



FirePoint Report No. FP2020-C1-01

CPO 1 Summary Closeout Report

- **Certification Requirements for Multicore Processors**
- **Science of Sustainment**
- **Architecting Complex Cyber-Physical Systems**

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Abbreviations and Acronyms

AMACC	Army Military Airworthiness Certification Criteria
AvMC	U.S. Army Aviation & Missile Center
CAS	Comprehensive Architecture Strategy
CAST	Certification Authorities Software Team
COI	Community of Interest
COTS	Commercial Off the Shelf
CPO	Collaborative Project Order
CPU	Central Processing Unit
DEVCOM	Combat Capabilities Development Command
DoDAF	Department of Defense Architecture Frameworks
DOORS	Dynamic Object-Oriented Requirements System
DOT	Department of Transportation
DOTMLPF-P	Doctrine, Organization, Training, Material, Leadership, Personnel, Facilities, and Policy
DTIC	Defense Technical Information Center
EASA	European Union Aviation Safety Agency
FAA	Federal Aviation Administration
FACE	Future Airborne Capability Environment
FPGA	Field Programmable Gate Array
FVL	Future Vertical Lift
GPU	Graphics Processing Unit
IMS	Integrated Mission Systems
IP	Intellectual Property
KBD	Key Business Drivers
KPP	Key Performance Parameter
MCP	Multi-Core Processor
MOSA	Modular Open System Approach
NIST	National Institute of Standards and Technology
OEM	Original Equipment Manufacturer
O&S	Operating and Support
PIA	Partnership Intermediary Agreement
PM	Program Management
PoP	Period of Performance
QAs	Quality Attributes
SIL	Systems Integration Test and Simulation Lab
SORE	Statement of Research Effort
SRD	Systems Readiness Directorate
TTU	Texas Tech University

Executive Summary

The FirePoint Innovations Center at Wichita State University partners with the U.S. Army DEVCOM Aviation and Missile Center (AvMC) via a Partnership Intermediary Agreement (PIA, see 15 U.S. Code § 3715) established September of 2017. Under its PIA with AvMC, FirePoint acts as a “force multiplier” for AvMC by finding, engaging and presenting the best expertise, technology and capabilities from traditional and non-traditional industry, university and government/military partners outside existing AvMC RDT&E activities.

Specific FirePoint efforts to support AvMC RDT&E are funded under Collaborative Project Orders (CPOs). FirePoint’s first CPO (CPO 1) was initiated October 1, 2017 to strengthen AvMC teams across three Statements of Research Effort (SOREs). These SOREs were:

SORE 1: Qualification Standards Development for integrated Mission Systems, Multi-Core Processors;

SORE 2: Science of Integrated Sustainment; and

SORE 3: Techniques of Architecting Complex Cyber Physical Systems.

The CPO 1 Period of Performance (PoP) was October 2017 through September 2019.

In **SORE 1** the Army tasked FirePoint to strengthen an AvMC team focused on the certification of multi-core processors. FirePoint began work by identifying and leveraging a network of experts to review, comment on and mark-up the Army’s existing draft requirements. FirePoint joined the existing Community of Interest at a workshop where the community’s marked-up draft requirements were discussed. Next, as a part of the Community of Interest, FirePoint created follow-on workshops to further work through and consider the revised certification requirements. In parallel, FirePoint continued to augment that initial Community of Interest group through networking and targeted outreach, adding Critical Mission Systems stakeholders and experts at all levels of the industry - beyond the OEMs - to the discussions. These events were successful, in part, due to FirePoint’s status as a neutral third-party collaborator and facilitator. This enabled FirePoint to provide a safe framework for industry, regulators, and government personal to openly engage and interact. This collaborative engagement with the expanded development chain comprised of both traditional and new, non-traditional partners who had never previously collaborated allowed the team to iterate on problems and potential solutions in real time. This helped enable the AvMC team to quickly create a balanced requirements document for Multi-Core Processor certification.

SORE 2 required agility from the AvMC and FirePoint teams. FirePoint was initially tasked to augment the Army’s efforts to shape a systems approach to sustainment. FirePoint intended to accomplish this by first building a new, broad Community of Interest and then providing a framework for that community to effectively collaborate. FirePoint started by completing an initial sustainment landscape study to identify the key stakeholders. Once that core group was identified, they created the first in a series of workshops to bring that community physically together to discuss Army sustainment goals and strategies for implementation. Following the landscape study and this first successful workshop, FirePoint intended to keep the momentum and conversations among stakeholders going through additional workshops and

virtual meetings. However, a change in Army priorities shifted AvMC focus away from the science of sustainment. Accordingly, FirePoint pivoted to focus on two new smaller but sustainment-related tasks.

The first new task was a tailored review of the Army's main airworthiness document by industry called Army Military Aviation Certification Criteria (AMACC). FirePoint created a large and diverse industry, government and university collaborative team through its existing network and targeted outreach to review and comment on a draft AMACC document. A large volume of comments was received, synthesized, and presented to AvMC, enabling them to create a much stronger revised AMACC draft document.

In the second new task, the Army's Corpus Christi Army Depot (CCAD) requested an analysis by FirePoint to specify what new capabilities the Army would need to setup a world class composites repair depot. As composite materials continue to find their way onto legacy aircraft and become the primary material in FVL aircraft, CCAD seeks to ensure it has the capabilities needed to sustain these vehicles well into the future. FirePoint, through leveraging its existing relationships with leading composite repair labs, performed the assessment and analysis of CCAD composite repair capabilities and reported out insights and recommendations to CCAD leadership. The results of this FirePoint effort will help enable CCAD to meet Army Aviation's future composite repair requirements.

In SORE 3, FirePoint was tasked to support the AvMC team focused on building the tools that will be required to ensure that all future platform acquisitions are Modular Open System Architecture (MOSA) compliant. To make that mandate a reality, the Army must be able to make measurable, non-subjective requirements, similar to how they might mandate performance requirements. Before coming to a list of measurable requirements, the Army needed to answer the more foundational question of whether measuring the "goodness" of software architecture was even possible. To help the Army answer this fundamental question, FirePoint leveraged its existing network as well as other software architecture experts it identified to put a diverse team and program plan together. FirePoint led the resulting team comprised of traditional and non-traditional industry, academic, and government experts as it began the work of tracing the mechanisms used in software architecture and mapping those mechanisms to quality attributes. FirePoint engineers systematically took a complex question and decomposed it into the fundamental facts where it could be analyzed without subjectivity. As a result, the team successfully mapped the connection between business objectives and the mechanisms used in the implementation of the architecture and determined that it was indeed possible to measure Key Business Drivers (KBD's) of software architecture in a non-subjective way. Through the work done in SORE 3, the Army now knows it's possible to measure architecture, allowing them to move to the next stage in their quest to mandate MOSA compliance-setting requirements.

An overarching conclusion from the work FirePoint performed for AvMC under CPO 1 is that the FirePoint PIA is an exceptionally effective tool for supporting AvMC scientists and engineers working in emerging technical areas, helping them to broaden strategic collaborations with traditional and, in particular, non-traditional partners from industry, universities, and government. FirePoint is a "force multiplier" for AvMC. It finds, engages and presents to AvMC the best expertise, technology and capabilities from outside the Army. New and diverse Communities of Interest (COIs) formed to support SORE objectives are a key PIA collaboration approach that resulted in robust requirements and requirements-development methodologies for each SORE.

I. SORE 1: Qualification Standards Development for integrated Mission Systems, Multi-Core Processors

The SORE 1 Assignment was as follows:

Embedded multi-core platforms and related software support tools are now at a maturity level suitable for use on military and aerospace programs. Introduction of multi-core processors (MCPs) in embedded aircraft systems may be considered inevitable due to the market evolution where single core processors will soon stop being manufactured. Industry working groups have been established to address the challenges of multi-core certification. The Federal Aviation Administration and their European Aviation Safety Agency counterparts are building guidelines for COTS multi-core processor introduction. Depending on program needs and risk sensitivity, three main porting scenarios are possible: 1) Re-hosting a single application to a single core, 2) Mapping multiple applications to multiple cores, and 3) Migrating uniprocessor code to parallel multi-core clusters. Risks vary by scenario. Additional recommendations for component selection and implementation are under development. Concurrently, DEVCOM Aviation & Missile Center is establishing airworthiness qualification standards for current and future fielded systems that will deliver and validate methods/techniques for incorporating and qualifying MCPs for use in Army platforms.

I.a. SORE 1 Background

The varied certification challenges Multi-Core Processors present have been studied for years. In 2017, a joint effort between the Department of Transportation (DOT) and the FAA identified and documented in DOT/FAA/TC-16/51 (Reference 1) performance and safety qualification concerns with the use of MCPs. In this document, the FAA proposed the use of three guidance documents for MCP certification. As a result, the DEVCOM Aviation & Missile Center Systems Readiness Directorate (SRD) added objectives from one of these guidance documents, CAST-32A (Reference 4), to its list of potential guidelines for satisfying military MCP airworthiness requirements. All of these guidance documents, however, provided minimal mitigation methods for MCP certification issues – including those related to test and verification.

Using MCPs allows for innovation and flexibility, but SRD needed insight on the available and optimal mitigation methods for certification issues encountered when fielding MCP enabled systems. As a result, SRD engaged FirePoint, through the PIA, to build a community of interest and framework to aid their development of robust test and verification requirements for MCP enabled systems in critical applications.

I.b. SORE 1 Summary

The SORE team – Army S&T, PM, CFT, and FirePoint – successfully conducted a review of the Army’s latest draft requirements for MCP certification. FirePoint augmented this review by engaging over 325

companies and certification experts, receiving over 270 discrete comments that were evaluated and dispositioned.

Following that effort, the U.S. Navy invited FirePoint to participate in a Dahlgren, Virginia workshop that discussed issues associated with the use of Multi-Core Processors. In this workshop, the issues associated with the use of MCPs were discussed and broken down into their root causes. The workshop provided an opportunity for the Army Labs to present the research they were performing relative to understanding how MCPs operate and the associated issues related to their application. FirePoint utilized the Dahlgren workshop as a springboard to solicit additional review and comments on the Army's draft requirements and to start a dialogue on how to solve the issues associated with the use of MCPs. The workshop enabled the FirePoint team to identify the key players in industry leading the efforts in MCP use and certification. The FirePoint role then expanded from Army researcher to *national MCP certification facilitator* focused on establishing a community of interest comprised of experts on MCP's and their use. One of the key outcomes of the Dahlgren workshop was that all of the issues associated with MCP's were then consolidated into four categories of concern: Cache, Memory, Interconnected Connected Devices and Interferences.

Approximately six months later, FirePoint took the lead and hosted a workshop in Huntsville, Alabama to identify methods for resolving the issues in using MCPs identified at Dahlgren. FirePoint grew the workshop participation beyond the core team of Army S&T, PM, and CFT representatives to include U.S. Navy, Air Force, FAA and EASA as well as experts from university, traditional and non-traditional industry. The workshop consisted of DoD and industry briefings as well as multiple breakout sessions to address the four categories of concern regarding MCPs. This workshop was significant because it brought together the entire development stream starting with chip manufacturers, to board level designers, through the component, system and platform level software and hardware integrators. This was the first time that the entire development stream was able to interact and discuss these issues and understand the cause and effects of their design decisions on the ability to qualify these new processors.

The momentum gained from the Dahlgren and Huntsville workshops resulted in a third FirePoint-organized and hosted workshop in Dayton, Ohio, that built upon the information gathered from the first two events and focused on the verification and validation of critical mission systems utilizing multi-core processors. The COI in this workshop included the U.S. Army, Navy, Air Force, and the FAA regulators as well as chip manufacturers, three board level suppliers, system integrators and OEMs, and developers of operating systems and software designed to test and monitor.

In this workshop, each regulator discussed their requirements and the aspects unique to MCPs. The COI's full complement of industry representatives (chip, board, and system) shared their work and their challenges, as the workshop participants – industry and regulators – moved from discussing MCP chip design, board requirements and assembly to the integration and validation of the system as integrators. Finally, the participants heard the system OEMs' perspectives, as they have the ultimate responsibility to certify or qualify the system of systems at the platform level. *This was the first time that any workshop participant could recall that regulators, university and industry representatives - many of whom normally compete with each other – teamed to address the challenges affecting the MCP community.*

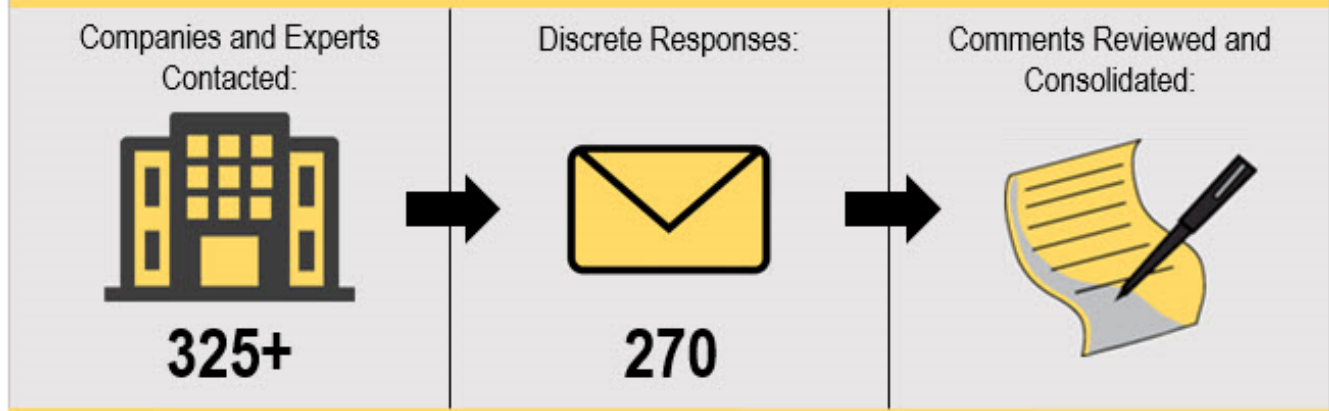
Beyond the large COI workshops described above, FirePoint also sought out, screened and ultimately introduced unknown technologists and researchers from small companies and promising university laboratories to the DEVCOM avionics personnel. In this capacity, FirePoint enabled the Army's vetting of researchers and technology without delays associated with separate contracting arrangements. FirePoint worked to keep the COI's engaged through our continued efforts on other related SOREs and the FirePoint website which hosted information from our workshops and papers.

FirePoint succeeded in achieving the objectives of this SORE because it was a "force multiplier" that strengthened the Army's ability to build a large – over 200 participants – and diverse team made from all the key MCP stakeholders within the Critical Mission Systems community, and provided a framework for that team to create balanced requirements that served the greater good of the government and industry. This outcome enabled the Army SORE team to meet their goals of finalizing documentation of balanced MCP certification requirements and begin to use them in new acquisitions.

SORE 1

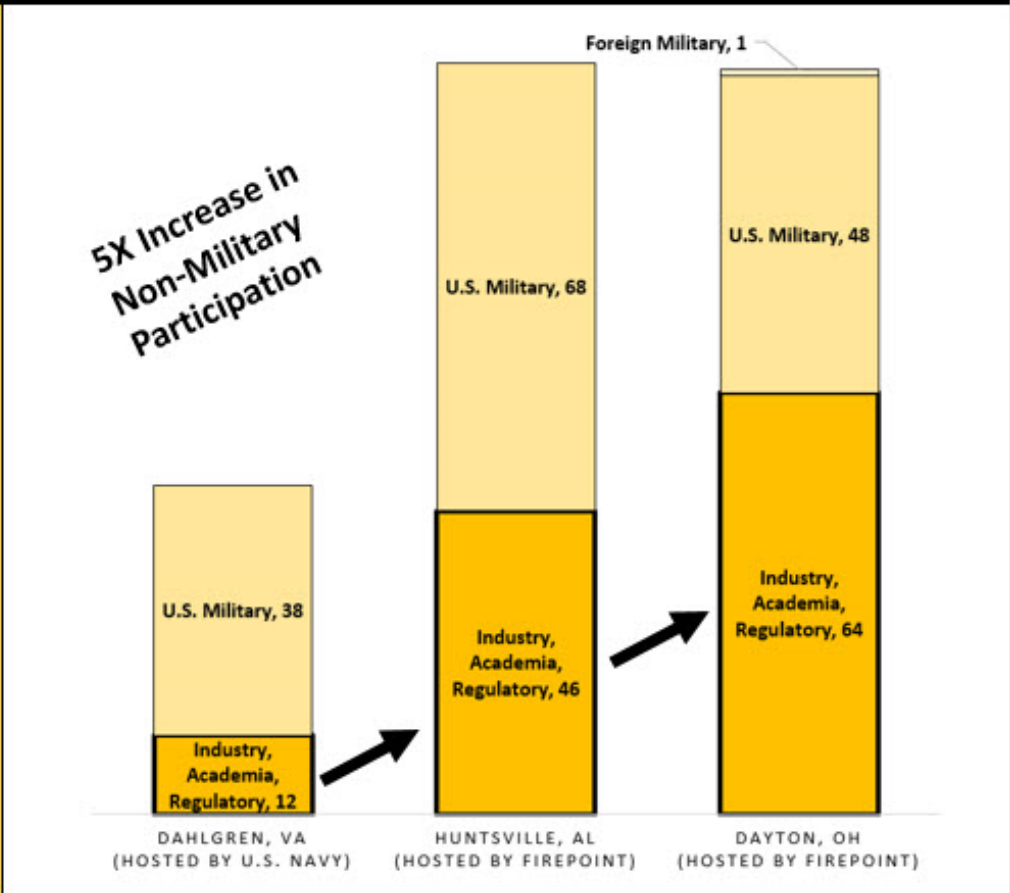
Qualification Standards Development for Integrated Mission Systems, Multi-Core Processors

Industry Input: Ask the Experts



Workshops: Increasing Engagement

“This was the first time that any participant could recall that regulators, university and industry representatives - many of whom normally compete with each other – teamed to resolve problems affecting the MCP community.”



II. SORE 2: Science of Integrated Sustainment:

The SORE 2 assignment was as follows:

Army Aviation Sustainment S&T is focused on enabling highly reliable, low maintenance platforms that can survive outside traditional sustainment in the multi-domain battle space for extended periods. A holistic, “innovative sustainment” approach to explore, develop, demonstrate, and transition futuristic technologies and integrated concepts is needed to realize this vision for the next generation of vertical lift manned and unmanned aircraft. Specific areas of interest include building the foundation for a future sustainment concept paradigm shift, as well as maturing through SIL demonstration technology solutions that enable aircraft health state awareness and vehicle adaptation.

II.a. SORE 2 Background

The U.S. Army’s number one priority according to former Army Secretary Mark Esper is readiness, that is, “ensuring the Total Army is ready to deploy, fight and win across the entire spectrum of conflict”. Despite this goal the Army’s rotorcraft fleet often fell short of their readiness targets. There are several reasons for this, including:

Lack of Robust Sustainment Requirements

- 1) Sustaining multiple platforms with vastly differing systems and technologies reduces interoperability and decreases opportunity for cross development and learning. Maintenance is often platform specific with little overlap.
- 2) Systems, airframe and engines are sustained independently and often have vastly different sustainment philosophies. Inspections are not coordinated and there is no holistic view of performance or maintenance.
- 3) Sustainment was not integrated into the basic platform Key Performance Parameters (KPPs). Sustainment is traded against critical performance requirements and is often removed entirely as it was seen as too costly to implement. Additionally, the incorporation of new sustainment technologies will require significant development investment. Upfront investment will produce dramatic full life cycle cost savings, but it is culturally and politically difficult to allocate future savings to current procurement costs.

Incorrect Design Assumptions

- 4) Our platforms are being utilized longer than previously envisioned resulting in the need to sustain systems long after their design life has expired.
- 5) The operating environments for Army rotorcraft in recent wars have much harsher (e.g., the desert) than the conditions for which such aircraft were designed. The extreme heat and fine, corrosive dust associated with desert conditions is a major factor for declining reliability rates of aircraft equipment.

Lack of Government Owned Data Packages

- 6) Spare parts and obsolescence are becoming a limiting factor in our ability to sustain our fleets. Parts are no longer in production and the U.S. Military does not typically have access to the original design data or drawings due to IP restrictions in the original contracts. Certifying alternate sources and the resulting design packages puts further strain on certification authorities.

Lack of an Army Sustainment Culture

- 7) Cultural inertia is an ongoing issue, that is, the fleet is maintained the way it’s always been done. With generations of old, systematic requirements and the absolute authority of the local leadership to override specified maintenance requirements, obtaining consensus in thought and action relative to sustainment will be extremely challenging.

Examining the costs associated with the life cycle of a typical U.S. Army platform reveals that up to 80% of the total life cycle cost, according to the Office of the Secretary of Defense Cost Analysis Improvement Group, as illustrated in Figure 1 - “Estimated Life Cycle Cost Analysis”, is expended in the Operating and Support (O&S) cost of the platform. Not only is this a massive financial cost to the Army, maintaining these platforms is labor intensive and requires an extensive and complex worldwide logistics and supply chain. To supporting a new modern, agile Army aircraft fleet needed for future multi-domain operations, it is imperative to examine and fundamentally change how these new platforms are designed and sustained.

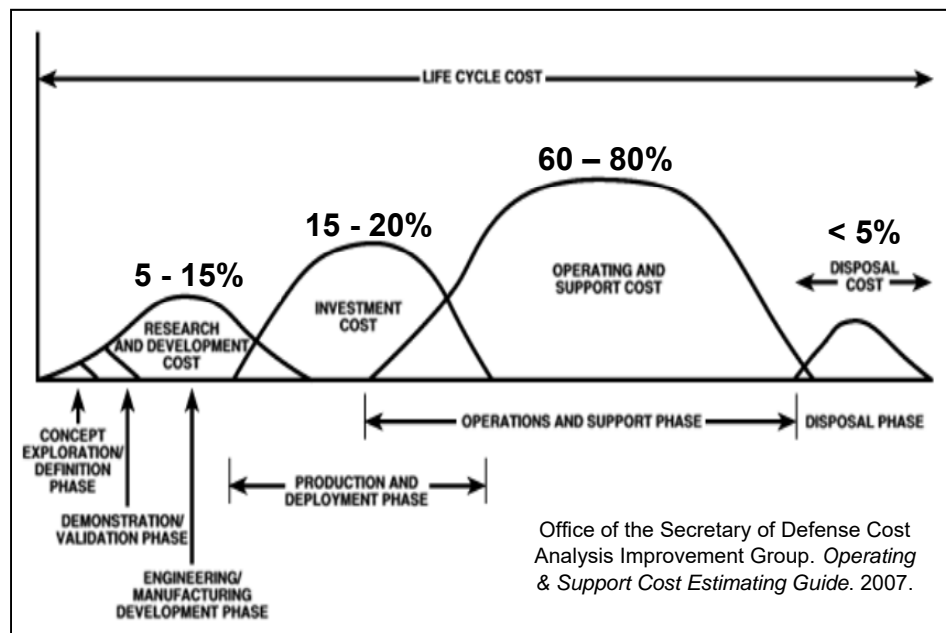


Figure 1: Estimated Life Cycle Cost Analysis

To drive these changes, the Army must look at enabling technologies and the requirements that define the necessary design for sustainment objectives sorely needed.

As a result, sustainment Science & Technology (S&T) has shifted focus to enable the capability of future aviation systems to operate “un-sustained” for a minimum Operating Period (MOP) in the multi-domain battle space. To achieve this, new designs focused on sustainment must be driven into the new family of FVL systems. These new designs will be significantly influenced by three essential sustainment elements:

1. Ultra-reliable, operationally durable, holistic system-level designs
2. Aircraft and fleet automated health-state awareness, and
3. Redundant, damage-tolerant, adaptable/reconfigurable platform systems.

These sustainment elements must be treated as an upfront investment and be seamlessly integrated to achieve the desired capabilities. A comprehensive, yet agile, sustainment construct is also required to evolve zero-maintenance aircraft into the future battlefield. Both proven and novel ideas are needed to align programmatic goals with university and industry best practices. **Importantly, all of these issues can be addressed in upcoming procurements with little impact to cost and performance through total integration within a systems engineering approach. With this in mind, FirePoint was tasked to augment the Army’s efforts to shape a systems approach to sustainment.**

(Note: A successful paradigm shift requires more than just S&T advancements. Implementation of an improved sustainment strategy will involve lines of effort across the entire Army Aviation Enterprise, including Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities, and Policy (DOTMLPF-P).)

II.b. SORE 2 Summary

FirePoint started this task by conducting several literature studies to understand the current state of U.S. Army aircraft sustainment and the factors affecting it. Next, to engage industry, universities and the U.S. Military in this discussion, FirePoint planned and conducted a collaborative “Science of Sustainment” workshop with the goals of starting dialogue and exploring solutions that would help move the U.S. Army closer to their future sustainment goals.

FirePoint collaborated with Texas Tech University (TTU) to host this workshop because of their recent efforts to address sustainment on a system and platform level. Texas Tech University was actively planning to construct a full-scale Sustainment SIL (Systems Integration Test and Simulation Lab) where new ideas and technologies of a holistic system would be interrogated and further developed. This collaboration also created the opportunity for DEVCOM Aviation and Missile Center staff to learn about relevant interests and capabilities of TTU.

The Science of Sustainment Workshop was held on March 6th and 7th, 2018 at the Texas Tech Innovation Hub in Lubbock, Texas. FirePoint put together a diverse group of attendees including: DEVCOM Aviation and Missile Center personnel, Army maintainers, industry, and university experts representing both commercial and military programs.

The goals of this workshop were to:

- Obtain comments, refine objectives, and gain acceptance of the Army Aviation's zero-maintenance S&T strategic plan,
- Inform integrated sustainment requirements for Future Vertical Lift (FVL) and,
- Develop a robust strategy for implementation.

The workshop was a success and some of the important outcomes the team was able to accomplish included:

- Mapped system-data-analysis relationships and normalized what is practical and achievable for a first-iteration, next-generation future vertical lift system to be defined in the 2025 timeframe
- Identified the gaps and issues associated with existing technologies, current levels of integration, and barriers related to technology implementation
- Defined a strategy to enable and implement paradigm-shifting sustainment for FVL
- Gained insight into what other industries are doing to address similar optimization objectives
- Informed the future S&T roadmap and key requirements associated with integrated sustainment

Unfortunately, just eight months into execution of this SORE, DEVCOM Aviation and Missile Center leadership was told to divest itself from further S&T activities relative to the science of sustainment. This meant that FirePoint's initial efforts supporting SORE 2 were halted and reconfigured upon direction of the DEVCOM Aviation and Missile Center FirePoint program manager.

Remaining SORE 2 funding was moved to other tasks that directly and indirectly supported sustainment. Those tasks are summarized here.

II.c. SORE 2 Additional Studies

III.c.1 Review of the AMACC

In this effort for the Army, specifically DEVCOM AvMC Systems Readiness Directorate (SRD), FirePoint was tasked to facilitate an external review of the draft Army Military Airworthiness Certification Criteria (AMACC) - the primary document they use to communicate airworthiness requirements to industry. The AMACC outlines the airworthiness processes and requirements in terms of criteria, standards, and methods of compliance to be used in development of data, software, and equipment to support systems, subsystems, and components of U.S. Army manned and unmanned aircraft systems.

The government was interested in industry's general perspective on the document, but they were specifically interested in feedback on the following:

- **Completeness:** Does the document cover all aspects of a thorough airworthiness assessment of an air vehicle? Are there gaps, omissions or duplication of requirements?

- **Accuracy:** Does the document accurately define the airworthiness criteria? Are there better criteria for demonstrating the airworthiness objective?
- **Conciseness:** Are the criteria properly defined? Are there better ways to define the criteria, standards or MOCs to meet the airworthiness objective?
- **Executability:** Can industry execute to the requirements of this document? What changes would enhance airworthiness program execution?
- **Understandability:** Does the document provide industry with an understanding of the complete airworthiness program requirements? What changes are required to better define the requirements?
- **Adequacy:** Do the standards identified provide adequate definition? Are there better existing standards? What areas require further standards development?
- **Harmonization:** Are there changes that would enhance harmonization across other airworthiness criteria documents?

A thorough review from an industry perspective would prove to be very valuable, but the document was daunting due to its size, scope, and complexity. It consists of a base document containing requirements across 16 functional areas and 20 appendices with additional requirements specific to systems and aircraft functions spanning thousands of pages. Adding to the complexity is the AMACC having been structured with future harmonization with other existing airworthiness criteria documents in mind, specifically the MIL-HDBK-516 and the European Military Airworthiness Certification Criteria (EMACC) document. In order to complete a thorough review of such a multifaceted and lengthy document a large, diverse group of industry-based airworthiness experts needed to be engaged.

To build such a review team, FirePoint leveraged its extensive industry network and ultimately requested comments on the areas of interest to over 250 airworthiness experts. Responses were collected, collated and summarized and presented to SRD leadership for review and comment.

The briefing *FP2019-C1-S2-RS01A*, “**Army Military Airworthiness Certification Criteria Document (AMACC) – Review**” summarizes the effort and its findings. This effort proved to be the “force multiplier” that SRD hoped for when they initially partnered with FirePoint to augment their AMACC review.

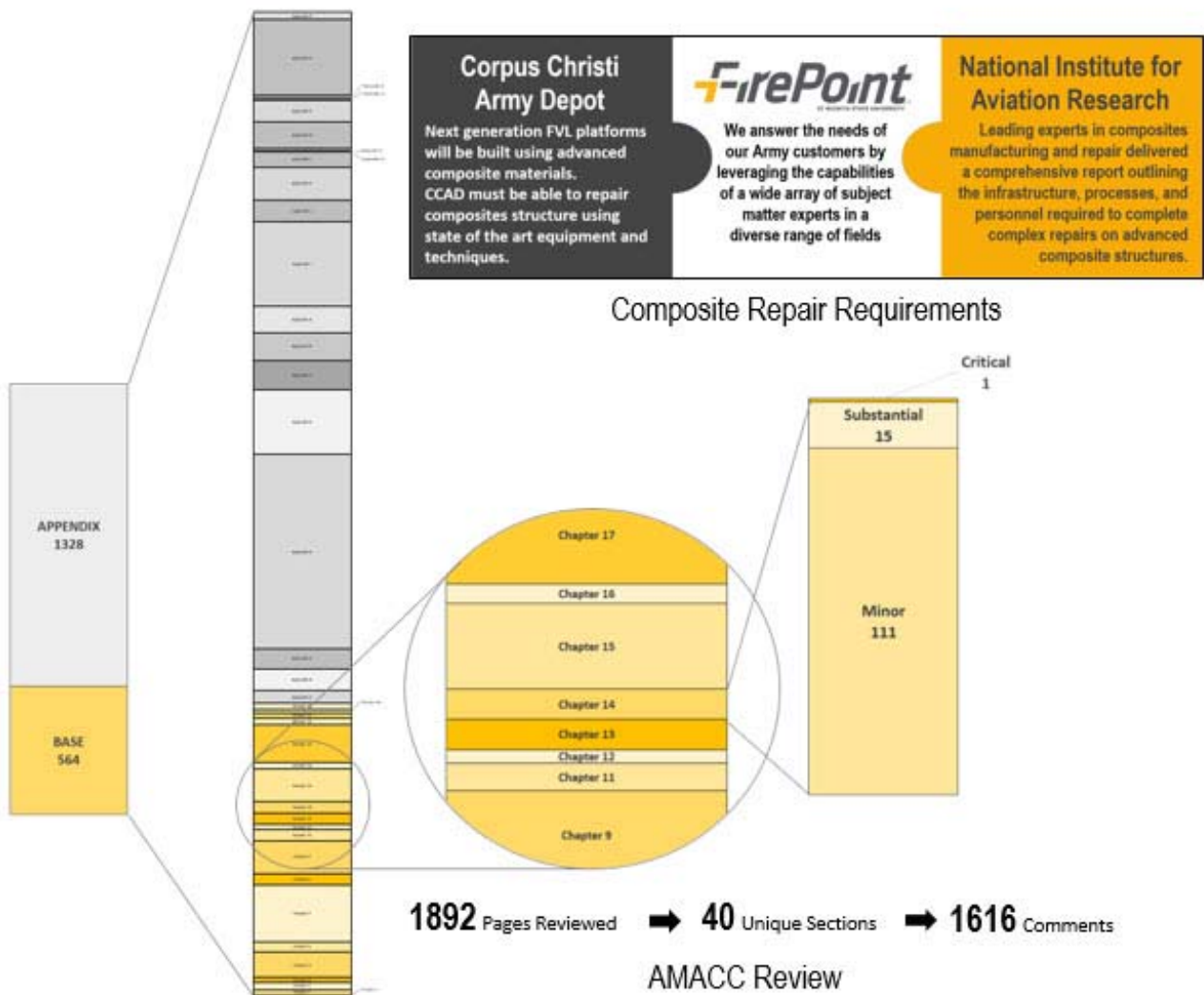
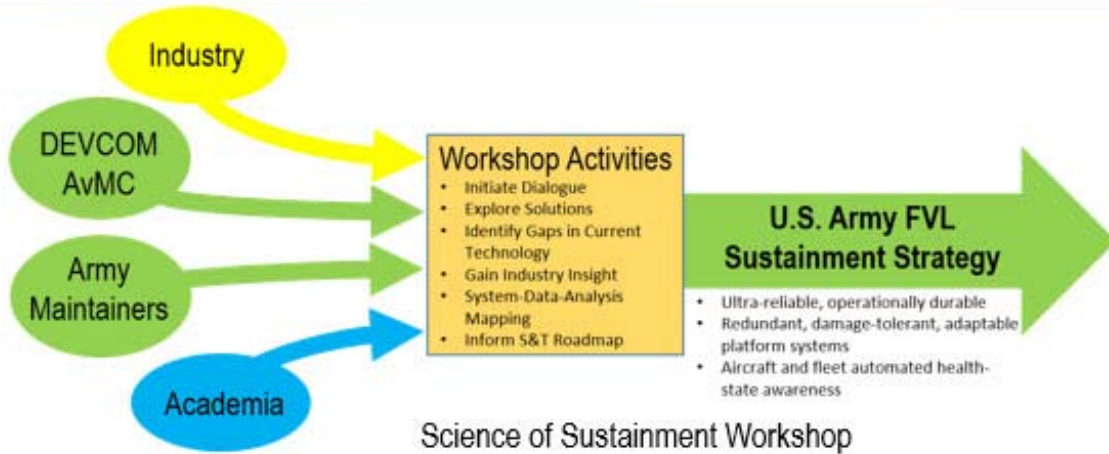
II.c.2 Advanced Composite Repair Requirements, Infrastructure, Equipment, and Personnel

As composite materials continue to find their way onto legacy aircraft and become the primary material in FVL aircraft, the Army’s Corpus Christi Army Depot (CCAD) seeks to ensure it has the composite repair capabilities needed to sustain these vehicles well into the future. In this effort, FirePoint was tasked to develop and provide to CCAD an accurate and thorough description of the conditions, supplies, and personnel necessary to establish a state-of-the-art structural composites and repair depot capability. FirePoint, through leveraging its existing relationships with leading composite repair labs, performed the assessment and analysis of CCAD composite repair capabilities and reported out insights and recommendations to CCAD leadership. The results of this FirePoint effort will help enable CCAD to effectively meet Army Aviation’s future composite repair requirements.

Laboratory requirements, major and minor hardware, other equipment, and consumables necessary for the composites depot capability are listed with general descriptions. FirePoint report *FP2019-C1-S2-RP01A*, **“Advanced Composite Repair Requirements: Infrastructure, Equipment, and Personnel”** presents the results of this study.

SORE 2

Science of Integrated Sustainment



III. SORE 3: Techniques of Architecting Complex Cyber Physical Systems:

The SORE 3 assignment was as follows:

In the context of systems and software engineering, there are hundreds of definitions for the term “architecture” which all mention components and component relationships. These definitions overlap with definitions for “design” with the difference typically explained simply as an issue of scale. This is problematic when applied to complex cyber-physical systems as scale is relative and does not account for conflicting priorities based on organizational concerns. Organizations managing the design have different objectives than an organization responsible for managing a family of systems or designs. One approach to differentiating between “architecture” and “design” is by separating the purpose behind the effort. Architecture is strategic in nature, focused on addressing the business and technical objectives of the organization procuring the system/family of systems to consistently achieve desired functional and non-functional characteristics. Design is tactical in nature, focused on realizing the desired technical and business objectives in the context of the required system characteristics. The challenge of separating architecture/design is further exasperated by the increasingly complex operations that require integration between multiple systems managed by disassociated organizations.

III.a. SORE 3 Background

The initial 8088 Central Processing Unit (CPU) released in 1979 contained 29,000 transistors, all designed and laid out by hand. Forty years later, transistor counts have grown exponentially; CPUs have 20-30 billion, Graphics Processing Units (GPUs) have 30-40+ billion, and Field Programmable Gate Arrays (FPGA) can have up to 50 billion gates. These computational devices aren’t designed by hand at the individual transistor level anymore – the massive numbers won’t allow it. However, when you examine the underlying processes used for system integration, messaging, and orchestration of these devices it is still fundamentally the same as it was in the late 70’s. While you can leverage model-based approaches, and higher-level programming languages for code generation and streamlining syntax manipulation-based tasks, shockingly, the integration of systems and system of systems is still done by hand.

Given the scale and complexity of most systems-of-systems it comes as no surprise that the Qualities of Use (robustness, flexibility, integrity, reliability, maintainability, etc.) do not meet the original desired goals and business-level objectives. Our manual approaches for integration simply don’t scale, and the complexity of the designs make the analysis of an architecture one of art and mystique.

FirePoint’s effort sought to distill and define the fundamentals of system and software architecture analysis and to form the basis to test a design prior to its implementation. This analysis, built on fundamentals, had to be scale-able and serve as the catalyst to transform integration. This capability was important to the Army because architectural design decisions made early in the process have a profound impact on the final product. Changes made late in the development cycle are always more costly both in

time and money. Therefore, the Army tasked FirePoint to augment their team in developing a tool to evaluate some of the early implementations and their impact on key business drivers (KBDs).

III.b. SORE 3 Summary

The U.S. Army's Comprehensive Architecture Strategy (CAS) paper, where the concept of defining Architecture independently of systems implementation, opened the door to the realization that the architecture utilized could be tailored to meet an independent set of requirements regardless of any system implementation. Through SORE 3, FirePoint's efforts centered on the organization and execution of workshops in which senior software architects (a.k.a "Gray Beards") from different areas of systems design were identified and assembled to better understand how they each developed architecture to support their implementation. FirePoint further expanded this knowledge base by hiring a consultant who was one of the leading experts in the field to help lead the workshops, thereby adding credibility, an expanded network, and technical rigor to the Army objectives.

Through the series of planned "Gray Beard" workshops FirePoint led the expert team through an analysis of three fundamental architecture questions to gain insight into the definitions, relationships and understandings of how software architecture could be utilized to achieve key business drivers (KBD's).

1. **How can a customer understand the quality of a delivered Architecture?**
2. **How do you flow customer Key Business Drivers to a System Design?**
3. **Can you measure the "Goodness" of the Architecture before you get to Design?**

The workshops answered these three basic questions as follows:

- **How can a customer understand the quality of a delivered Architecture?**
 - As shown through this effort, the CAS process provided a working concept for optimizing customer Key Business Drivers into an Architectural design. The quality attributes of a KBD can be traced within a Model-Based Architectural design to measure their ability to meet the System or Product Line Systems Design Architecture.
- **How do you flow customer Key Business Drivers to a System Design?**
 - This effort documented that customer Key Business Drivers could be incorporated into a platform software architecture (or multiple implementations of a Product Line). Being able to trace KBD's through an Architecture allows the use of existing systems engineering tools to measure the implementation through all levels of the software implementation.
- **Can you measure the "Goodness" of the Architecture before you get to Design?**
 - The simple answer is "Yes". "Goodness" is a relative term, but relates to the ability of a delivered Architecture to achieve customer goals in ways that can be measured and understood. As this work evolves, mapping higher levels of fidelity of Mechanisms and Quality Attributes is expected to provide increased levels of automation to measure levels of "Goodness".

The workshops provided key insights on how Key Business Drivers (KBDs), Architecture Quality Attributes (QAs) and their mechanisms relate to each other and other levels of Quality Attributes dealing with Regulatory, Design, Implementation and Performance. The workshops also identified additional areas of possible research in how to create a knowledge base which will enhance architectural advances. The best way to understand this effort is through analogy. In the same way that steel has multiple attributes like shear and tensile strength that can be measured independent of the design, so, too, does software architecture. The workshops were an attempt to map those software attributes and begin to understand how they related to one another with the end goal being to provide a framework for creating measurable requirements that can be incorporated from the earliest stages of design.

The workshops strained to avoid creating deviations from standard engineering efforts to sidestep major retraining, and instead focused on enhancing the details and understanding of the Architectural process approach to systems and software development. The processes that were identified include standard modeling-based efforts, requirements tracing and use of standards such as DoD Architecture Frameworks (DoDAF), Future Airborne Capability Environment (FACE™) Architecture and NIST Cyber processes and designs.

This SORE concluded that Architecture can be evaluated for relationships to customer Key Business Drivers. Through the evaluation of the Architecture, the customer can understand whether the Architecture provides the Quality Attributes and Mechanisms necessary to provide the basis for meeting customer objectives.

One of the key evaluations of the Software architecture is the capability of the infrastructure needed to meet the Key Business Drivers. A solid infrastructure lays the foundation for layering mission execution functions. The infrastructure ties the Hardware architecture design, the Data architecture and the Functional architecture providing a key building block for the Software architecture to deliver the needed system(s) designs.

A report documenting the work and findings of this SORE was published. It includes all of the pertinent information and findings from the various workshops and was submitted to DTIC for future reference. *FirePoint Report No. FP2019-C1-S3-01A, "Analysis of Architectural Requirements"*

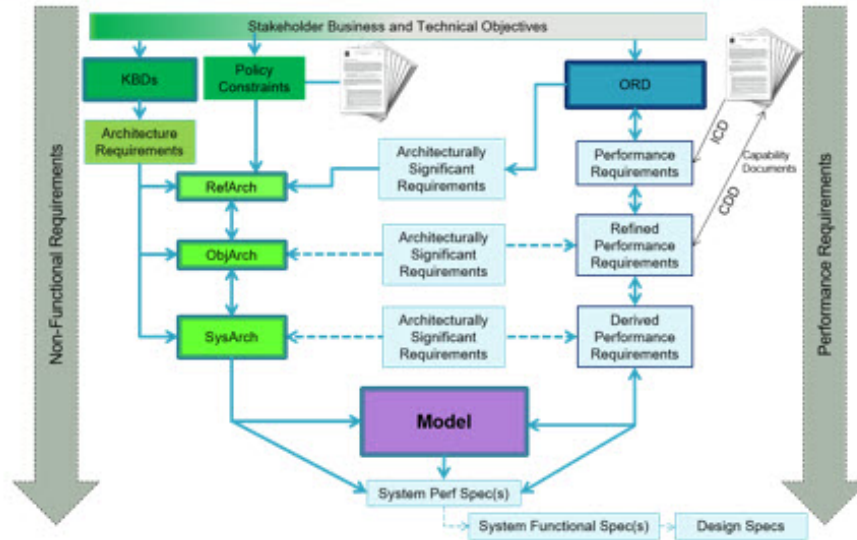
To aid in the distribution of the findings of this research, a paper was prepared and was presented during the spring of 2020 Vertical Flight Society conference. The publication is: ***"Is Architecture Measurable? Towards Creating, Managing, and Measuring Architecture and Resulting Product Line Implementations"***, Hunt, Jonas, Townsen and Wigginton, May, 2020.

A summary report was prepared and presented to the IMS PM briefing on 23 March 2020. The briefing informed the Army Program Managers and other collaborators working in the IMS and Modular Open System Approach (MOSA) areas of the study and its findings. The study was well received because it gave the PMs a tool they did not have before – a way to measure Key Business Drivers. This is akin to discovering properties of steel such as tensile strength and shear strength that are independent of application whether it's a building or a bridge. The work is foundational and needs further effort to be done to expand and automate it – which FirePoint has been tasked to do in a future study – but the basic approach has been developed and verified. The AvMC team's use of FirePoint to bring together a world-class community of interest led by a FirePoint subject matter expert helped them achieve a very important

component on the path to measurable MOSA requirements – validation that the “goodness” of software architecture can be measured.

SORE 3

Techniques of Architecting Complex Cyber Physical Systems



Non-functional requirements are derivable, verifiable, and testable.

Measuring Systems and Software Architecture

What did we DO?

- Exploration of Quality Attributes and their Characteristics
- Explorations of Mechanisms and their Characteristics
- Explored the relationships between QA/Mechanisms
- Performed an Assessment of a process to measure utilizing modeled content and relationships

Who Was Involved

- Industry (traditional and non-traditional)
- Academia
- Government (acquisition, research, and operational)

<h3>SORE 3 – Insights</h3> <p>There are Defined Relationships</p> <ul style="list-style-type: none"> • Between Categories of Architecture • Across Levels of Architecture • Between QAs and KADs • Between QAs and KBDs • Between QAs & Mechanisms • QAs to Categories of Architecture • Between QAs & Other QAs 	<h3>Key Questions Answered</h3> <p>How can a customer understand the quality of a delivered Architecture?</p> <p>How do you flow customer Key Business Drivers to a System Design?</p> <p>Can you measure the “Goodness” of the Architecture before you get to Design?</p>
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Where Do We Go From Here?

SORE 11 - Develop Techniques to Optimize Cyber-Physical Systems Architectures

- Build a Database of the Fundamental Characteristics of Software Mechanisms
- Map the Mechanisms against the Fundamental Characteristics

IV. CPO Budget Summary

Total funding provided for the CPO 1 effort was \$1,900,000 and was expended as shown in **Appendix A**. The effort initiated October 1, 2017 and extended through September 2020. The initial period of performance was scheduled to be two years, but a no cost extension was granted allowing the remaining funds to be used on related efforts.

FirePoint was a successful “force multiplier” for the Army because it efficiently used the available funding to expand the number of traditional, non-traditional, university and research partners, thereby augmenting and enriching the research of FirePoint’s Army Aviation and Missile Center customers.

V. CPO Deliverables

All SORE deliverables can be found in their full version in **Appendix B**.

V.a. SORE 1 – Certification of Multi-Core Processors

The deliverables for SORE 1 can be found in Appendix A of this report. Those deliverables are as follows:

V.a.1 FP2019-C1-S1-RP01A: Proceedings from the Multi-Core Processors Solutions Workshop, November 2018, Huntsville, Alabama

V.a.2 FP2019-C1-S1-RP02A: Proceedings from the Multi-Core Processors Test and Validation Workshop, April 30 – May 1, 2019, Dayton, OH

V.a.3 FP2019-C1-S1-RP03A: Feasibility Study for Developing a Community of Practice for the Use of Multi-Core Processors in Critical Application

V.b. SORE 2 – Science of Integrated Sustainment

The deliverables for SORE 2 can be found in Appendix B of this report. Those deliverables are as follows:

V.b.1 FP2019-C1-S2-RS01A: Army Military Airworthiness Certification Criteria Document (AMACC) – Review

V.b.2 FP2019-C1-S2-RP01A: Advanced Composite Repair Requirements: Infrastructure, Equipment, and Personnel

V.c. SORE 3 – Techniques of Architecting Complex Cyber Physical Systems

The deliverables for SORE 3 can be found in Appendix C of this report. Those deliverables are as follows:

V.c.1 FP2019-C1-S3-RP01A: Analysis of Architectural Requirements

V.c.2 FP2020-C1-S3-WP01A: Is Architecture Measurable? Towards Creating, Managing, and Measuring Architecture and Resulting Product Line Implementations.

V.c.3 FP2018-C1-S3-MN01A: Fire Point SORE 3 Workshop Mar 2018

V.c.4 FP2018-C1-S3-MN02A: CAS – Mini-Workshop June 28, 2018 Grand Rapids MI

END

Appendix

A. CPO1 Financial Summary

Category	Budget	Expenditures (through 09/30/2020)
Personnel	\$ 488,845.03	\$ 486,753.67
Fringe Benefits	\$ 91,803.30	\$ 91,230.09
Total Personnel Costs	\$ 580,648.33	\$ 577,983.76
Participant Support Costs	\$ 6,367.88	\$ 4,367.88
Total Participant Support Costs	\$ 6,367.88	\$ 4,367.88
Travel	\$ 63,704.49	\$ 62,003.33
Supplies	\$ 28,368.70	\$ 26,733.61
Equipment	\$ 6,069.00	\$ 6,069.00
Consultant Services	\$ 407,814.23	\$ 407,708.47
Subawards	\$ 12,330.00	\$ 12,330.00
Other Direct Costs	\$ 505,098.18	\$ 494,447.27
Total Other Direct Costs	\$1,023,384.60	\$1,009,291.68
Total Direct Costs	\$1,610,400.81	\$1,591,643.32
<i>Indirect Costs (26% MTDC)</i>	<i>\$ 289,599.19</i>	<i>\$ 285,242.24</i>
Total Costs	\$1,900,000.00	\$1,876,885.56

B. SORE Deliverables

The SORE deliverables listed in Section V of the report can be found on the following pages.