WRT 1012: Global Positioning Systems - Mission Engineering and Integration of Emerging Technologies

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TABLE OF CONTENTS

LIST OF FIGURES

EXECUTIVE SUMMARY

The University of Southern California (USC) and its Information Sciences Institute (USC-ISI), undertook research and systems engineering analysis to explore the mission engineering methods, analysis, and metrics needed to transition from a traditional DoD 5000 waterfall development environment to an Agile/DevSecOps environment, including integration of emerging technologies and related education for the future workforce. Over the 18-month period of performance at the U.S. Space Force Space and Missile Systems Center, Production Corp (SMC/PC), the project team embedded into the SMC/PC acquisition environment, developed performance measuring tools, collected performance metrics and provided subject matter expertise on two projects – a traditional Waterfall project (Project A) and a hybrid Waterfall/Agile project (Project B). In addition, during the final ten months of the project, the project team embedded in another acquisition project (Project C).

After adjusting for differences in periods of performance and software lines of code, the hybrid Waterfall/Agile project (Project B) produced approximately 85.4% less open problem reports (PRs) than the traditional Waterfall project (Project A). Both projects exhibited the same level of software and systems complexity.

Comparing the performance between the Waterfall and Agile portions of the Hybrid project (Project B), the Agile effort produced approximately 95.7% less open problem reports compared to the Waterfall portion of the effort. Both efforts exhibited similar code complexity and software lines of code, however, the Agile effort took 10 months less time to complete and its workforce was considerably less experienced than the Waterfall team.

Although impressive, these results represent one data point and the focus was only on measuring open problem report performance between two very well-defined projects. Impacts from manpower allocations and from the merging of three base code updates (sustainment efforts) into the Waterfall effort of Project B were not measured as this information was not available. Other issues such as measuring the impact of changing requirements or end-user engagement (feedback) were not considered as system requirements remained stable throughout both projects and there was very little end-user engagement due to availability of operators.

During the last 10-months of the period of performance, the project team began embedding into a new project (Project C). Project C is focused on using an Agile/DevSecOps framework in the development of a next generation system. Using lessons learned from the two prior projects (A and B), the project team is providing subject matter expertise, developing performance metric measuring tools and developing and applying workforce training materials to the project team. The plan (via a follow-on to WRT-1012) is to actively engage, participate and collect performance metrics throughout the lifecycle of the Project C.

One of the objectives of the WRT-1012 project was to generate a list of recommendations that can be generalized and applied to other government acquisition projects. A key recommendation is workforce training. Many members of the government acquisition

environment are experts in the waterfall method of systems development and, in some cases, have knowledge of the Agile/DevSecOps approach, but few have practical experience in working in the Agile/DevSecOps environment. Another key recommendation is ensuring the appropriate performance measuring tools are available for collecting performance metrics to help monitor the development process. Also important is the need for Agile "champions" in both the contractor and government environments. This is particularly true when first introducing the Agile/DevSecOps method in a traditional Waterfall development environment. Finally, it is essential that the project schedule include "ramp-up" time to allow members of the acquisition environment – in both the contractor and government sides of the effort – to become familiar with Agile/DevSecOps approaches, consistent with DoDI 5000.87 and their relationship to traditional Waterfall markers

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INTRODUCTION

The University of Southern California (USC) and its Information Sciences Institute (USC-ISI), undertook research and systems engineering analysis to explore the mission engineering methods, analysis, and metrics needed to transition from a traditional DoD 5000 waterfall development environment to an Agile/DevSecOps environment, including integration of emerging technologies and related education for the future workforce. Many DoD programs are struggling with executing agile development processes in the

DoD framework which includes Preliminary Design Reviews, Critical Design Reviews, Milestone B and C. Systems engineering and agile development need to comply with DoD 5000 without sacrificing the efficiencies of agile development processes. This challenge is particularly an issue in environments – such as at the U.S. Space Force Space and Missile Systems Center, Production Corp (SMC/PC) –that are attempting to transition from a traditional DoD 5000 waterfall process to an Agile/DevSecOps approach, consistent with DoDI 5000.87, in real-time while also incorporating new systems capabilities and functionality. The need to support both approaches during the transition without sacrificing system quality, metrics and timelines is a major challenge - particularly in an environment that relies on different organizations, each with different levels of Agile/DevSecOps experience, to produce mission-critical systems that can't fail when delivered. Finally, there is a critical need to develop a workforce training program that covers both development and management to ensure success of future Agile/DevOps operations.

Over the 18-month period of performance, the project team accomplished the following:

A. Investigated and analyzed the current system software development environment. Analysis included reviews and evaluations of the current information system/software approaches, metrics, and practices. The assessment identified several opportunities for improvement.
B. Developed methods for measuring/monitoring system development during both transition and future development efforts.
C. Developed and piloted related education/training materials and approaches for the future development workforce
D. Provided software system engineering trades/evaluations of mission alternatives, emerging technologies and recommended execution priorities to improve development effectiveness
E. Provided research and engineering support for future system technologies
F. Provided research evaluations of enterprise, segment, external program activities and higher headquarters direction to support deliveries to DoD weapons systems

APPROACH

The project team's approach consisted of simultaneously undertaking the following three activities:

1. Understand the current acquisition environment. The project team immersed into the SMC/PC acquisition environment and became part of the acquisition team. This immersion included working within both the SMC/PC and prime contractor environments. During immersion, the project team collected and analyzed performance metrics and participated in the day-to-day acquisition process to better understand the challenges and opportunities of inserting Agile/DevSecOps into a Waterfall acquisition workflow.

2. Developed approaches to transition acquisition elements from DoD 5000 to Agile/DevSecOps. As part of the immersion process, the project team developed tools and methods for collecting performance metrics, provided recommendations on applying Agile/DevSecOps approaches to the acquisition process and

developed workforce training materials to help transition the government workforce from Waterfall to Agile/DevSecOps

3. Incorporated processes and "lessons-learned" into a transition process to apply to other domains. This effort involved documenting lessons learned from applying Agile/DevSecOps to existing waterfall acquisition processes and generalizing for use in other government acquisition domains

TEST ENVIRONMENT

The acquisition environment served as the test environment for this project. During the project period of performance, the project team was involved in the following three acquisition projects:

1. Project A: A 39-month, 178k source lines of code (SLOC) project that relied on a tradition waterfall acquisition framework. Project A served as the baseline for the analysis comparing the benefits of applying Agile/DevSecOps to the traditional waterfall framework

2. Project B (Hybrid Project): A 25-month, 113k source lines of code (SLOC) project that was composed of both a traditional waterfall effort and an Agile/DevSecOps effort. These two efforts were undertaken in parallel (although the agile effort started 10 months after the waterfall effort, but both efforts finished at the same time), had roughly the same numbers of line of code (Waterfall: 55.4K SLOC, Agile: 57.6K) and were gauged to be similar in source code and system complexity. The complexity of Project B was gauged to be like that of Project A.

3. Project C: A newly started project with an approximate 54-month period of performance. This effort will be mostly an Agile/DevSecOps effort. Source code and system complexity is approximately the same as Projects A and B.

ANALYSIS

The primary focus of this effort was collecting and analyzing performance data from Projects A and B. Two efforts were undertaken; comparing the performance of a Water fall effort against a hybrid Waterfall/Agile effort (i.e., comparing Project A against Project B) and comparing the performance of a strictly waterfall effort against a strictly agile effort (Project A against Project B Agile aspect only)

PROJECTS A AND B ONLY (WATERFALL VS. HYBRID)

Due to the stability of the project requirements, the inability to engage end-users during the development, and the inability to collect manpower allocation data for both projects A and B, the only performance parameters collected and analyzed were open problem reports (PRs). Open problem reports are those problems that are identified, assessed, written-up and assigned to an engineer to be worked. Such problem reports are generally developed during the integration and testing phases of a project. Although it is preferred to include such factors as changing requirements and end-user feedback in analyzing the

benefits (or detriments) that agile brings to a traditional waterfall environment, the project team felt that tracking Open PRs was a sufficient performance metric as such PRs are reflective of the efficiency of an overall project. The more PRs discovered and worked (i.e., fixed), the more manpower that is required and, therefore, the more time and effort required to complete the project.

Throughout both projects, the number of PRs in an Open (unresolved) state were captured at the end of each week of software development (includes integration and testing). The PR counts were plotted on a line graph (Figure 1) to compare the development history of the two software development projects. Because Project A started earlier than Project B, the timeline of the waterfall project (Project A) was shifted so that the Formal Qualification Testing (FQT) period overlaid that of the Hybrid project (Project B). In addition, to account for the differences in SLOC between the two projects, the PR counts of the waterfall project (i.e., Project A) were proportionally reduced using the relative SLOC counts of the waterfall and hybrid projects. The intent here was to be able to compare the PRs apples to apples.

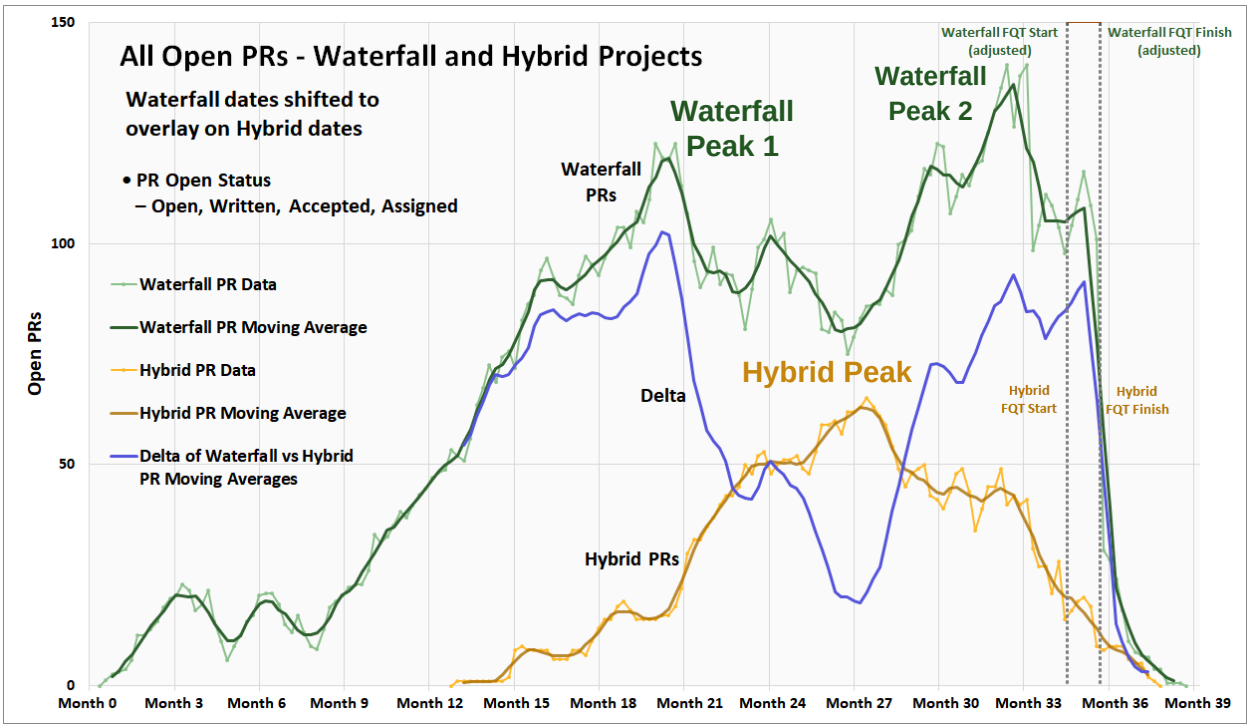

Figure 1 Project A vs. Project B

Referring to Figure 1, the two "PR peaks" for Project A reflect a situation where there were so many PRs identified during CIT (Component Integration and Testing) that the development team was overwhelmed and had to stretch the project out to allow time to address the PRs before completing CIT (the second peak) and then FQT (Formal Qualification Testing). For Project B, the Waterfall and Agile teams worked in parallel, with periodic "merges" that underwent integration and testing. This helped reduce the "PR bow wave" typically experienced in Waterfall efforts because integration problems were discovered early during these "merge" events. In addition, there were three "merge"

events between the waterfall effort and three updates from the base code sustainment effort.

During development of Project A, 2,360 “Open PRs” were recorded. For Project B, 344 “Open PRs” were recorded – an 85.4% reduction in the number of “Open PRs.” In summary, by combining a hybrid waterfall method with an agile method, assuming everything else is constant (i.e., SLOC, code complexity, manpower loading, etc.), an 85.4% reduction in Open PRs were realized without cost or schedule overrun. Although impressive, these results are from two projects that were closely matched in complexity with very little requirement volatility and need for end user engagement.

PROJECTS B ONLY (WATERFALL VS. AGILE COMPONENTS)

For Project B, an analysis was undertaken to compare the performance between the Waterfall portion of the effort compared to the Agile portion of the effort. Figure 2 shows the plot of Open PRs between the two efforts. As previously noted, the code size and complexity between the two efforts were roughly the same, however, the experience level of the agile development team was less than that of the waterfall team members (i.e., the agile effort included “ramp-up” time for the team). In addition, the agile effort started 10 months after the start of the Waterfall effort, yet both ended at the same time during FQT.

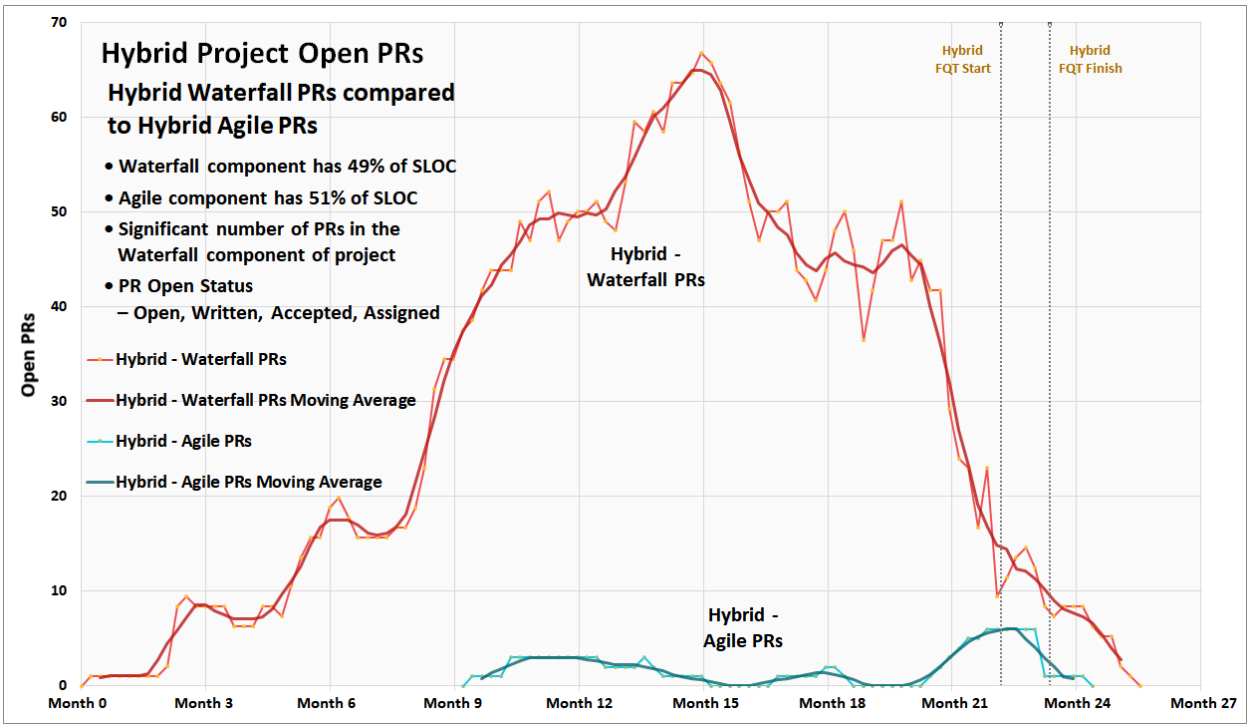

Figure 2 Project B: Waterfall vs. Agile

Over the course of Project B, 330 Open PRs were recorded for the Waterfall portion of the project and 14 Open PRs were recorded for the Agile effort, resulting in a 95.8% reduction in Open PRs...this despite an inexperienced Agile development team that started 10 months after the start of the Waterfall team. Although impressive, these results

don't include the impact of integrating modifications from the system baseline into the Waterfall effort on the overall performance of the Waterfall team.

DISCUSSION

Comparing Project A (Waterfall) with Project B (Hybrid mixture of Waterfall and Agile) the introduction of Agile/DevSecOps reduced PRs and helped keep the schedule and cost from growing. At this point, we only have data from two projects (i.e., Projects A and B). There was limited end-user engagement to influence future agile "builds." The reduction of PRs in Project B (as compared to Project A) can also be attributed to both the introduction of agile and to the introduction of the frequent "merge" events between the agile and waterfall efforts. Data from other projects will need to be collected to fully understand the benefits of introducing Agile/DevSecOps into a traditional government weapon system acquisition environment.

PROJECT C

During the last 10 months of the project, the project team began an initial immersion into a new project named Project C. Project C is focused on implementing an Agile/DevSecOps framework using the Scaled Agile Framework ® from Scaled Agile[1]. Project C will enhance an existing platform that was developed using Waterfall. Code complexity is very similar to projects A and B. Like Project B, the new project exists within an acquisition management system that still relies on waterfall metrics (lines of code written/tested, number of PRs reported and worked off, etc.).

[1] https://www.scaledagileframework.com/

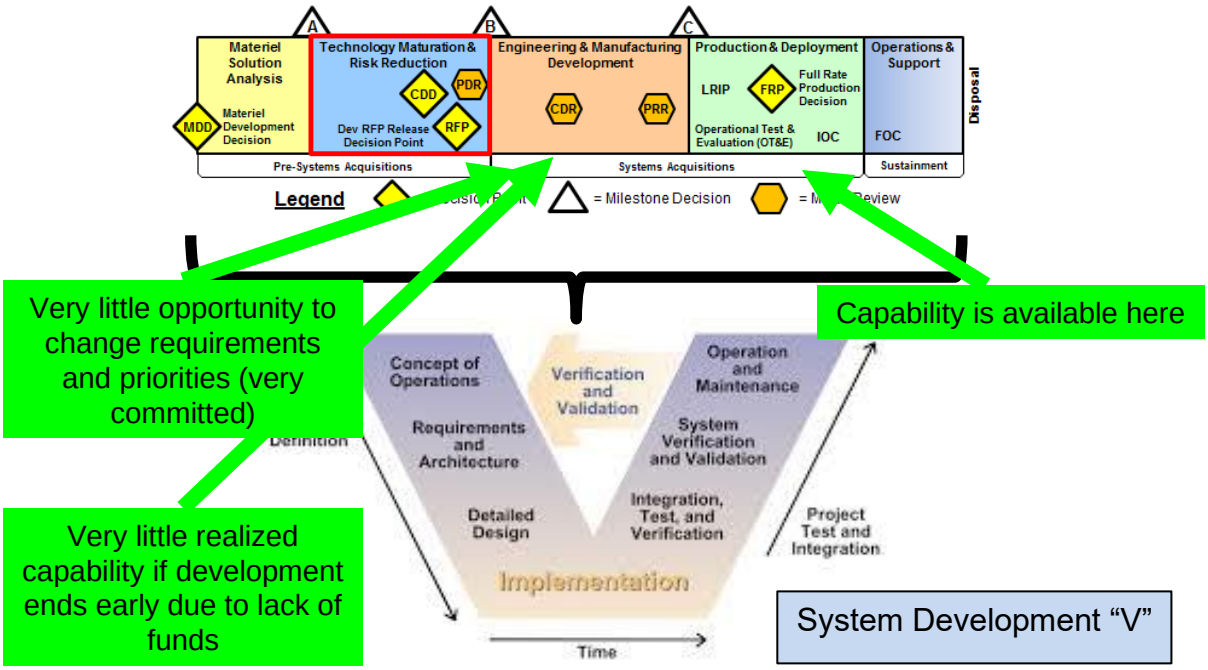

Figure 3 Mini System Development V

During the last 10 months of the project, the project team focused on the development of training materials and presentations to introduce the Government acquisition team to the Agile development framework and how to transition from the Waterfall effort. This effort focused on developing "Rosetta Stones" to map agile concepts to waterfall markers. Issues such as how requirements are tied to capabilities, capabilities are comprised of features; features comprised of user stories; and how user stories may break down into tasks were covered. Other topics covered included how a capability can span multiple Program Increments (PI), that features must be completed within a PI; and that stories will follow a 2 or 3-week sprint cadence. Performance is measured by capability produced, not SLOC. Additional concepts covered include the relationship between project backlogs, velocity, capability, SLOC, PDR, CDR, FQT, and other Agile and Waterfall constructs.

Key to the translation is to first view the traditional Waterfall environment as a "System Development V" (Figure 3) and each Program Increment (PI) as a miniature "System Development V" (Figure 4).

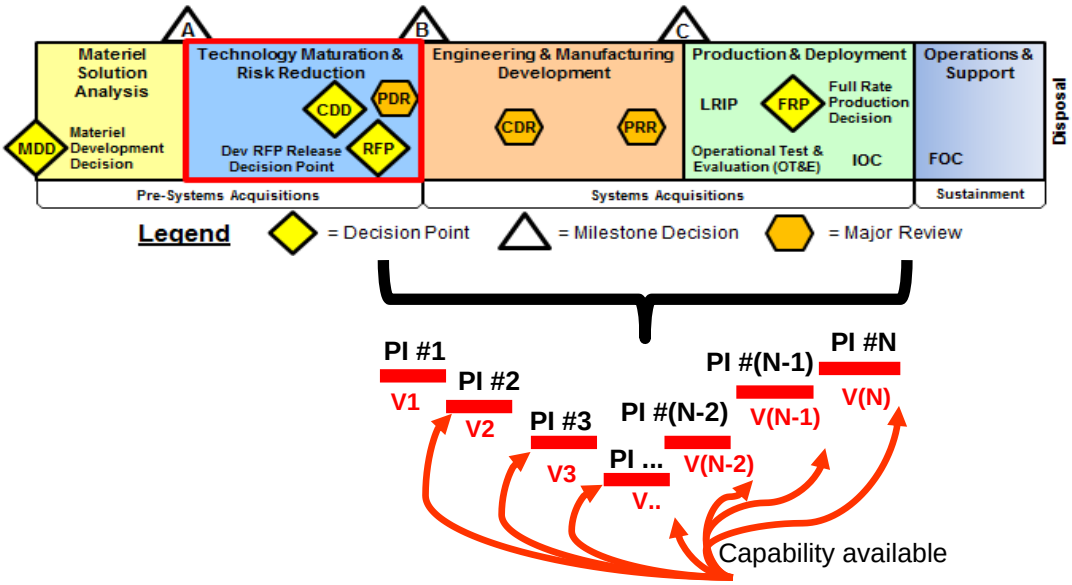

Figure 4 Each Program Increment (PI) is a Mini-Development Systm V

LESSONS LEARNED

One of the objectives of the WRT-1012 project was to generate a list of recommendations that can be generalized and applied to other government acquisition projects. A key recommendation is workforce training. Many members of the government acquisition environment are experts in the waterfall method of systems development and, in some cases, have knowledge of the Agile/DevSecOps approach, but few have practical experience in working in the Agile/DevSecOps environment. Another key recommendation is ensuring the appropriate performance measuring tools are available for collecting performance metrics to help monitor the development process. Also important is the need for Agile "champions" in both the contractor and government environments. This is particularly true when first introducing the Agile/DevSecOps method in a traditional Waterfall development environment. Finally, it is essential that the project schedule include "ramp-up" time to allow members of the acquisition environment – in both the contractor and government sides of the effort – to become familiar with Agile/DevSecOps approaches, consistent with DoDI 5000.87, and their relationship to traditional Waterfall markers.

CONCLUSION

After adjusting for differences in periods of performance and software lines of code, the hybrid Waterfall/Agile project (Project B) produced approximately 85.4% less problem reports (PRs) than the traditional Waterfall project (Project A). Both projects exhibited approximately the same level of software and systems complexity.

Comparing the performance between the Waterfall and Agile portions of the Hybrid project (Project B), the Agile effort produced approximately 95.7% less problem reports

compared to the Waterfall portion of the effort. Both efforts exhibited similar code complexity and software lines of code, however, the Agile effort took 10 months less time to complete and its workforce was considerably less experienced than the Waterfall team.

Although impressive, these results represent one data point and the focus was only on measuring problem report performance between very well-defined projects. Issues such as rapidly adjusting to changing system requirements, end user engagement (feedback) and impacts of merges from base code (sustainment) modifications were not included in the analysis. For the most part, system requirements were well defined and remained stable throughout the development and testing efforts of both projects. End user engagement was not possible due to availability and for the most part – not needed due to the nature of the projects.

During the last 10-months of the period of performance, the project team began embedding into a new project (Project C). Project C is focused on using an Agile/DevSecOps framework in the development of a next generation system. Using lessons learned from the two prior projects, the project team is providing subject matter expertise, developing performance metric measuring tools and developing and applying workforce training materials to the project team. The plan is to actively engage, participate and collect performance metrics throughout the lifecycle of the project.

Finally, workforce training, embedding Agile/DevSecOps "champions" into the development environment and introducing "ramp-up" time into the development schedule to allow the workforce time to adapt to the Agile/DevSecOps method is highly recommended when transitioning from waterfall to Agile/DevSecOps, consistent with DoDI 5000.87.

PROJECT TIMELINE & TRANSITION PLAN

What is the long-term transition goal for the research if continued? Enable SMC and partner organizations to transition from the existing DoD 5000 Waterfall system development framework to the more flexible Agile/DevSecOps approach. This goal includes documentation and implementation of the necessary platform, tools, and workflow approaches.

List the potential tools, guides, educational units, or other artifacts that resulted from this research that might be used by external sponsors if the long-term transition goals are met? One of the goals of this project was the development of performance measurement tools that track Agile/DevSecOps performance, but meet the reporting needs of the US Government. Some of the tools developed to date and in use:

- **Excel-based Kanban viewer**: MS Excel-based tool that enables viewing Jira issue exports in a Kanban format
- **Excel-based Jira issue viewer**: MS Excel-based tool for off-line viewing of Jira issues
- **Excel-based Jira visualization tool**: MS Excel-based tool providing a dashboard view of Feature Team progress status based on data from

periodic Jira issue exports

- **Software Problem Analysis Tool**: MS Excel-based tool used to track problem reports (PRs) created during integration and testing of system components

The project team also provided training materials to be used by the US Government to guide the transition of other traditional waterfall development/acquisition environments to an Agile/DevSecOps process. Included in these guides are lessons learned and recommendations/metrics that indicate when Agile/DevSecOps is not the appropriate approach to take for a specific program.

Which of these might be or are planned to be incrementally delivered in a future research task? We plan to incrementally deliver various versions of the performance measurement tools in the follow-up project. For example, we are currently using the tools for a new project underway at SMC/PC.

Did you identify any transition partners? Are there other advocates or potential adopters of this research? The SMC/PC team will be the primary benefactors of these deliverables and will be involved in using/testing various releases of the technology. In addition, these tools will be introduced to the prime contractors developing technology for SMC/PC. We are also looking to introduce the tools and processes developed to other agencies of the US Government that have similar challenges in systems acquisition.

1. Was the research piloted with a potential transition partner? Are there others who would conduct pilot use of the research if fully funded? SMC/PC is currently using the performance monitoring tools. In addition, training materials have been developed and used to introduce how Agile/DevSecOps is implemented in a newly started project.

APPENDIX A: LIST OF PUBLICATIONS/PRESENTATIONS RESULTED

Orosz, M., Evans, J., Duffy, B., & Charlton, C. (2020). Global Positioning Systems – Mission Engineering and Integration of Emerging Technologies (Update), Presented at 12th SERC Research Review, On-line.

Orosz, M., Evans, J., Duffy, B., Charlton, C., & Mitchell, R. (2019). Global Positioning Systems – Mission Engineering and Integration of Emerging Technologies, Presented at 11th SERC Research Review, Washington DC.

APPENDIX B: CITED AND RELATED REFERENCES

Advanced Maui Optical and Space Surveillance Technologies Conference, 2017

Blake, T., (2015). DARPA Perspective on Space Situational Awareness, International Symposium on Sustainable Space Development and Space Situational Awareness, 2015

Brey, D., Crowe, P., Nidiffer, K. Walker, J., Boardman, R., Matuzic, P., Carlson, R., & Molin, C., (2014). Agile Software Teams: How They Engage with Systems Engineering on DoD Acquisition Programs, https://apps.dtic.mil/sti/pdfs/ADA610363.pdf. TECHICAL NOTE, CMU/SEI-2014-TN-013, Software Solutions Division, July 2014.

Drews, P. & Shirmer, I. (2017). Bimodal Enterprise Architecture Management. IEEE international Enterprise Distributed Object Computing Workshop, 2017

Hoffman, R., Metzger, A., Nelson, C., Taylor, O., Postupack, M., & Babcock, C., (2015). DoD Acquisitions Reform: Embracing and Implementing Agile, https://www.airuniversity.af.edu/Portals/10/ASPJ/journals/Volume-29_Issue-6/DoD_Acquisitions_Reform.pdf, Air & Space Power Journal, Air University, Maxwell AFB, AL, November 2015.

Maurer, Harprit, Grewel, & Frank. (2007). Scaling Agile Methodologies for Developing a Production Accounting System for the Oil & Gas Industry. IEEE Computer Society, 2007

Morgan, D. (2009). Covert Agile: Development at the Speed of… Government? 2009 Agile Conference

Rouse, M. (2018). Search IT Operations, https://searchitoperations.techtarget.com/definition/blue-green-deployment, Sept 12, 2018

Strategic Space Command and Control (C2) Concept of Operations (CONOPS), 13 Jul 2017

Strategic Space Situational Awareness (SSA)/Indications and Warning (I&W) Concept of Operations (CONOPS), 13 Jul 2017

Wrubel, E., & Gross, J., (2015). Contracting for Agile Software Development in the Department of Defense: An Introduction, https://kilthub.cmu.edu/articles/journal_contribution/Contracting_for_Agile_Software_Development_in_the_Department_of_Defense_An_Introduction/6572768/files/12057812.pdf. TECHNICAL NOTE CMU/SEI-2015-TN-006, Software Solutions Division, August 2015