Houston, We Have a Success Story: Technology Transfer at the NASA IV&V Facility

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ABSTRACT

This paper details, from the point of view of researchers and from the point of view of program managers, the development of and technology transfer from NASA's research program in Independent Verification and Validation (IV&V).

Categories and Subject Descriptors
D.2 Software Engineering, D.2.4 Software/Program Verification – *reliability, validation,* D.2.1 Requirements/Specifications – *tools*, D.2.9 Management - *Software quality assurance (SQA)*

General Terms
Management, Measurement, Documentation, Experimentation, Human Factors, Verification.

Keywords
Technology transfer, Independent Verification and Validation, Research.

1. INTRODUCTION
Our Position: A shift in research management focus at the National Aeronautics and Space Administration (NASA) Independent Verification and Validation (IV&V) Facility has lead to a seven-fold increase in research results being applied to actual NASA projects over a three-year period.

Background: Software IV&V is a systems engineering process employing rigorous methodologies for evaluating the correctness and quality of the software product throughout the software life cycle.[1] Here, "Independent" means that the organization conducting IV&V is financially and managerially separate from the development organization. The IV&V organization should have no bias or conflict of interest. Verification is the practice of ensuring that a product meets all applicable specifications. Validation is the practice of ensuring that the product will actually fulfill its intended purpose.

NASA's IV&V Facility[2] manages and conducts research to improve its own processes and to advance the state of software engineering across NASA. The reasons to engage in research are fivefold. The IV&V facility wants to (a) advance the practice of software assurance and software engineering across NASA developers and (b) to improve the IV&V Facility's current practices. In a longer term, the Facility wants (c) to expand beyond current practices and (d) to be able to adapt to new software development technologies. Finally, (e) the Facility is keenly interested in being able to adapt to new technologies beyond the realm of software development.

Since its inception, the IV&V Facility has managed and conducted research in support of various combinations of the above objectives. Initially, the Facility was delegated responsibility of the Software Assurance Research Program (SARP). The NASA Office of Safety and Mission Assurance (OSMA) established SARP to advance the practice of software assurance and software engineering across NASA developers. SARP was and remains a competitive research program with researchers at the NASA Centers, contractors, and universities submitting research proposals each year. In addition to the SARP program, the IV&V Facility also entered into a cooperative agreement with West Virginia University (WVU) that served to augment the IV&V Facility's internal research capabilities with WVU professors.

This paper discusses the story of the Facility-sponsored research on IV&V from both the research managers' and the researchers' perspectives. We track changes in the overall research program goals over time and describe how researchers had to adjust their work to meet these goals. In describing the research process this way, we point out the synergy between the

[1] IV&V Internal Strategic Plan, July 2002, Page 4

[2] The loss of Space Shuttle Challenger increased NASA's awareness of the need for enhanced safety and mission assurance practices, including IV&V. In 1993, NASA established the IV&V Facility in Fairmont, West Virginia (U.S.A.) as part of an agency-wide software strategy to provide the highest achievable levels of safety and cost-effectiveness for NASA mission-critical software. The IV&V Facility initially performed IV&V on manned space vehicles: the Space Shuttle and the International Space Station (ISS). In recent years, the Facility's role has expanded to include observatories, satellites, and robotic missions. The majority of high criticality NASA missions undergo IV&V via the IV&V Facility. The Facility currently employs approximately 45 civil servants and 200 contractors.

two sides and outline the key components of the success of the program.

Section 2 briefly describes the history of the software assurance research at NASA. Section 3 presents an overview of a research project from the academic viewpoint. The NASA (research acquirer) viewpoint of the IV&V research program is presented in Section 4. Finally, Section 5 discusses the success of the technology transfer program and suggests some best practices.

2. THE STORY OF THE PROGRAM

Since inception, and until 2003, SARP research proposals were for one-year efforts. Researchers had to re-propose each year for follow-on work. Research at the IV&V Facility enjoyed periods of success and periods that were not as successful. As with most research programs, *success or failure is not measured on an absolute scale*. Research success is measured *relative to the objectives of the funding body and those who manage the research*. At the IV&V Facility, these objectives went through an evolutionary process, as discussed below.

In April 2000, the management of the IV&V Facility, including IV&V research, was completely restructured. NASA moved the administrative control of the IV&V Facility from Ames Research Center (ARC) to Goddard Space Fight Center (GSFC) and appointed Dr. Linda Rosenberg from GSFC to oversee the research effort, while Kenneth McGill (the first author) became the Research Lead at the IV&V Facility. Although he had previously managed a research and development effort, Mr. McGill was a project manager, not a researcher. His background was in system safety and weapon system acquisition.

The new management team quickly identified needed changes. A support contractor responsible for maintaining the database of research deliverables told the first author: "Nobody uses this stuff." A quick review of the supported research concluded it was valid and legitimate work, but found no evidence that research results were being applied at NASA. The list of recommended research topics was found to have no relationship to problems actually faced by NASA software developers. The initial months under new management resulted in a major paradigm shift and a new definition of successful research. Success was now defined in terms of relevance to NASA missions.

Within two years after establishing a focus on transferring research results to NASA projects, two significant challenges arose causing the research team to re-evaluate its definition of success again:

- The IV&V Facility received "research" proposals for project development that were specific to only a single project. The individuals managing SARP determined that these were not research but were project development. The definition of a successful research project was thus expanded to include *external validity*, and
- On the opposite end of the spectrum, contractors performing IV&V stated a need for custom tools which integrated multiple existing capabilities into a single package. After careful consideration, the SARP management team determined that this concept could not be considered legitimate research. This and similar experiences led the SARP management team to include *acceptance in peer reviewed publications* as a measure of success.

Throughout this time, SARP remained focused on software assurance at the Agency level. This focus corresponds to the first of the five broad reasons for the IV&V Facility to participate in research. To meet the more specific research needs of the IV&V Facility, the Facility Director, Dr. Ned Keeler, set aside discretionary funds. These funds have allowed for a separate research program focused on the other four broad reasons. This program is termed the Director's Discretionary Fund (DDF) Research. Both SARP and DDF Research are currently managed through the exact same processes. The only difference is the manner in which research initiatives are selected. These experiences were captured concisely as research objectives in the 2005 version of the IV&V Facility implementation plan[3]:

a. Research addresses validated NASA software assurance and IV&V Facility needs for both current challenges and anticipated future changes.
b. The appropriate blend of basic and applied research is maintained.
c. Research is accepted in leading peer-reviewed journals and conferences.
d. Research has a clear path to technology transition.
e. Research is externally valid beyond the environment in which it was conducted.
f. Research results are communicated to the Facility, the Agency, and the public as appropriate.[4]

3. A STORY OF A PROJECT

Since the Spring of 2002, the IV&V Facility has supported a project at the University of Kentucky (UK) headed by two of the co-authors. The key idea investigated at UK is the use of information retrieval (IR) and data/text mining techniques to automate and facilitate requirements tracing, one of the most tedious and time-consuming steps of the IV&V process.

Key results of this project have been reported in [RE03, RE04, MSR04, PROMISE05, IJSEKE'05, SOFTWARE'05, NASAJ'05, MSR'05, TEFSE'05, TSE'06, CSEET'06]. The UK investigators have shown that information retrieval methods are good enough to provide candidate traceability matrices and can be used by IV&V analysts in a feedback loop to shape the final requirements traceability matrix (RTM).

The story of the project is separated into several areas: co-PI expertise, uniqueness of NASA research grants, communication, tool development, and how all these factors resulted in successful technology transfer.

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[3] 2005 IV&V Facility Implementation Plan

[4] Additional information on the IV&V Facility's research can be found at: http://www.ivv.nasa.gov/forresearchers/index.php. Selected research finding from both SARP and DDF research are publicly available at: http://sarpresults.ivv.nasa.gov/

3.1 Expertise of the co-PIs

The two co-PIs had distinctly different backgrounds at the outset of the project: one being a software engineering expert with significant industry experience and expertise in IV&V, but with only basic knowledge of the underlying technology to be employed; the other being a computer scientist working in the areas of databases and artificial intelligence, teaching an Information Retrieval course at the time, but with little knowledge of IV&V and no industry experience. As the project proceeded, the combined expertise of the co-PIs made it possible to achieve practical advances in the project at a pace and of a significance that would not have been possible individually by either co-PI.

3.2 Uniqueness of NASA Research Grants

The two co-PIs have had funding from a number of disparate sources over their careers: National Science Foundation (NSF), U.S. Nuclear Regulatory Commission (NRC), Electric Power Research Institute (EPRI), and the Richter Foundation, to name a few. Comparing the NASA-sponsored project to these others, it is clear that the differences outweigh the similarities. Similarities include: requirement for proposals describing innovative and original research with important impacts, level of competition for the funding, desire to positively impact software engineering quality, etc. The NRC, EPRI, and NASA grants all required a much larger number and variety of deliverables than the others. For example, it is not unusual to present program management reviews (PMRs) highlighting progress to date on tasks and deliverables, status of funds expenditures, any open issues, etc. to the research sponsors on a quarterly basis. This was not a significant burden, as one co-PI had come from industry and was very accustomed to such requirements. Most academics might find this limiting or constraining or burdensome, however.

The NASA research sponsors hold an annual research symposium, bringing together the researchers, sponsors, as well as the programs who will benefit from the research. This venue resulted in a number of technology transfer success stories for us. For example, the UK co-authors met Mike Chapman of the Metrics Data Program (MDP), who assisted us by providing sanitized NASA project data for our research, Tim Menzies who convinced us to contribute some of our datasets to the PROMISE[5] data repository, several practitioners who were interested in using our technology, etc. Frequent informal interaction with the NASA research sponsors occurred as well.

The NRC, EPRI, and NASA grants had a huge benefit, in our opinion - they came with real problems for real projects. Because their overall mission is being impeded by lack of the research and advances, they have defined problems and issues and are personally invested in the success of the research. Even proposal assessment differs - NASA proposal review is performed by not only academicians and researchers (Jet Propulsion Laboratory) but also contractors, project managers, and practitioners who have a desire to have their problems solved.

3.3 Communication

Communication is a mindset of the NASA IV&V Facility employee. The UK co-PIs have found their NASA contacts to be very forthcoming with information and tools to provide information There are also many opportunities to provide feedback to NASA on the research program as a whole. **And we have seen our feedback put into action**. For example, in 2002 there was little emphasis on publication of results in academic venues. At the suggestions of the PIs of different research initiatives, this emphasis was restored.

In addition, NASA goes to great lengths to foster and encourage communication between all of the various parties working with them: researchers, practitioners, contractors, civil servants. The UK co-authors were introduced to representatives of projects with interest in automating traceability. This assisted in obtaining data for the project. In short, the ability of the project co-PIs to engage in extensive communication with NASA contacts made the project much more efficient and less frustrating.

3.4 Tool Development

Another area in which NASA's project management policies have significantly contributed to the success of the traceability project at UK is software development. NASA emphasizes deliverables and encourages research teams to deliver code developed in the course of the project. To support research and experimentation on the project, the UK team developed a special-purpose tracing tool RETRO (REquirements TRacing On-target) [RE04, TSE06]. The original version, developed for internal use, ran under Linux OS and had a primitive GUI. During consultation with NASA contractors working on tracing projects at the IV& V Facility, it became apparent that there is significant interest in a standalone, special-purpose, lightweight requirement tracing tool, that can be integrated into the processes employed by contractors for requirements tracing. At NASA's suggestion, the UK research team productized RETRO. The development was split into two branches: the older *research version* included a wider range of methods (some – utterly unsuccessful at the tracing task), while the new *NASA version*, developed for the Windows platform, stressed usability and functionality facilitating interaction with users but included only the most successful methods.

Working on the NASA project allowed the UK team to field-test the NASA version of RETRO with one of NASA's IV&V contractors. During the field test, it became apparent that the delivered tool suffered from all of the ailments commonly seen in "academic software." This is not surprising, considering that the software was developed by several M.S. and Ph.D. students working in the emerging research group who were not used to collaborating on software development tasks. Senior software analysts with NASA's contractor quickly uncovered "scalability and usability problems" with the tool. By working with NASA and the IV&V contractors, the UK team was able to not only improve that first delivered product, but was able to develop a successful process for making academic software "NASA worthy." In August 2005, RETRO version 2.0, with a brand new front-end and enhanced functionality was delivered to NASA. This time, the UK team and the IV&V contractor were able to establish a real-time collaboration on testing: all bugs discovered during the field test were fixed within 24 hours of being reported.

3.5 Successful Technology Transfer

NASA's desire for successful technology transfer is exemplified in one of their key measures of project success: *Penetration*

[5] http://promise.site.uottawa.ca/SERepository/

Factor (PF) (developed by Dr. Tim Menzies, WVU liaison to the IV&V Facility). The values for PF are defined as follows:

9: Results actually used by project
8: Data passed back to project
7: Data used by researcher
6: Data passed to the researcher
5: Project agrees to provide data to the researcher
4: Positive response to contact
3: Project contacted
2: NASA project targeted
1: No project targeted

The PF factor of research grants is reported to NASA at every quarterly review. This reveals to NASA how well the project is doing at getting others to use its results. The UK team was inspired to work very hard to increase the penetration factor of the project at each review to ensure that the highest level was achieved as soon as possible.

In summary, working with NASA has been a very successful undertaking for all parties involved: the UK team has been able to perform interesting research on real problems working with real programs and real data. NASA practitioners have benefited from the project's results. In addition, dissemination of research results in high quality venues has been very successful [RE03,RE04,MSR04,MSR05,IJSEKE05,SOFTWARE05,TSE06].

4. VIEW FROM THE TOP

From the IV&V Facility point of view, it took considerable effort to achieve success as defined by NASA. It was an evolutionary process requiring many small steps, none of which yielded immediate results. The following are the steps taken.

The first step was to *overcome adversarial relationships with researchers*. In most cases, the situation was improved by showing a higher level of respect for the researchers and by establishing realistic requirements.

Another early step was *to revise the research topics list to bring it in line with the needs of actual NASA software developers*. As no single individual could capture the breadth of software assurance research needs across NASA, the IV&V research management team asked for input from OSMA, from the NASA Software Working Group – Software Assurance Subgroup, and from IV&V practitioners. In 2004, Wes Deadrick (the second author) of the IV&V Facility conducted a formal research needs survey of the IV&V Facility personnel and contractors. He then condensed the results and validated them in a review. This new list of needs was distributed as a guide to help in the preparation of DDF research proposals for 2005.

NASA uses a **"Level 1 Plan"** as a means of soliciting research proposals from NASA Centers. The IV&V *Facility added selection criteria* to the SARP Level 1 Plan. These criteria included "*relevance to software assurance*" and "*potential for technology transfer*."

Based on experience with SARP, the first author determined that grading should be on the basis of: 1) how well the research met *the original selection criteria to include potential for technology transfer*, 2) *Project penetration:* the degree to which a research initiative had formed a relationship with a NASA development or IV&V Project, and 3) *Publication impact* - the frequency of publications in peer-reviewed conferences and journals.

NASA OSMA hired Martha Wetherholt as the Agency point of contact for software assurance. Headquarters responsibility for SARP eventually transferred from Dr. Rosenberg to Mrs. Wetherholt. She and others had realized that one-year funding resulted in a lack of stability within SARP. In this capacity, she pushed for *three year funding of SARP initiatives*. This had previously been thought of as an insurmountable barrier. Strong communication between the IV&V Facility and Dr. John Kelly, representing the NASA Office of the Chief Engineer (OCE), made this change possible.

Dr. Ned Keeler, the IV&V Facility Director at the time, **made a significant contribution** by mandating that *all research initiatives directly managed by the IV&V Facility have a designated Point of Contact (POC*) chosen from the ranks of IV&V Project Managers. Appointing IV&V Project Managers as POCs formed a potential link between the research project, IV&V projects that the POC was managing, and the actual development projects undergoing IV&V.

5. WHERE DID WE GO RIGHT?

Figure 1 shows the increase in the PF for SARP and IV&V DDF research over the past three years. Note that the percentage of research initiatives having a PF of 9 has increased by a factor of seven. In the opinion of the authors, this dramatic increase is due to the implementation of the changes outlined above. These improvements follow the new three-year lifecycle of the sponsored projects. The project PIs have known from the beginning that their research needed to transition to a NASA project. The IV&V Facility has found that researchers are very willing to comply if the expectations are clearly spelled out. Hence, much of the credit goes to the researchers themselves.

The figure also shows a two-fold increase in the number of research initiatives achieving a PF of 7. Much of this increase can be attributed to the availability of actual NASA project data on the internet. The IV&V Facility maintains the MDP website containing sanitized artifacts from past projects. While these artifacts are very useful in helping a research initiative get to PF 7, a project that depends solely on MDP for artifacts cannot get beyond a PF of 7 as interaction with an Active NASA project is required.

The IV&V Facility research management team maintains that it has increased the flow of technology from research to actual practice by conducting research that is externally valid as well as accepted in leading conferences and journals.

Additionally, the researchers feel that a few other best practices have contributed to this success:

- Researchers should collaborate with other researchers where the combination of expertise is synergistic.
- Research acquirers should provide venues that allow researchers and practitioners to interact.
- Research acquirers should have a vested interest in the research success, and use proposal assessment processes that reflect that vested interest.
- Frequent communication, formal and informal, is a must.

- Research acquirers and researchers should poll each other for suggestions on improving the overall program, and then follow through.

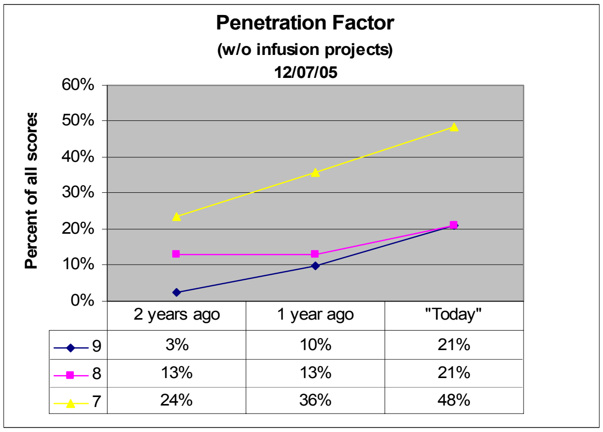

Figure 1. Penetration Factor Improved 7-Fold over Three Years.

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