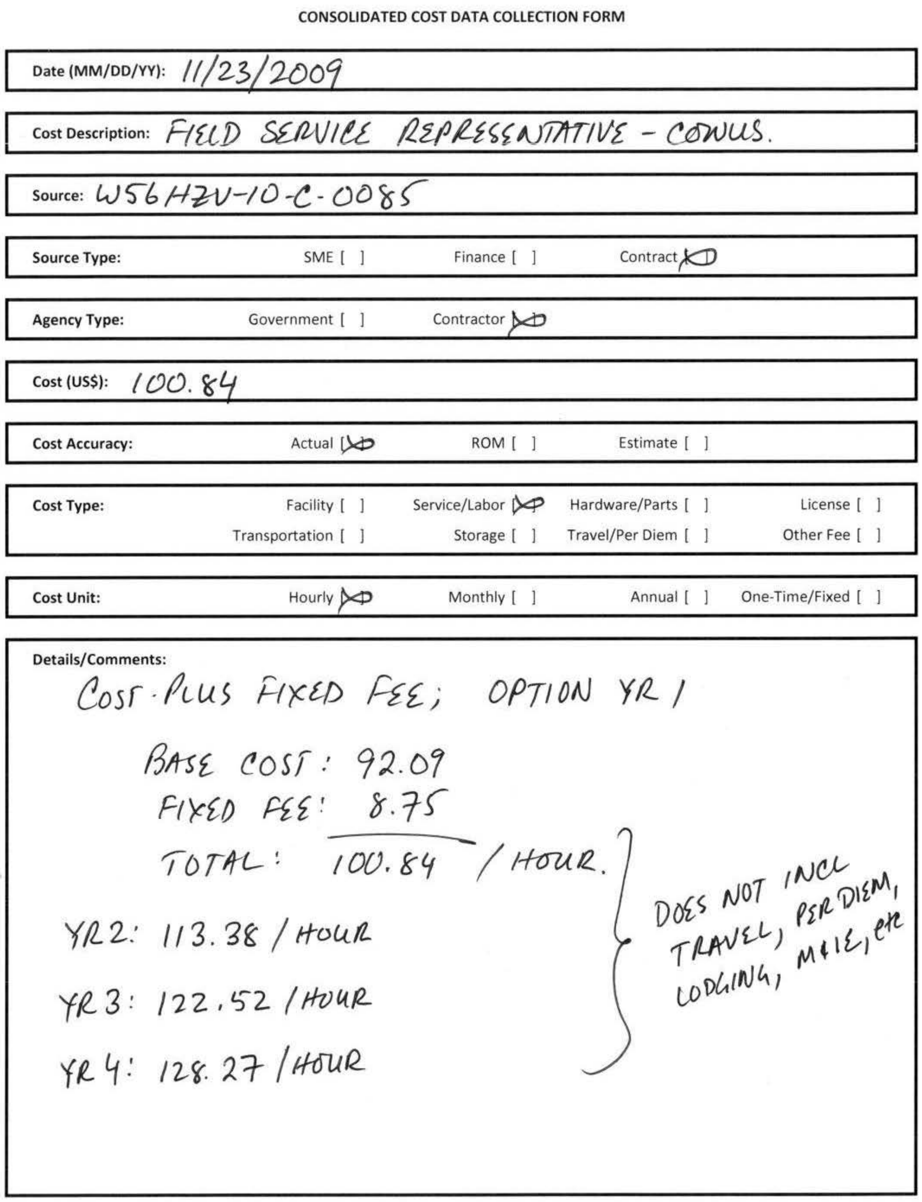
Per-diem calculations require the incorporation of logic based on the following standard per-diem calculation guidelines. For the lodging calculation: if the duration of travel is only one day, then the traveler is not paid for lodging; else the traveler is paid for the number of nights away from home (i.e. one less than the total number of days traveling). M&IE is calculated slightly different: the traveler is paid for 75% of M&IE for the first and last day of travel; all other days are paid at the full M&IE rate. For example, if the duration of travel is two days, then the traveler would be paid for one night of lodging, and 75% of M&IE for each of the two days of travel. If the duration of travel is four days, then the traveler would be paid for three nights of lodging, 75% of M&IE for two days (first and last), and 100% of M&IE for two days (remaining).

In addition to the lodging and M&IE expenses, airfare and car rental expenses must be considered for each traveler. While there are other expenses associated with traveling (such as tolls, fuel, etc.) these are relatively small compared to the major expenses and are therefore not necessary when computing ROM costs.

The logic for calculating travel and per-diem expenses was embedded into the spreadsheets to automate calculation for each labor category; if additional labor categories were needed, the spreadsheet could be simply extended to include those additional categories to formulate the ROM costs.

CHAPTER FOUR: FINDINGS

Data collection was completed using worksheets developed for this research activity (as depicted in Figure 2). Sources of data include quotations from SMEs, financial analysts, or contract source documentation. The rationale for collecting each category of data, and the associated collection sheet is depicted and described in detail below:



CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY): 11/23/2009

Cost Description: FIELD SERVICE REPRESENTATIVE - CONUS.

Source: W56HZV-10-C-0085

Source Type: SME [ ] Finance [ ] Contract [X]

Agency Type: Government [ ] Contractor [X]

Cost (US$): 100.84

Cost Accuracy: Actual [X] ROM [ ] Estimate [ ]

Cost Type: Facility [ ] Service/Labor [X] Hardware/Parts [ ] License [ ] Transportation [ ] Storage [ ] Travel/Per Diem [ ] Other Fee [ ]

Cost Unit: Hourly [X] Monthly [ ] Annual [ ] One-Time/Fixed [ ]

Details/Comments:

COST-PLUS FIXED FEE; OPTION YR 1

BASE COST: 92.09
FIXED FEE: 8.75
TOTAL: 100.84 / HOUR.

YR2: 113.38 / HOUR

YR3: 122.52 / HOUR

YR4: 128.27 / HOUR

DOES NOT INCL TRAVEL, PER DIEM, LODGING, M&IE, etc

Figure 5 - Cost Data for CONUS FSR

During experimentation and testing, the maintenance of hardware (vehicles, other systems, etc.) is conducted by FSRs, therefore it is critical in the development of ROMs and cost estimates to understand what the cost of FSRs are. FSR labor rates are generally broken down by location: either within the continental United States (CONUS), or outside the continental United States (OCONUS); the labor rates for CONUS FSRs are shown in Figure 5 as collected from the contract source document. FSRs are generally contractors who provide general mechanic support to repair hardware during test (or while deployed) and are instrumental to ensuring operational availability of assets.

The labor rate provided for the CONUS FSRs was US$ 100.84 for the first option year (which is when the Case Studies were conducted); out-year rates are also available in the contract document and are captured in the cost data collection form. This hourly rate does not include travel, per-diem, or any other costs, which are billed in addition to the hourly rate of the FSRs.

In developing the alternate scenarios for Case Studies 1 and 2, the availability of FSRs was critical to support operational availability of assets and to ensure any issues that arose during testing with the assets were addressed immediately. At the given rate, the daily cost of an FSR supporting APG, YPG, or any other CONUS location, is US$ 806.72, which translates to US$ 4,033.60 per week of test activity (based on an eight hour work day); the rates provided in the source document are composite rates and do not change for overtime, therefore the burden to provide additional personnel if needed to accomplish the task is shifted to the contractor based on the number of hours awarded on contract.

Each test site (APG and YPG) retains at minimum two FSRs at any given time; therefore, when calculating cost of alternate scenarios for Case Studies 1 and 2, the daily labor rate for FSRs alone would be US$ 1,613.44.

CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY): 11/23/2009

Cost Description: FIELD SERVICE REPRESENTATIVE – OCONUS

Source: W56HZV-10-C-0085

Source Type: SME [ ] Finance [ ] Contract [X]

Agency Type: Government [ ] Contractor [X]

Cost (US$): 118.92

Cost Accuracy: Actual [X] ROM [ ] Estimate [ ]

Cost Type: Facility [ ] Service/Labor [X] Hardware/Parts [ ] License [ ] Transportation [ ] Storage [ ] Travel/Per Diem [ ] Other Fee [ ]

Cost Unit: Hourly [X] Monthly [ ] Annual [ ] One-Time/Fixed [ ]

Details/Comments:

C.P.F.F; OPT. YR. 1 (LABOR ONLY)

BASE COST: 108.60
FIXED FEE: 10.32
TOTAL: 118.92

YR 2: 133.70/HOUR
YR 3: 144.49/HOUR
YR 4: 151.26/HOUR

Figure 6 - Cost Data for OCONUS FSR

Similar to CONUS FSRs, OCONUS FSRs are also billed using a composite rate, with the difference being that additional costs (hazard pay, insurance, etc.) are factored into their composite hourly rate. Figure 6 shows the OCONUS FSR hourly rates.

Per source contract documents, the composite hourly rate for OCONUS FSRs for the first option year was US$ 118.92. OCONUS FSRs generally work 12-hour shifts per day, and therefore their daily rate is US$ 1,427.04, which is significantly higher than the daily rate of a CONUS FSR.

While alternate scenarios for Case Studies 1 and 2 were developed using CONUS test sites, the data for OCONUS FSRs was collected for comparison purposes if the product were to be fielded without testing; while rare in structured acquisition environments, certain components are fielded prior to completing CONUS testing, which results in using OCONUS FSRs to support fielded hardware. This adds significant cost risk to programs if the fielded item fails and requires significant FSR support to maintain; in such alternate scenarios, it is quite evident that up-front M&S would reduce the cost risks associated with fielded hardware failing. In addition to increased labor costs for OCONUS FSRs, travel and lodging are significantly more expensive than CONUS based employees as the OCONUS locations are generally in hostile environments (international hotels, operating bases, etc.).

CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY): 11/23/2009

Cost Description: ENGINEERING SERVICES - GENERAL

Source: W56HZV-10-C-0085

Source Type: SME [ ] Finance [ ] Contract [X]

Agency Type: Government [ ] Contractor [X]

Cost (US$): 111.30

Cost Accuracy: Actual [X] ROM [ ] Estimate [ ]

Cost Type: Facility [ ] Service/Labor [X] Hardware/Parts [ ] License [ ] Transportation [ ] Storage [ ] Travel/Per Diem [ ] Other Fee [ ]

Cost Unit: Hourly [X] Monthly [ ] Annual [ ] One-Time/Fixed [ ]

Details/Comments:

C.P.F.F; OPT. YR. 1 (LABOR ONLY)

BASE COST: 1[illegible].60

FIXED FEE: 9.66

TOTAL: 111.30

YR 2: 125.13

YR 3: 135.22

YR 4: 141.57

Figure 7 - Cost Data for General Engineering Services

While conducting tests at CONUS locations, test assets are supported at minimum by one Engineer to ensure issue resolution and communication with programmatic staff. Figure 7 shows the composite hourly rate for a contractor engineer, which was derived from contract documentation. At US$ 111.30 per hour, the daily rate of an engineer is US$ 890.40, with the weekly rate being US$ 4,452.00. While FSRs are generally long-term residents at various test sites, the Engineer is usually rotated on a weekly basis, therefore in addition to the composite weekly rate, travel costs associated with the Engineer at the test site must be calculated in any ROM formulation.

The Engineer provides critical analysis and problem solving during test activities and is required to ensure that TIRs are addressed and engineering solutions are communicated back to the program acquisition activity through Engineering Change Proposals (ECPs). For purposes of developing the alternate scenario for Case Studies 1 and 2, one Engineer was assumed to be on site at the test site in support of the activity; by reviewing past test activities of similar scope, this level of staffing was deemed sufficient for each of the Case Studies.

CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY): 11/23/2009

Cost Description: LOGISTICS SERVICES

Source: W56HZV-10-C-0085

Source Type: SME [ ] Finance [ ] Contract [X]

Agency Type: Government [ ] Contractor [X]

Cost (US$): 96.90

Cost Accuracy: Actual [X] ROM [ ] Estimate [ ]

Cost Type: Facility [ ] Service/Labor [X] Hardware/Parts [ ] License [ ] Transportation [ ] Storage [ ] Travel/Per Diem [ ] Other Fee [ ]

Cost Unit: Hourly [X] Monthly [ ] Annual [ ] One-Time/Fixed [ ]

Details/Comments:

C.P.F.F; OPT YR1 (LABOR ONLY)

BASE COST: 88.49

FIXED FEE: 8.41

TOTAL: 96.90

YR 2: 108.94

YR 3: 117.73

YR 4: 123.25

Figure 8 - Cost Data for General Logistics Services

While FSRs and Engineers provide the mechanical and technical labor necessary to conduct test activities, background support for facilitating hardware/equipment transportation, spare parts provisions, tool kits, etc. are provided through Logistics Services, also referred to as Logistics Engineering Support within the contract documentation. The composite hourly rate for

Logisticians, as shown in Figure 8, is US$ 96.90, which translates to a daily rate of US$ 775.20, and a weekly rate of US$ 3,876.00. The alternate scenarios for Case Studies 1 and 2 recommended 50% tasking of one Logistician for the duration of the test activities; while FSRs and the Engineer were required to be at the testing sites, Logistics support is generally provided from the program office and travel is not required.

The addition of Logisticians in support of test activities, while minimally increasing cost, provides significant risk reduction in the event that unforeseen issues arise during the test activity. Logisticians provide expedited processing of spare parts requests, locating of alternate hardware, provisioning support, as well as standard Logistics Services activities such as technical manual development and updating as issues are found and resolved during test activities. For example, in Case Study 1: as changes were made to the technical data package during the physical simulation testing, the technical manuals were updated accordingly with the updated part drawings as needed to accurately describe the fixes. While ancillary to the actual testing activity, accurate manuals are required prior to fielding any hardware component, and therefore logistics support during test-fix-test activities is critical.

CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY): 05APR2010

Cost Description: TURRET MOTION BASE SIM / BAR ARMOR SHAKE-DOWN

Source: S.S. / EMAIL 05APR2010 0727

Source Type:	SME [X]	Finance [ ]	Contract [ ]	
Agency Type:	Government [X]	Contractor [ ]		
Cost (US$): 39.4 K				
Cost Accuracy:	Actual [X]	ROM [ ]	Estimate [ ]	
Cost Type:	Facility [X]	Service/Labor [X]	Hardware/Parts [ ]	License [ ]
	Transportation [ ]	Storage [ ]	Travel/Per Diem [ ]	Other Fee [ ]
Cost Unit:	Hourly [ ]	Monthly [ ]	Annual [ ]	One-Time/Fixed [X]

Details/Comments:

TOTAL BAR-ARMOR SHAKE-DOWN (PHYSICAL SIM) COST INCL OF PERSONNEL COST, FACILITY USAGE, ETC.
TEST DURATION: 2 WEEKS / 3,000 MILES.
NORMAL WORK HRS = 700 MILES/WK, O.T. REQ'D TO COMPLETE 3000 MILES IN TWO WEEKS.

TIMING DRIVEN BY SHIPMENT DATE OF TEST ASSET TO Y.P.G.

Figure 9 - Cost Data for TMBS / Bar Armor Shake-Down Experiment

In order to conduct the physical simulation activity beyond the virtual prototyping phase (and before physical testing), the TARDEC Turret Motion Based Simulator (TMBS) team was contracted to conduct the physical "shake-down" activity to determine if any hardware failures would occur on virtual miles. Figure 9 shows the consolidated cost received from the TMBS team to conduct the physical simulation activity, which consisted of running 3,000 virtual miles using the 4-post shakers.

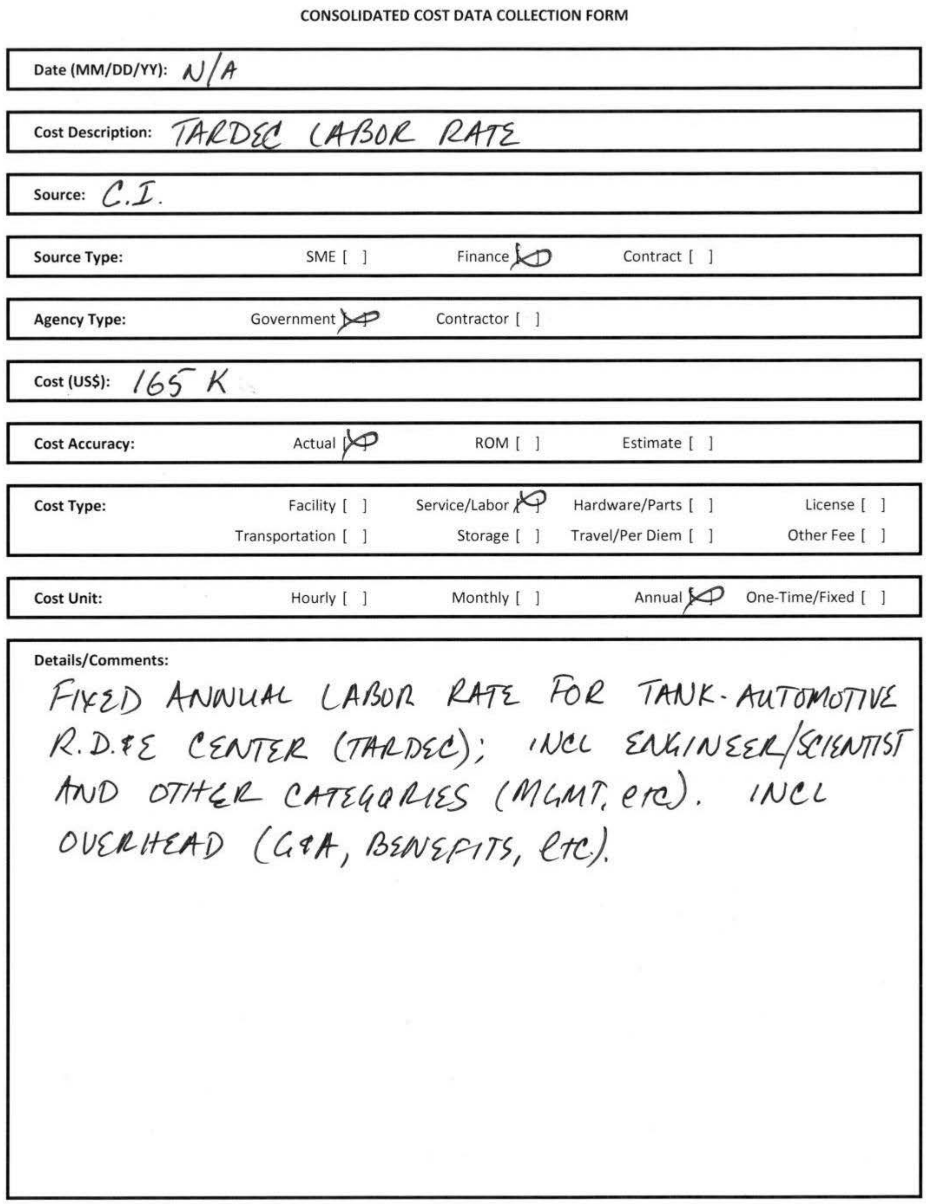
The quote for conducting 3,000 miles of testing on the 4-post shaker was US$ 39,400, which was based on conducting two weeks of accelerated testing. Under normal circumstances, the TMBS facility can conduct 700 miles of testing per week, however, due to scheduling constraints imposed by the program office, the requirement to conduct 3,000 miles was driven by the asset departure date from the TARDEC TMBS facility to move on to physical testing at YPG. Therefore, the TMBS facility operated at twice their normal rate incurring overtime for the engineers and support personnel required to conduct the activity.

The quote provided by TARDEC was a one-time fixed cost as established by the lead SME conducting the activity, and was based on past performance of similar activities for other program offices. Upon briefing the cost of this M&S activity to the program management staff, the activity was approved for execution to support the acquisition activity within the schedule constraints.

During execution of the 3,000 mile shake-down test, five minor issues were found which resulted in design changes to the product: front door latching mechanism, rear door latching mechanism, and three armor mounting provision changes. The changes were incorporated into technical manuals by the logistics staff within the acquisition office as needed to support further physical testing and fielding of the product. While the issues and changes were relatively minor, incorporating these changes during physical testing would be significantly more expensive as they would cause down-time during physical testing at YPG. In the development of the alternate scenario, these delays would potentially cause one-day delays per incident; therefore, up to one week of additional testing on-site at YPG would be required. In addition to the regular testing at

YPG, the labor cost of one additional week of testing at YPG would be US$ 14,457.20 (50% of one Logistician, one dedicated Engineer, and two CONUS FSRs), in addition to range time, travel and hardware costs; for each additional 1-day delay, the daily labor rate for the aforementioned labor categories would be US$ 2,891.44 in addition to the other costs.

The CBA of the TMBS Team's M&S activity vice additional physical testing quickly begins to show the value in risk reduction through using M&S physical simulation to the acquisition program. At near break-even cost with extended physical testing (which would need additional test-fix-test time), any additional failures exhibited during the M&S physical simulation shake-down activity would put the M&S physical simulation shake-down activity significantly ahead of extended physical testing at YPG in the CBA. As the number of failures exhibited during testing cannot be predicted, the value in risk reduction by using physical simulation for this Case Study was clearly evident from the experiment.


CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY): N/A

Cost Description: TARDEC LABOR RATE

Source: C.I.

Source Type: SME [ ] Finance [X] Contract [ ]

Agency Type: Government [X] Contractor [ ]

Cost (US$): 165 K

Cost Accuracy: Actual [X] ROM [ ] Estimate [ ]

Cost Type: Facility [ ] Service/Labor [X] Hardware/Parts [ ] License [ ] Transportation [ ] Storage [ ] Travel/Per Diem [ ] Other Fee [ ]

Cost Unit: Hourly [ ] Monthly [ ] Annual [X] One-Time/Fixed [ ]

Details/Comments:
FIXED ANNUAL LABOR RATE FOR TANK-AUTOMOTIVE R.D.&E CENTER (TARDEC); INCL ENGINEER/SCIENTIST AND OTHER CATEGORIES (MGMT, ETC). INCL OVERHEAD (G&A, BENEFITS, ETC).

Figure 10 - Cost Data for R&D Center Composite Labor Rate

In addition to contractor labor rates (Engineer, Logistics Support, (O)CONUS FSRs), it is important to capture labor rates for acquisition support management and engineering staff. The standard labor rate provided by the R&D Center, which is comparable to acquisition support staff rates, is shown in Figure 10 and is fixed at US$ 165,000 per year; hourly support is not available from this organization, however, partial man-year support can be requested if needed and is calculated as required. This composite rate includes all professional career fields (engineers, scientists, program management staff, and other fields employed by TARDEC) and also includes costs such as General and Administrative (G&A), training, benefits, and other overhead costs.

The figure obtained as the R&D Center composite annual rate was used to determine the fractional Full Time Equivalent (FTE) of various quotes received from R&D Center SMEs for activities performed for Case Studies 1 and 2; 1.0 FTE is equivalent to 2,080 hours, which is one man-year.

CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY):	05/17/2010
Cost Description:	TARDEC SUSPENSION ANALYSIS SME (FY10)
Source:	K.B. / EMAIL 05/17/2010 1613
Source Type:	SME [ ] Finance [X] Contract [ ]
Agency Type:	Government [X] Contractor [ ]
Cost (US$):	50 K
Cost Accuracy:	Actual [X] ROM [ ] Estimate [ ]
Cost Type:	Facility [ ] Service/Labor [X] Hardware/Parts [ ] Software License [X] Transportation [ ] Storage [ ] Travel/Per Diem [ ] Other Fee [X]
Cost Unit:	Hourly [ ] Monthly [ ] Annual [ ] One-Time/Fixed [X]

Details/Comments:

50K total funding to perform analysis of suspension system upgrade activities. + partial funding to be used for software licensing. Potential future labor cost may increase – may need to plus-up at later date.

Figure 11 - Cost Data for R&D Center Suspension Analysis SME Activity

In order to support Case Study 2, R&D SMEs were asked to provide a quote for performing M&S analysis on suspension system upgrades. This activity consisted of performing quarter suspension modeling, study of energy management concerns with the vehicle system, analyzing desired weight characteristics and rightsizing suspension component parts, and providing analysis of alternatives of various suspension component parts to provide the acquisition activity multiple options based on desired performance requirements. Figure 11 shows the cost quote provided by the R&D Center SME to provide the required M&S analysis support to the suspension upgrade activity, which also included collaboration with the Proving Ground SMEs.

While the quote initially indicated that partial funding would be used for software licensing costs, the actual cost of software licensing was provided at a later date and the US$ 50,000 figure was used for labor support. As the R&D Center's composite annual labor rate is US$ 165,000, the labor required to perform the M&S analysis support for Case Study 2 equated to approximately 0.3 FTE (or 630 hours based on 2,080 hours per man-year). The hours requested were for approximately three months of support during which the suspension M&S analysis was to be completed.

Beyond the technical SME activities conducted for Case Study 2, the SME was also tasked with presenting findings to the acquisition activity office, and also to provide technical reports and briefings of the findings. The cost of supporting meetings, preparing and presenting reports, and potential travel costs for collaboration with the Proving Ground SMEs was included in the 0.3 FTE quote, however, details or ROM costs for individual activities was not provided.

CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY): 05/17/2010

Cost Description: ATC SUSPENSION ANALYSIS SME (FY10)

Source: K.B./EMAIL 05/17/2010 1613

Source Type: SME [ ] Finance [X] Contract [ ]

Agency Type: Government [X] Contractor [ ]

Cost (US$): 150 K

Cost Accuracy: Actual [X] ROM [ ] Estimate [ ]

Cost Type: Facility [ ] Service/Labor [X] Hardware/Parts [ ] License [ ] Transportation [ ] Storage [ ] Travel/Per Diem [ ] Other Fee [ ]

Cost Unit: Hourly [ ] Monthly [ ] Annual [ ] One-Time/Fixed [X]

Details/Comments:
Labor cost for ATC SME to support Suspension Analysis activity. (Case Study 2). Inclusive of any external costs (software/licenses/etc); ATC cost model does not charge "customers" for external costs – SME will use tools available in-house to perform analysis, any additional tools will be procured thru overhead. (G&A).

Figure 12 - Cost Data for Proving Ground Suspension Analysis SME Activity

To provide support to Case Study 2, the APG ATC SMEs provided a quote of US$ 150,000 as shown in Figure 12; the cost per man-year for Proving Ground personnel was mentioned as US$ 190,000, therefore the cost for ATC to support the M&S analysis activity for Case Study 2 was computed as approximately 0.8 FTE.

ATC SMEs involvement in this activity was to jointly work with the R&D Center SMEs in analysis the quarter suspension model of the vehicle and supporting the meetings and presentations of reports as required for the acquisition team's decision making process.

In order to develop the quarter suspension model of the vehicle's existing suspension system, both ATC and R&D Center SMEs were required to characterize the components on the vehicle; this required multiple discussions with OEMs. Given the short amount of time that was allotted to perform this work, the SMEs indicated that assumptions of some components' characteristics had to be made due to the unavailability of the information from the OEMs due to IP issues. Additionally, in order to support the M&S activity, a high fidelity model of the suspension system was also created using scanned data, as the complete model was not delivered by the OEM again due to IP rights issues associated with the technical data packages. These added complications drive up the cost of organic M&S without the full support of OEM in conducting analysis of their components.

CONSOLIDATED COST DATA COLLECTION FORM

Date (MM/DD/YY): 06/29/2010

Cost Description: LMS DADS SOFTWARE (DYNAMIC MOTION SIM)

Source: D.G./EMAIL 06/29/2010 0954

Source Type: SME [X] Finance [ ] Contract [ ]

Agency Type: Government [X] Contractor [ ]

Cost (US$): 49.5

Cost Accuracy: Actual [X] ROM [ ] Estimate [ ]

Cost Type: Facility [ ] Service/Labor [ ] Hardware/Parts [ ] Software/License [X] Transportation [ ] Storage [ ] Travel/Per Diem [ ] Other Fee [ ]

Cost Unit: Hourly [ ] Monthly [ ] Annual [ ] One-Time/Fixed [X]

Details/Comments:
Procurement of Dynamic Analysis and Design System (DADS) - used for Suspension System analysis Case Study 2. → Procured from LMS, used by in-house SME's at TARDEC.

Figure 13 - Cost Data for R&D Center Suspension Analysis Software License

The R&D Center provided an additional funding request beyond the initial 0.3 FTE labor hours to procure software licenses for M&S analysis software. Figure 13 shows the software licensing cost associated with acquiring multi-body dynamics virtual prototyping software.

Case Study 1 Findings Summary

The cost of conducting the physical simulation M&S activity was US$ 39,400 as shown in Figure 9 for a two-week 3,000 mile virtual "shake-down" test. To develop the alternate scenario, facts and assumptions are presented as follows:

- Fact: YPG has the ability to conduct 50-miles per 8-hour shift (with additional hours needed for maintenance if required); at the standard pace, this would mean 50 miles per day requiring 60 days of testing to complete 3,000 endurance miles. If two shifts are conducted per day, total test time can be halved; however, the labor costs per day would be doubled. Given that individuals are limited to work only 8-hour days, the number of personnel would need to be doubled to reflect the two-shift work schedule. This also adds to travel, per-diem, and lodging costs. The number of logisticians supporting the test activity remains at one, with 50% tasking, as the acquisition office does not need to provide support during evening hours testing.

- Fact: Five faults were found in the virtual "shake-down" test, therefore the alternate scenario should account for five additional days of testing beyond the base test days.

- Per-diem location cost for YPG is $86 for lodging and $39 for M&IE.

- Assumption: Labor rate for YPG is based on Proving Ground rates (i.e. for driver); therefore, the assumed composite hourly rate of US$ 91.35 is assumed for the additional resource required for testing. As this would be considered an excursion test, additional cost for data collectors is not considered (which would also be computed at the same composite rate).

1	**Off-Site Personnel and Travel Cost Simulator**						
2							
3	# of Days:	60					
4	Work-day (hours)	8					
5							
6	Personnel Labor Costs						
7		# People	Utilization	Rate ($/hr)	Traveling?*	Days Traveling**	
8	Field Service Rep	2	100%	$ 100.84	Yes	60	
9	Engineer	1	100%	$ 111.30	Yes	60	
10	Logistician	1	50%	$ 96.90	No	0	
11	Driver	1	100%	$ 91.35	No	0	
12							
13	Per Diem Calculation						
14		Lodging	M&IE	Total	Airfare***	Car Rental****	
15	Proving Ground	$ 86.00	$ 39.00	$ 125.00	$1,500	$ 25.00	
16							
17	Total Cost Calculations						
18		Labor Hours	Labor Cost	Lodging	M&IE	Airfare	Car Rental
19	FSR Cost	960	$ 96,806.40	$ 10,148.00	$ 4,641.00	$ 3,000.00	$1,500.00
20	Engineer Cost	480	$ 53,424.00	$ 5,074.00	$ 2,320.50	$ 1,500.00	$1,500.00
21	Logistician Cost	240	$ 23,256.00	$ -	$ -	$ -	$ -
22	Driver Cost	480	$ 43,848.00	$ -	$ -	$ -	$ -
23	Sub-totals	2160	$ 217,334.40	$ 15,222.00	$ 6,961.50	$ 4,500.00	$3,000.00
24							
25	Total Cost	$ 247,017.90					
26							
27	Notes (assumptions for purposes of calculation)						
28	* If Yes, per-diem costs will be calculated for this labor category						
29	** Days are calculated based on utilization and Traveling flag						
30	*** Assumes one round-trip ticket per person for duration of stay						
31	**** Daily rate, assumes one shared vehicle per labor category						

Figure 14 - Case Study 1 ROM Cost for 60 Days, Single Shift

Based on the facts and assumptions required for running 3,000 miles of endurance testing at YPG, ROM costs were developed for alternate scenarios to determine the most cost effective staffing and length of activity to successfully complete the test.

If daily workload were to be kept at single shift, 60 days would be required to complete 3,000 miles of endurance testing; during this time, a minimal staff of two FSRs, one Engineer, one Logistician, and one Driver would be necessary, as indicated in **Figure 14**. The total cost of this basic experiment would be US$ 247,017.90.

	A	B	C	D	E	F	G
1	**Off-Site Personnel and Travel Cost Simulator**						
2							
3	# of Days:	30					
4	Work-day (hours)	8					
5							
6	Personnel Labor Costs						
7		# People	Utilization	Rate ($/hr)	Traveling?*	Days Traveling**	
8	Field Service Rep	4	100%	$ 100.84	Yes	30	
9	Engineer	2	100%	$ 111.30	Yes	30	
10	Logistician	1	50%	$ 96.90	No	0	
11	Driver	2	100%	$ 91.35	No	0	
12							
13	Per Diem Calculation						
14		Lodging	M&IE	Total	Airfare***	Car Rental****	
15	Proving Ground	$ 86.00	$ 39.00	$ 125.00	$1,500	$ 25.00	
16							
17	Total Cost Calculations						
18		Labor Hours	Labor Cost	Lodging	M&IE	Airfare	Car Rental
19	FSR Cost	960	$ 96,806.40	$ 9,976.00	$ 4,602.00	$ 6,000.00	$ 750.00
20	Engineer Cost	480	$ 53,424.00	$ 4,988.00	$ 2,301.00	$ 3,000.00	$ 750.00
21	Logistician Cost	120	$ 11,628.00	$ -	$ -	$ -	$ -
22	Driver Cost	480	$ 43,848.00	$ -	$ -	$ -	$ -
23	Sub-totals	2040	$ 205,706.40	$ 14,964.00	$ 6,903.00	$ 9,000.00	$1,500.00
24							
25	Total Cost	$ 238,073.40					
26							
27	Notes (assumptions for purposes of calculation)						
28	* If Yes, per-diem costs will be calculated for this labor category						
29	** Days are calculated based on utilization and Traveling flag						
30	*** Assumes one round-trip ticket per person for duration of stay						
31	**** Daily rate, assumes one shared vehicle per labor category						

Figure 15 - Case Study 1 ROM Cost for 30 Days, Two Shifts

If the same number of endurance miles were to be run with daily workload of double shifts (of eight hours each), 30 days would be required to complete 3,000 miles of endurance testing; during this time, a the staffing would need to be increased to four FSRs, two Engineers, and two Drivers as indicated in Figure 14. As discussed earlier, only one Logistician tasked at 50% would be required as with the previous alternate scenario. The total cost of this experiment would be US$ 238,073.40 as shown in Figure 15.

While the staffing level is increased, the overall duration for the experiment is shorter, with a cost saving realization of US$ 8,944.50; this is primarily from labor, airfare, and car rental costs.

	A	B	C	D	E	F	G
1	**Off-Site Personnel and Travel Cost Simulator**						
2							
3	# of Days:	5					
4	Work-day (hours)	8					
5							
6	Personnel Labor Costs						
7		# People	Utilization	Rate ($/hr)	Traveling?*	Days Traveling**	
8	Field Service Rep	2	100%	$ 100.84	Yes	5	
9	Engineer	1	100%	$ 111.30	Yes	5	
10	Logistician	1	50%	$ 96.90	No	0	
11	Driver	1	100%	$ 91.35	No	0	
12							
13	Per Diem Calculation						
14		Lodging	M&IE	Total	Airfare***	Car Rental****	
15	Proving Ground	$ 86.00	$ 39.00	$ 125.00	$1,500	$ 25.00	
16							
17	Total Cost Calculations						
18		Labor Hours	Labor Cost	Lodging	M&IE	Airfare	Car Rental
19	FSR Cost	80	$ 8,067.20	$ 688.00	$ 351.00	$ 3,000.00	$ 125.00
20	Engineer Cost	40	$ 4,452.00	$ 344.00	$ 175.50	$ 1,500.00	$ 125.00
21	Logistician Cost	20	$ 1,938.00	$ -	$ -	$ -	$ -
22	Driver Cost	40	$ 3,654.00	$ -	$ -	$ -	$ -
23	Sub-totals	180	$ 18,111.20	$ 1,032.00	$ 526.50	$ 4,500.00	$ 250.00
24							
25	Total Cost	$ 24,419.70					
26							
27	Notes (assumptions for purposes of calculation)						
28	* If Yes, per-diem costs will be calculated for this labor category						
29	** Days are calculated based on utilization and Traveling flag						
30	*** Assumes one round-trip ticket per person for duration of stay						
31	**** Daily rate, assumes one shared vehicle per labor category						

Figure 16 - Case Study 1 ROM Cost for 5 Days, Single Shift

As the virtual “shake-down” testing for Case Study 1 resulted in finding five faults, each predicted to cause approximately one day of down time at the Proving Ground; running at single shift, five days of additional testing would cost US$ 24,419.70 as shown in Figure 16.

	A	B	C	D	E	F	G
1	**Off-Site Personnel and Travel Cost Simulator**						
2							
3	# of Days:	2.5					
4	Work-day (hours)	8					
5							
6	Personnel Labor Costs						
7		# People	Utilization	Rate ($/hr)	Traveling?*	Days Traveling**	
8	Field Service Rep	4	100%	$ 100.84	Yes	2	
9	Engineer	2	100%	$ 111.30	Yes	2	
10	Logistician	1	50%	$ 96.90	No	0	
11	Driver	2	100%	$ 91.35	No	0	
12							
13	Per Diem Calculation						
14		Lodging	M&IE	Total	Airfare***	Car Rental****	
15	Proving Ground	$ 86.00	$ 39.00	$ 125.00	$1,500	$ 25.00	
16							
17	Total Cost Calculations						
18		Labor Hours	Labor Cost	Lodging	M&IE	Airfare	Car Rental
19	FSR Cost	80	$ 8,067.20	$ 344.00	$ 234.00	$ 6,000.00	$ 50.00
20	Engineer Cost	40	$ 4,452.00	$ 172.00	$ 117.00	$ 3,000.00	$ 50.00
21	Logistician Cost	10	$ 969.00	$ -	$ -	$ -	$ -
22	Driver Cost	40	$ 3,654.00	$ -	$ -	$ -	$ -
23	Sub-totals	170	$ 17,142.20	$ 516.00	$ 351.00	$ 9,000.00	$ 100.00
24							
25	Total Cost	$ 27,109.20					
26							
27	Notes (assumptions for purposes of calculation)						
28	* If Yes, per-diem costs will be calculated for this labor category						
29	** Days are calculated based on utilization and Traveling flag						
30	*** Assumes one round-trip ticket per person for duration of stay						
31	**** Daily rate, assumes one shared vehicle per labor category						

Figure 17 - Case Study 1 ROM Cost for 2.5 Days, Two Shifts

If fixes are applied at an accelerated pace and testing continues using two shifts for approximately two and a half additional days, the total cost of additional testing with faults fixed would be US$ 27,109.20 as shown in Figure 17.

In comparison, the cost of running 3,000 miles using physical simulation “shake-down” is significantly lower than either alternate scenario of 60 or 30 days of physical, depending on schedule, with additional 5 or 2.5 days of extended testing due to faults.

Table 1 compares the cost of each exercise and it is evident that using the M&S approach prior to the required endurance testing in Case Study 1 was a fraction (approximately 15%) of the cost of the next lowest cost non-M&S approach to testing.

Table 1 - CBA for Case Study 1

	M&S Activity	Alternate Scenario 1	Alternate Scenario 2
Base Test	$ 39,400.00	$ 247,017.90	$ 238,073.40
Additional	$ -	$ 24,419.70	$ 27,109.20
Total Cost	$ 39,400.00	$ 271,437.60	$ 265,182.60

The cost savings delivered to the acquisition activity in Case Study 1 significantly contributed to the overall successful delivery of the product. Within the triple constraint environment, the M&S activity was able to deliver benefits on all three constraints of cost, schedule, and performance. The M&S activity was able to conduct 3,000 miles of physical simulation “shake-down” testing in two weeks, whereas the earliest completion time of testing at the proving ground would require at minimum 30 days with an additional 2.5 days of testing due to faults.

Case Study 2 Findings Summary

There are significant complexities associated with pricing the complete analysis and design phases of the suspension redesign activity. Case Study 2 consisted of several segments of design with multiple organizations working in collaboration within government as well as the OEM community. Cost for organizational support was measured through SME quotes, and hardware procurement and testing costs were priced based on information retrieved from various contracting and cost analysis activities. The following facts and assumptions were established to determine the ROM price of the complete M&S activity, and from which to base the alternate scenario:

- Fact: Virtual prototyping requires high-fidelity models of the vehicle system as well as candidate suspension systems. In collaboration with the vehicle system OEM, the models were provided with restrictions on further distribution; each involved organization was required to sign a non-disclosure agreement (NDA) to ensure proprietary technical information was not released.

- Fact: Multiple organizations collaborated to support the effort; ATC and TARDEC SMEs were involved in conducting the FEA analysis and right-sizing of suspension components based on performance requirements.

- Fact: Quantity three complete suspension systems would need to be procured to conduct 3,000 miles of endurance testing. Cost of suspension system was received as US$ 197,000 per vehicle kit (inclusive of front and rear suspension system and associated subsystems for complete vehicle upgrade).

- Fact: 3,000 miles of endurance testing conducted at APG, with four full-time contract Engineers, four full-time contract FSRs, as well as SMEs supporting the effort. The cost of SMEs was included in the support costs provided by their organizations; ROM costs for endurance testing needs to consider contractor FSR, contractor Engineer, Data Collector and Driver costs. One Logistician (50% utilized), two Drivers and two Data Collectors were used in the experiment for 30-days (two eight hour shifts per day).

- Per-diem location cost for APG is $83 for lodging and $44 for M&IE.

- Assumption: Data Collector and Driver composite hourly rates are based on Proving Ground annual rate; the assumed composite hourly rate for these categories is US$ 91.35.

- Assumption: Alternate scenario was based on multiple acquisitions of various suspension systems with an assumed comparable cost of US$ 200,000 per complete vehicle suspension system. The complexity associated with developing the alternate scenario is that assumptions need to be made that the acquisition office would forego much of the M&S analysis of the suspension system; therefore, it is assumed that three candidate suspensions would be tested to 500 miles each, and the best performing suspension system would be picked. This methodology is in contrast to the M&S approach taken to design and right-size the system, and procuring the final design solution for 3,000 miles of endurance testing.

In order to calculate the total cost of M&S and the associated follow-on test activity, the costs for each activity was viewed separately based on SME costs as described in Chapter 4. The cost for 3,000 miles of testing at APG was developed comparable to Case Study 1, with additional consideration for hardware costs and increased support personnel.

	A	B	C	D	E	F	G
1	**Off-Site Personnel and Travel Cost Simulator**						
2							
3	# of Days:	30					
4	Work-day (hours)	8					
5							
6	Personnel Labor Costs						
7		# People	Utilization	Rate ($/hr)	Traveling?*	Days Traveling**	
8	Field Service Rep	4	100%	$ 100.84	Yes	30	
9	Engineer	4	100%	$ 111.30	Yes	30	
10	Logistician	1	50%	$ 96.90	No	0	
11	Data Collector	2	100%	$ 91.35	No	0	
12	Driver	2	100%	$ 91.35	No	0	
13							
14	Per Diem Calculation						
15		Lodging	M&IE	Total	Airfare***	Car Rental****	
16	Proving Ground	$ 83.00	$ 44.00	$ 127.00	$1,500	$ 25.00	
17							
18	Total Labor and Travel Costs						
19		Labor Hours	Labor Cost	Lodging	M&IE	Airfare	Car Rental
20	FSR Cost	960	$ 96,806.40	$ 9,628.00	$ 5,192.00	$ 6,000.00	$ 750.00
21	Engineer Cost	960	$ 106,848.00	$ 9,628.00	$ 5,192.00	$ 6,000.00	$ 750.00
22	Logistician Cost	120	$ 11,628.00	$ -	$ -	$ -	$ -
23	Data Collector Cost	480	$ 43,848.00	$ -	$ -	$ -	$ -
24	Driver Cost	480	$ 43,848.00	$ -	$ -	$ -	$ -
25	Sub-totals	3000	$ 302,978.40	$ 19,256.00	$ 10,384.00	$ 12,000.00	$1,500.00
26							
27	Total Hardware Costs						
28		Unit Cost	Quanitity				
29	Suspension Kits	$ 197,000.00	3	$ 591,000.00			
30							
31							
32	Total Cost	$ 937,118.40					
33							
34	Notes (assumptions for purposes of calculation)						
35	* If Yes, per-diem costs will be calculated for this labor category						
36	** Days are calculated based on utilization and Traveling flag						
37	*** Assumes one round-trip ticket per person for duration of stay						
38	**** Daily rate, assumes one shared vehicle per labor category						

Figure 18 - Case Study 2 ROM for 3,000 Miles Endurance Testing

By using a similar calculation methodology as Case Study 1 for assessing the field testing cost of the suspension development activity, a ROM was developed for conducting 3,000 miles of endurance testing at APG. As shown in Figure 18, the total cost of running endurance miles over 30 days, including the hardware necessary to support the testing, was calculated at US$ 937,118.40. This cost is in addition to the SME costs, which were provided by the individual support activities.

The total cost of the Case Study 2 activity in which M&S was utilized to analyze and design the suspension system, the cost of TARDEC SME support, additional software, ATC SME support, and the additional endurance mileage testing was aggregated in a table:

Table 2 - Total M&S Cost for Case Study 2

	Activity Cost	
Prototype/Design/Analysis		
→TARDEC SME	$	50,000.00
→Software	$	49,500.00
→ATC SME	$	150,000.00
Endurance Testing	$	937,118.40
Total Cost	$	1,186,618.40

As summarized in Table 2, the total cost of the design effort was approximated at US$ 1.2M. In order to compare this cost to the alternate scenario in which M&S is not used, individual costs of items identified prior as facts and assumptions need to be tabulated.

Based on the aforementioned facts and assumptions, the alternate scenario was created around a "brute force" design process in which three acceptable suspension system solutions are picked for application and prototypes are tested for 500 miles each. This would require the procurement of one prototype system for each of the three suspension system candidates (at approximately US$ 200,000 for each vehicle hardware kit). The total prototype testing would result in 1,500 miles during which the performance of each system would be assessed. This scenario would require similar staffing levels as endurance testing, therefore four FSRs, four Engineers, one Logistician, two Data Collectors, and two Drivers were assumed in the development of the ROM.

	A	B	C	D	E	F	G
1	**Off-Site Personnel and Travel Cost Simulator**						
2							
3	# of Days:	15					
4	Work-day (hours)	8					
5							
6	Personnel Labor Costs						
7		# People	Utilization	Rate ($/hr)	Traveling?*	Days Traveling**	
8	Field Service Rep	4	100%	$ 100.84	Yes	15	
9	Engineer	4	100%	$ 111.30	Yes	15	
10	Logistician	1	50%	$ 96.90	No	0	
11	Data Collector	2	100%	$ 91.35	No	0	
12	Driver	2	100%	$ 91.35	No	0	
13							
14	Per Diem Calculation						
15		Lodging	M&IE	Total	Airfare***	Car Rental****	
16	Proving Ground	$ 83.00	$ 44.00	$ 127.00	$1,500	$ 25.00	
17							
18	Total Labor and Travel Costs						
19		Labor Hours	Labor Cost	Lodging	M&IE	Airfare	Car Rental
20	FSR Cost	480	$ 48,403.20	$ 4,648.00	$ 2,552.00	$ 6,000.00	$ 375.00
21	Engineer Cost	480	$ 53,424.00	$ 4,648.00	$ 2,552.00	$ 6,000.00	$ 375.00
22	Logistician Cost	60	$ 5,814.00	$ -	$ -	$ -	$ -
23	Data Collector Cos	240	$ 21,924.00	$ -	$ -	$ -	$ -
24	Driver Cost	240	$ 21,924.00	$ -	$ -	$ -	$ -
25	Sub-totals	1500	$ 151,489.20	$ 9,296.00	$ 5,104.00	$ 12,000.00	$ 750.00
26							
27	Total Hardware Costs						
28		Unit Cost	Quanitity				
29	Suspension Kits	$ 200,000.00	3	$ 600,000.00			
30							
31							
32	Total Cost	$ 778,639.20					
33							
34	Notes (assumptions for purposes of calculation)						
35	* If Yes, per-diem costs will be calculated for this labor category						
36	** Days are calculated based on utilization and Traveling flag						
37	*** Assumes one round-trip ticket per person for duration of stay						
38	**** Daily rate, assumes one shared vehicle per labor category						

Figure 19 - Case Study 2 ROM for 1,500 Miles Prototype Testing (3 Suspension Kits)

Prototype hardware testing for 500 miles for each suspension system kit, summarized as 1,500 miles of testing for three suspension kits, costs approximately US$ 778,639.20. This would be analogous to the design and analysis effort for Case Study 2 prior to running 3,000 miles of endurance testing after a final design solution is selected. Therefore, in addition to the costs identified in Figure 19, the resulting design solution suspension system would need to be procured for endurance testing; this cost would be comparable to the US$ 937k as computed in Figure 18.

The total cost of the alternate scenario would be the 1,500 miles prototype testing effort plus the additional 3,000 miles endurance testing of the final solution; the total cost is approximated to be US$ 1.7M.

Table 3 - CBA for Case Study 2

	M&S Activity		Alternate Scenario	
Prototype/Design/Analysis	$	249,500.00	$	778,369.20
Endurance Testing	$	937,118.40	$	937,118.40
Total Cost	$	1,186,618.40	$	1,715,487.60

As shown in Table 3, the use of M&S for the prototype/design/analysis phase of Case Study 2 resulted in lower overall activity cost. While the cost-only analysis shows savings, it is prudent to review the impact to schedule and performance:

- The M&S activity prior to endurance testing lasted approximately two months, whereas the prototype testing in the alternate scenario was schedule for 15 days.
- The brute force approach to picking three suitable suspension systems for test, without further optimization, would result in an imperfect solution that may or may not meet the performance requirements set forth by the acquisition activity.

Within triple constraints of cost, schedule, and performance, the application of M&S in Case Study 2 provided a better value overall in terms of cost and performance; while schedule was longer for the M&S activity, the overall benefit to the acquisition activity was higher.

Case Study 3 Findings Summary

Case Study 3 presented significant challenges in developing ROMs and alternate scenarios; the current process does not utilize M&S for blast testing, therefore the base scenario represents the as-is process which approximates the cost of destructively testing one complete vehicle. In addition to reviewing the cost of destructive testing, costs of current M&S activities that may contribute to the field in the future are examined, as well as other destructive testing scenarios for ballistics testing on disposed assets.

	A	B	C	D	E
1	**Armor Testing Cost Simulator**				
2					
3	# of Days:	10			
4	Work-day (hours)	8			
5					
6	Personnel Labor Costs				
7		# People	Utilization	Rate ($/hr)	
8	Support Staff	10	100%	$ 91.35	
9					
10	Total Hardware Costs				
11		Unit Cost	Quanitity		
12	Coupons or Hulk*	$ 750,000.00	1	$ 750,000.00	
13	^ Transportation	$ 20,000.00	1	$ 20,000.00	
14	Sub-totals			$ 770,000.00	
15					
16	Total Labor Cost Calculations				
17		Labor Hours	Labor Cost		
18	SME Cost	800	$ 73,080.00		
19					
20	Total Cost	$ 843,080.00			
21					
22	Notes (assumptions for purposes of calculation)				
23	* If Hulk, use capitalized vehicle/hulk cost (as if testing new), set qty. to 1				
24	Transportation qty. for hulk should also be set to 1				

Figure 20 - Case Study 3 ROM for Destructive Testing Vehicle

The rule-of-thumb within the SME community for destructively testing a vehicle has generally been discussed as being approximately US$ 1M per blast event. In order to gain fidelity on the breakdown of costs per blast event, SMEs provided insight into the hardware and labor required to perform the test. While there are additional costs associated with conducting a blast event, such as potential travel cost for SMEs to witness events, the major cost drivers were determined to be the cost of the vehicle or hulk under test, and labor cost of personnel supporting the event. Additionally, in preparation for blast events, approximately 10 SMEs support the activity at any given time: the functions of these SMEs can range from test director, instrumentation engineer, data collectors, range specialists, etc. as needed to prepare and execute the test event. This again is a ROM figure that may change from test to test; however, given the short duration of the test, the cost of personnel is again small compared to the actual hardware cost. At the macro level, the cost of the vehicle far outweighs any other cost associated with conducting a destructive test event; therefore as a ROM cost, one could conceivably use the cost of the vehicle as the basis for the cost of conducting a blast test with a margin for labor cost.

The approximate cost of the vehicle blast event analyzed for Case Study 3 was approximately US$ 750,000 (procurement cost from OEM) without any integrated products (mission equipment, etc). If this vehicle alone were being testing, the cost of labor was calculated at approximately US$ 73,080.00 in addition to the base vehicle in addition to approximately US$ 20,000 in transportation costs to move the asset to the test location. If the vehicle were to be fully integrated with mission equipment, the cost could easily double per feedback received from SMEs. It is apparent from viewing the costs associated with destructively testing one single vehicle why there are significant R&D efforts aimed at improving the fidelity of blast M&S; prior to fielding any vehicle or any major component change to a vehicle, such as internal layout or armor changes, multiple blast tests are conducted which drive the overall cost of testing to multiple millions of dollars.

While acquisition programs rely heavily on blast testing, feedback received from SMEs when gathering data for Case Study 3 suggests that techniques and methodologies currently used in destructive testing are not necessarily fully developed; there is significant room for improvement in the repeatability of destructive tests and significant resources are being applied towards R&D to develop enhanced techniques which minimize variance in test results. For example, minor changes to soil compaction and environmental effects can significantly alter the results of a destructive test where all other parameters are held constant (vehicle configuration, test charge location, etc.); the efforts within the R&D and test communities to date have yet to produce a standard methodology that minimizes variance.

Data collected from SMEs suggest that some R&D agencies are spending upwards of US$ 7-10M per year to improve the fidelity of M&S techniques for predictive blast modeling; this is in addition to the significant computing hardware and software resources, collaborative efforts, and cost of Industry and Academic engagements to bring best of breed capabilities to the field. In comparison to the number of physical blast test events which are conducted prior to acquiring or fielding new vehicle systems, the initial investment costs may eventually be recouped when the fidelity of M&S reaches a point where V&V of the tools can occur; the paradox of this situation being that repeatability of destructive tests has yet to be perfected.

An area where fidelity of both destructive testing and M&S are significantly higher is that of ballistic coupon testing. Techniques used for ballistic testing of coupons have significantly matured over the past decades and modern methods provide significant repeatability and reliability of results gained from such tests; the chambers in which these tests are conducted provide for stable and controlled environments, with the material properties of the coupons being held constant along with the characteristics of the ballistic projectile (speed, distance, etc.). As such, there is significant historic data available from which the R&D community has been able to develop their models to closely match the results seen from physical destructive tests. Software has been developed to incorporate advanced FEA techniques, soil mechanics, and fluid dynamics, which take into consideration significant level of detail of material properties, threat characteristics, and environmental factors, to produce results that are reliable when compared with physical test results.

The major cost drivers for both vehicle-level and coupon-level ballistic M&S are personnel labor, computing hardware/software, high fidelity models of the system under test, and the V&V process which oftentimes requires physical destructive testing when well-documented historic data for comparison is unavailable. A repeat frustration of SMEs discussed during data collection for Case Study 3 has been the availability of high fidelity vehicle-level models which have not been acquired by the R&D agencies; vehicle OEMs are reluctant to provide detailed CAD models due to IP concerns, and reverse engineering of complete vehicle systems produces crude models since full material properties and exact dimensions may not be known. While reverse engineering of vehicle systems may provide crude models, the process can cost in excess of US$ 250,000 as suggested by one SME; the product of this process may not necessarily produce models which are useable for high-fidelity M&S exercises such as blast M&S, and are better suitable for M&S activities relating to space claim studies and virtual prototyping. There is, however, significant availability of high fidelity coupon-level models, since the primary data of concern is thickness and material properties (with shape being fixed square or rectangle of a defined size); this has resulted in significant improvements in the ability of M&S to produce results comparable to physical destructive ballistic tests of coupons.

Costs of running coupon-level physical destructive test experiments range from US$ 25,000 for short defined tests (for example, on a single piece of armor with a well defined set of threats), and increases as the complexity of test grows; if dedicated personnel or resources are required for testing, then the cost would increase accordingly. Similarly, SMEs suggested that if

M&S experimentation were to be utilized for comparable testing, the costs would be similar for the level of effort; this suggests that if an acquisition activity were to require significant coupon-level testing, then M&S may provide an additional or alternate mechanism which could provide reliable results. The CBA for coupon-level M&S vice physical destructive testing shows that costs are comparable.

CHAPTER FIVE: CONCLUSION

The premise of this research indicated that M&S should be viewed comparable to other PI initiatives when applied to acquisition program environments operating within triple constraints of cost, schedule, and performance. When viewed as a PI initiative, comparisons can be made to how VE, LSS, and other initiatives quantify their CBA based on as-is, as-applied, and alternate scenarios; while objective metrics can show cost savings and benefits, subjective reasoning and understanding of the PI initiative can help qualify the intangible benefits and savings which could potentially be realized through application of the PI initiative. The Case Studies reviewed as part of this research, and the associated data that has been gathered and presented, indicate that M&S can play a vital role in delivering benefits to acquisition activities operating within triple constraints; much like other PI initiatives, there exist perception issues and the knowledge base may not necessarily exist within programmatic environments to fully comprehend the application of M&S, and therefore it is incumbent upon SMEs to provide their expertise in the implementation and execution of activities involving M&S.

As shown in Case Studies 1 and 2, significant cost savings were delivered to acquisition programs through the appropriate application of M&S in critical areas requiring design, analysis, and testing prior to procurement and fielding of hardware. The intangible benefits of conducting the M&S analysis activities, such as FEA to understand limits and weaknesses of various components, have also potentially delivered significant intangible benefits of reduced future failures and repairs; while the cost savings of these intangible benefits cannot be quantified, they can be presented comparable to other PI initiatives as discussed. An additional intangible benefit of the application of M&S in Case Studies 1 and 2, which is significantly more difficult to measure, is the change in perception of M&S by programmatic staff; while initially hesitant to apply M&S techniques, the results and benefits gained by utilizing SMEs to conduct the activities improved the perception of M&S within the acquisition activity. As indicated briefly in the introduction and further in the literature review, cultural change and acceptance when implementing any PI initiative is slow and tedious, and the application and use of M&S within acquisition environments is not an exception to this trend; future use of M&S within the organizations from which the Case Studies were derived would need to be closely monitored for future activity, similar to how other PI initiatives such DMAIC prescribes in the "control" phase.

Case Study 3 presented significant challenges where neither the as-is scenario of utilizing destructive testing, nor the alternate scenario of M&S application, has produced results of significant fidelity which could be comparable. As such, the RDT&E community has relied solely on destructive blast testing as the best-available current methodology for testing products, while continuing to mature the techniques to provide increased repeatability; concurrently, the R&D community has continued to improve the M&S techniques to increase fidelity and provide comparable results. As discussed in the findings, while vehicle-level blast M&S is still relatively immature and unable to undergo VV&A, in addition to the lack of repeatability of physical test events, the field of coupon-level M&S is significantly more mature. The CBA for Case Study 3 shows that until a time where vehicle-level blast M&S is matured and validated against repeatable destructive blast tests, there will need to be significant R&D and resources invested by organizations to increase the fidelity of these techniques to make them more matured, and in the meantime there cannot be a reliance on M&S alone to answer questions related to blast testing. While M&S in this field provides a good comparison point, it does not provide conclusive and verified results from which designs could be safely fielded to users.

In each of the case studies, the establishment of the methodology of viewing M&S as a PI initiative and conducting CBA as has been done in similar fields proved to be a favorable mechanism through which to study the impacts of M&S on the acquisition activity. While the methodologies of different PI initiatives are vastly diverse (for example, Lean may improve business processes while LSS improves manufacturing quality), the overall measurement technique of conducting CBA on as-is/applied and alternate scenarios indicates that M&S can indeed be viewed as a macro level PI initiative which could potentially provide cost, schedule, and performance benefits depending on how and where in the acquisition value stream it is applied.

While the two case studies reviewed for this research which yielded favorable CBA were in well controlled environments and executed by experienced SMEs, it is important to note that there may be many instances where the application of M&S may not yield a favorable CBA. Again, viewing M&S as a PI initiative, there may be instances where there is nothing to improve through the application of M&S in the value stream, and therefore it may not be required; and there may be instances where such application could indeed yield negative results. As such, it is critical for the CBA to be conducted by acquisition staff in an objective manner without a bias either for or against the application of M&S. In addition to conducting the CBA, there also needs to be critical assessment of the "right sized" application of M&S; questions regarding the fidelity of the models required, the level of effort necessary to gain acceptable results, etc., need to be discussed and answered objectively to ensure that the application can fit within triple constraints and that risks associated with each constraint are quantified.

Additional conclusions from this research suggests that, at the macro level, the field of M&S management continues to provide significant challenges and opportunities which requires practitioners in the field of M&S to continue to educate peers as well as counterparts in acquisition environments. Similar to other PI initiatives, these are common issues that require additional research and future work to improve.

In conclusion of this research, the following sections present some of the lessons learned while conducting this study, a critical review of limitations and shortcomings, and suggestions of potential future work in this field.

Lessons Learned

Several lessons were learned while conducting this research activity which could help potential future work in this area. The limited amount of work done in the area of applied M&S within acquisition environments presents a relatively large field for new and future work, however, due to this being a relatively new field, there is a significant lack of historic data and sparse research publications. As evident in the Findings section of this research, much of the data collected has been from SME sources and requesting information from various cost and procurement analysts; if this activity were to be repeated in the future, additional level of detail would be recommended through further investigations into cost structures and models. This may be significantly more difficult as the formant of cost information, as currently collected, is not conducive to break-outs by M&S specific activities; additional case studies could have potentially been studies, however, there was again a lack of availability of information from which to base conclusive results. Therefore, the case studies reviewed for this research were the ones where concrete data could be obtained for defined M&S activities, and from which reasonable alternate scenarios could be developed for CBA comparisons as has been recommended by PI practitioners as indicated in the literature review.

IP concerns, while initially thought to be a minor issue, did indeed prove out to present significant challenges; particularly in Case Study 3, where detailed models would be required by organizations to conduct M&S analysis, the lack of high fidelity models due to IP issues was a recurrent theme within multiple organizations. While IP and legal concerns present a set of challenges, SMEs must also content with the significant cost procurement of high fidelity models either through direct purchase from the OEM or through reverse engineering; neither of these options prove viable from either a cost or schedule standpoint, and a reverse engineered model does not provide the desired level of performance.

In addition to reviewing the as-is/applied scenarios, the development of alternate scenarios provided challenges as they present hypothetical "what-if" applications; while the development of alternate scenarios is common with other PI initiatives in conducting CBA, the development of alternate scenarios for M&S application required diligence and input from SMEs to ensure realistic and achievable scenarios were developed. It was critical to rely on historic information from various test sites as well as SME input on past performance when developing these alternate scenarios, most of which are based on similar tests conducted in the past. As such, it is critical to ensure that SMEs are consulted when creating alternate scenarios and conducting CBA to build the case of M&S as a PI initiative.

One of the significant findings, as discussed earlier, was that not all situations may require M&S support and that there are numerous instances where M&S could be a detractor to one or more of the triple constraints within the acquisition environment. This again points to the necessity of working with SMEs to ensure the appropriate level and application of M&S is being considered in programmatic environments, and that objective analysis is done prior to application. This again is a common trait with other PI initiatives; for example, there are business environment processes which do not necessarily benefit from further application of Lean techniques and as sufficient as-is, and therefore there is no need to further push PI initiatives on those processes.

Simplification of Cost Estimation

While having fidelity in the cost data was important for this research study, it was observed that there could be significant simplification of cost estimation based on previous experiments. For Case Study 1, where the facility had conducted numerous such studies in the past, it would have been appropriate to use ROM costs on condition that there was sufficient understanding of what costs were factored in the ROM estimate. While oversimplification of costs could raise issues, as discussed in the following Limitations and Shortcomings sections, an appropriate level of simplification of costs from known entities with proven track records would be acceptable in environments where there is a general understanding of M&S capabilities and what its contributions to the acquisition activity would be.

The two major cost factors observed in Case Studies 1 and 2 were manpower and hardware (or facility) costs. The easiest way to simplify cost estimation of M&S activities would be to determine what the reasonable timeline for the project would be, and then calculate the cost of manpower (accounting for number of personnel, overtime, etc.) and the various hardware or facilities charges associated with that timeline. This could clearly be done for the first two case studies where the SMEs had a good understanding of what tasks needed to be accomplished in order to provide the level of M&S support to the acquisition activity. It is significantly more difficult to provide any simplification of cost estimation for Case Study 3 as the activity remains nebulous with no established dates for milestones; in activities which are heavily dependent on maturity of technology during the course of execution, there are significant risks from “unknown unknowns" which could significantly impact cost, schedule, and performance, therefore there is no easy way to simplify the cost; most of these activities remain within the R&D community and are not mature to a point of being used by acquisition environments, therefore the closest simplification of assessing cost of these activities would be by assessing the amount of personnel resources (man-years), hardware/software licensing costs, destructive testing costs for V&V, and other high level costs which could be calculated with low fidelity. These ROM estimates for activities such as Case Study 3 could be used to determine how much is being spent to bring the technology to a level of maturity that is eventually usable by an acquisition environment.

In addition to simplifying the cost estimation method for M&S activities, the same technique could be used to calculate the cost of alternate scenarios where M&S is not used; for example, Case Studies 1 and 2 had clear alternate scenarios where one could determine the resources which would be needed to accomplish the tasks without M&S. Using the information collected on the cost consolidated data forms, one could estimate the cost of various types of personnel, travel expenses, etc. that would be necessary to accomplish test activities defined in the alternate scenarios (i.e. 10 days of testing involving three FSRs and two engineers at APG). The spreadsheet tables developed for this study, "Test Activity Cost Approximation" and "Off-Site Personnel and Travel Cost Approximation," aimed to provide simplified cost estimation tools for these activities by capturing the major cost drivers; when compared with historic test activities of similar scope, these ROM estimates provided by these tools proved to be relatively accurate and could be used to provide reasonable estimates of costs.

For macro budgeting purposes within acquisition environments, ROM estimates for M&S activities as well as alternate scenarios can prove to be useful tools in decision making. The caveat to this is the level of understanding of M&S by the programmatic staff; in the event that most decision makers understand the technical capabilities of the M&S activity being proposed, it is sufficient to use ROM estimates to show comparison of M&S costs vice alternate scenarios. However, if there is limited understanding of M&S, the acceptability of ROM estimates for M&S activities will be low. This is further discussed in the limitations and shortcomings section of this research, with the general recommendation that ROM estimates be used in environments where there is understanding of the technical merits M&S, else there should be detailed cost breakdowns of M&S activities beyond what the simplified cost estimation tools can provide.

While the ROM estimates provided by cost estimation tools can be used for decision making as to whether or not M&S should be utilized in various scenarios, there needs to be management of expectations within the decision making bodies as to what is being provided for the cost; this again leads to the discussion of the appropriate level of M&S application towards various scenarios, and what the "right" level of application should be.

Limitations and Shortcomings

The initial literature review revealed that while some work has been done in the field of studying applied M&S in acquisition environments, there has not been any concerted effort to trace cost information and quantify the benefits of M&S in triple constraint environments. Quantification of costs required this research activity to devise cost data collection mechanisms that would holistically capture cost elements, such as personnel or hardware costs, and provide that information in a consolidated manner which would allow for comparison across multiple cost categories and be conducive to calculating overall cost of M&S activities. As such, a rudimentary data collection mechanism was established which limited the type of cost information to the domain of the case studies associated with this research.

While the consolidated cost data collection form was sufficient for the case studies, it has limited use in wider domains as there may be additional cost centers that need to be accounted for. If the research activity were to be expanded to include multiple programs and M&S activities, a more comprehensive cost data collection form or tool could be devised to capture the cost information. This opens the door for potential interactive applications that would allow for the research to dynamically add cost categories and varying data categories which could then provide a better understanding of the M&S activity's costs.

Another challenge which contributed to the limitations and shortcomings of this research was the availability of cost data itself; while some cost information, such as personnel hourly costs, travel expenses, etc. are easily available through well documented sources (published contracts, finance documents, etc.), there remained certain items for which cost information was unavailable or at best estimated. ROM costs without further breakdowns received from organizations for M&S activities make it difficult to establish what the funding would be used for, or whether or not the actual cost of M&S activities was being presented to the organization. An example of this is in Case Study 1 where ROM estimates were provided to the program office for executing the physical simulation "shake-down" activity; clarifications of ROMs required significant time and effort to break down the cost of the simulation activity. Use of ROM costs without further clarifications, while appropriate for approximately budgeting, does not provide the appropriate level of detail necessary to provide full justification for application of M&S to acquisition activities. Furthermore, while SMEs may understand the inherent costs associated with the M&S activity, programmatic staff receiving ROM estimates may not fully appreciate the capability being provided and this could potentially be a detractor to M&S in instances where it is appropriate.

Behavioral factors, such as unwillingness to discuss cost structures, or inherent aversion to M&S due to negative past experiences or unfamiliarity with the technology, also proved to contribute to limitations and shortcomings of this research. Significant time was spent convincing individuals to discuss M&S topics or to advise on the application of M&S where it provided clear benefits; almost all individuals exhibiting frustration with M&S application had negative experiences with other acquisition programs where M&S was misused or over-used, in which case the triple constraints of the program were negatively impacted. Instances where individuals experienced M&S activities overrunning costs or schedule detracted those individuals from approaching SMEs in the future. While this research activity focused on cost data collection and comparison for the case studies presented, the behavioral factors observed during the course of data collection did indeed contribute to the limitation or shortcoming which could provide opportunities in the future for further study; it would be interesting to conduct future research in the area of perception of M&S within various environments (acquisition/programmatic, SME, R&D, etc.). While not measured for this research, there appeared to be a correlation between the behavioral factors (attitudes or perception towards M&S) and the level of familiarity with M&S and the technical subject matter. Programmatic staff with little or no engineering background expressed the most concern with M&S, whereas staff with engineering and scientific backgrounds were more open to the idea of using M&S for problem solving within the acquisition environment – again, Case Study 1 and 2 where M&S was used for practical problem solving within the triple constraint environment was where these factors were primarily observed. Case Study 3 was in the realm of R&D and most individuals associated with the program had a high level of understanding of M&S, therefore the behavioral factors were not observed to be an issue.

These limitations and shortcomings provide significant opportunities for future work and research in these areas to improve data collection, identify additional data sources, and also in the realm of studying the perception of M&S within various environments. While these limitations did not significantly constrain the data collected or analyzed for this study, having a better understanding of these limitations would improve the fidelity of results.

Future Work

There are significant opportunities for additional research contributions to the area of Simulation Management and its application to defense acquisition within the triple constraints of cost, schedule, and performance. The limited results of the literature review reveals that the subject has not been studied in depth and that significant shortcomings exist in the understanding of M&S applications in programmatic environments: the spectrum ranges from no application of M&S in certain instances, to over-reliance on M&S to a point which is unfeasible, thereby violating the metrics of cost or schedule.

To address potential future work in this field, the limitations and shortcomings in data collection can be addressed, which would result in significantly better understanding of the holistic costs associated with programmatic activities: a better method for determining the full cost of experimentation at proving grounds could help reveal the true costs of testing to acquisition activities. One of the limitations in gathering such cost information is the unavailability or inaccessibility of data associated with external testing agencies. Funding of test activities seldom captures full test costs, much of which are sunk costs already paid by other agencies to ensure the availability of facilities, personnel, hardware, etc. needed to ensure availability of the test sites.

For purposes of this research activity, costs were captured from various sources and consolidated on data sheets pertinent to the case studies presented. A holistic study of the various data sources and a better data collection tool would significantly improve the verbosity of the data and provide a better picture of cost information. For example, instead of using the forms designed for this study, if a generic cost data collection tool is created to allow capturing of wide array of cost information apart from what is currently captured, it would allow for greater fidelity in calculating the overall cost of activities. Such a tool could be implemented in an interactive spreadsheet that could allow the data collector to enter additional information based on current entry; for example, if the type of cost data being collected is associated with software licensing, the tool could potentially ask further questions or clarifications on how license costs as calculated, either by seat, or user, etc. When this data is used to compute the cost of the overall M&S activity, the higher fidelity cost information could provide more accurate total costs.

As described in the case studies, several challenges exist for M&S application in each instance; while the first two case studies presented minimal M&S challenges, the third Case Study in which M&S was being used as a tool to predict blast results provided significant technical and programmatic challenges. From a technical standpoint, the technology currently cannot be relied upon to provide accurate results which can be reasonably repeated in physical tests. The test community heavily relies on physical destructive testing to ensure safety of vehicle systems for which M&S cannot provide accurate predictions: compounding this issue is the fact that no two physical blast events, however comparable, can provide identical results from test to test. There are significant efforts within the defense test community to devise repeatable blast test methodologies; while the vehicle/system level designs can be held constant, the environmental and soil factors associated with these tests need to be better understood and significant resources are being devoted to studying these effects. There exists great potential for future work in this area, and the ability to provide a repeatable physical destructive/blast methodology will significantly enhance and complement the advances in M&S techniques currently available to study these events. V&V of M&S for blast environments will become an approachable subject once repeatability is established in the physical testing realm.

There are significant opportunities for future work in establishing repeatability of destructive physical blast testing and V&V of M&S tools. This presents opportunities for advancement individually in the physical testing realm, through which better test methodologies can be developed, as well as with M&S toolsets through increasing maturity and fidelity of capabilities. Several strategies have been suggested for bridging the gap between physical and virtual blast testing, and while the inherent variable nature of blat testing ensures that no two tests will be identical, certain techniques can be utilized to increase repeatability; among these techniques are studies of soil density and compaction, environmental effects, type/size/placement of charges, etc. all of which, if difference, can substantially alter the results of tests. Additional research needs to be conducted in this area to ensure sound test protocols are developed that increase repeatability. Concurrently, results of blast M&S tools can be compared to results obtained during the development of repeatable destructive test events; the integration of these two activities provides significant opportunities for research and future work in this area.

In reviewing the conclusions drawn from this research, it is evident that basic understanding of M&S is still lacking in many programmatic environments which allows for opportunities to increase the level of M&S education among non-engineering program staff. While the consolidated data collection sheets do not capture the various discussions with staff during the data collection process, it was quite evident from discussions during data collection that there was significant misunderstanding of the capabilities, application, and results of M&S activities, particularly in the first two case studies; these case studies followed the actual application of M&S in triple-constraint environments and therefore programmatic staff were aware of its use. This allows for opportunities to enhance the level of understanding of M&S, more importantly, the appropriate application of capabilities or the concept of “right model” based on programmatic requirements. While high fidelity models may be desired to obtain the most accurate results for various M&S activities, the ability to provide a “good enough” answer through using lower fidelity and more cost effective tools may be a more palatable option given the constraints of cost, schedule, and performance. The level of understanding of M&S capabilities within the programmatic environment significantly effects the choice of which M&S capabilities are used, if any, and increasing this level of understanding within programmatic environments could help in the decision making process.

In Conclusion

This research indicates that there is significant work to be done in the field of applied M&S and Simulation Management, and that there is significant room for research and future work in this field. The conclusions from this study show that the appropriate application of M&S can indeed provide significant cost savings and benefits in triple constraint programmatic environments, however, there are certain M&S activities which are still immature and will require additional work before contributing favorably to acquisition programs; of the case studies reviewed for this research, the field of blast M&S requires significant development before its results will be accepted in lieu of physical destructive testing. Increasing the level of understanding of M&S within acquisition programs can significantly improve both the perception and value through utilization of M&S tools. While the execution of M&S activities remains firmly planted within the technical SME, R&D, and training communities, enhancing the macro understanding of these capabilities from a high level technical and financial standpoint within programmatic communities can significantly increase the utilization of M&S in acquisition programs.

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