An approach to Return on Investment (ROI) for Independent Verification and Validation (IV&V) at NASA

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Dulos, Inc.
Exceptional Service
The NASA IV&V Program was established in 1993 as part of an Agency-wide strategy to provide the highest achievable levels of safety and cost-effectiveness for mission critical software.

The NASA IV&V Program was founded under the NASA Office of Safety and Mission Assurance (OSMA) as a direct result of recommendations made by the National Research Council (NRC) and the Report of the Presidential Commission on the Space Shuttle Challenger Accident.

IV&V is an Agency-level function, delegated from OSMA to Goddard Space Flight Center (GSFC) and managed by NASA IV&V. The NASA IV&V Program's primary business, software IV&V, is sponsored by OSMA as a software assurance technology. Having been reassigned as GSFC, NASA IV&V is Code 180 (Center Director's direct report).
What is Independent Verification and Validation (IV&V)?

• Verification answers the question, "Are we building the product right?" Verification is the process of determining whether or not the software products of a given phase of the SDLC fulfill the established requirements for that phase.

• Validation answers the question, "Are we building the right product?" Validation evaluates the software products throughout the SDLC to ensure those products meet the mission and customer's needs.

Verification often a by-product of bugs i.e. Microsoft
Validation a by-product of mission failure i.e. AF C130J
What is Independence?

- **IEEE** defines independence in IV&V as three parameters:
  - **Technical independence** is achieved by IV&V practitioners who use their expertise to assess development processes and products independent of the developer.
  - **Managerial independence** requires responsibility for the IV&V effort to be vested in an organization separate from the organization responsible for performing the system implementation.
    - The IV&V effort independently selects the segments of the software and system to analyze and test, chooses the IV&V techniques, defines the schedule of IV&V activities, and selects the specific technical issues and problems to act upon.
    - Most projects view V&V as sufficient and do not recognize the added value the independence brings.
  - **Financial:** Typically funded from Corporate General & Administrative (Expense). Projects may directly fund services.
What is Software IV&V?

- A systems engineering process employing rigorous methodologies for evaluating the correctness and quality of the software product throughout the SDLC.
- Is adapted to the characteristics of the project
- Independence is provided through various “authority”
  - Air Force - Independent Readiness Review Team (IRRT)
    - More reactive to already known troubled projects
    - Assigned by a committee/Senior command
    (The Role of Independent Assessments for Mission Readiness; Crosslink Fall 2007)
  - FAA – Designated Engineering Representative (DER)
    - Proactive with an assigned DER at project inception
    (FAA CONSULTANT DER DIRECTORY June 20, 2011)
  - NASA - NASA IV&V Facility; 100 University Drive Fairmont, WV 26554
    - Commercial Vendors – SAIC; TrustedQA; (and more; see slide 10)
  - IV&V is Defect Discovery, and does not include fixing defects
Return On Investment (ROI)

ROI is a performance measure used to evaluate the efficiency of an investment or to compare the efficiency of a number of different investments. To calculate ROI, the benefit (return) of an investment is divided by the cost of the investment; the result is expressed as a percentage or a ratio.

A return on investment formula can be expressed as:

\[
\text{ROI} = \frac{\text{Gain from Investment} - \text{Cost of Investment}}{\text{Cost of Investment}}
\]

For NASA the key questions become:

1. What was the gain – Tangible and Non-tangible or fiscal and non-fiscal?
2. What was the cost of the investment?
• Data from March 2008 KPMG WebEx

• QA/IV&V can typically cost 5 to 10 percent of the total cost of an IT project, depending on the complexity of the project and the specific scope of QA/IV&V activities*

• Several studies indicate that the ROI on QA/IV&V investments can be 2 to 10 times the investment in QA/IV&V activities**

[Graph: Direct IV&V Return on Investment by Technique]

• NASA PAE 2008 Study show ROI values from 1.5 to 12; but says, “There is a wide range of opinions and studies regarding the cost effectiveness of IV&V. The study team was unable to identify a common methodology for calculating ROI, and individual Case Studies using the same methodology resulted in a range of values.


**A Case Study of IV&V Return on Investment (ROI), R.A. Rogers, D. McCaugherty, F. Martin, NASA, October 2000
Additional ROI Studies

• Using Software Process Simulation to Assess the Impact of IV&V Activities; David M. Raffo, Umanath Nayak, Siri-on Setamanit, Patrick Sullivan, Wayne Wakeland; Portland State University, Portland, Oregon, USA

• ESTIMATING DIRECT RETURN ON INVESTMENT OF INDEPENDENT VERIFICATION AND VALIDATION, James B. Dabney (Department of Systems Engineering, University of Houston), Gary Barber, Titan Systems Corp., NASA IV&V Facility

• ESTIMATING DIRECT RETURN ON INVESTMENT OF INDEPENDENT VERIFICATION AND VALIDATION USING COCOMO-II, James B. Dabney (Department of Systems Engineering, University of Houston), Gary Barber, Titan Systems Corp., NASA IV&V Facility

All these studies have interesting approaches, but are difficult to apply when looking forward.
How Does IV&V Differ from Project Testing

- The Key difference is “independence”

- Hailpern and Santhanam: "... debugging, testing, and verification activities can easily range from 50 to 75 percent of the total development cost. “ (Software debugging, testing and verification by Hailpern and Santhanam, 2002, see http://www.research.ibm.com/journal/sj/411/hailpern.pdf)

- Data from The Case for Automated Software Testing (Bernie Gauf and Elfriede Dustin, IDT; Software Tech News)

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What Should You Pay for IV&V

• You would expect IV&V cost to at least equal internal defect discovery costs – unless less testing is required

• An increase factor of up to 2.0 is not unrealistic for “complete” IV&V versus Internal Software Project Testing (source Bob Hunt)

• IV&V is, conceptually, pretty simple:
  • Identify the products and processes to undergo verification and validation (preferably before or in the early stages of development),
  • Determine the criteria with which each of those products and processes can be evaluated (starting with standards where available e.g. the IEEE-1012-2004 standard for software verification and validation),
  • Assess the products/processes while in production and upon completion to verify they meet the predefined criteria and note where they don’t,
  • Re-assess products/processes when deficiencies have been addressed.

• IV&V Vendors are very protective of any internal methodology they use to estimate IV&V costs - Then they guess
**IV&V Cost Equation**

**Assumptions:**

- A Software Development program has a Total Development Cost of $X = (x/SM)(SM)$* (simplistic express of software equations)
- The Cost of Internal Software Testing (IST) is 30% of the total Software Development cost, or IST = (0.3)($X) = (0.3)(x/SM)(Zsize)
- IV&V cost equals IST or IV&V = (1)(0.3)(x/SM)(Zsize)
- There are Y delivered defects per size metric
- The cost per size metric to rewrite code is the same as the cost per size metric to generate original code
- The Cost of Defect Recovery and Removal follows the “1:10:100” rule and all “Y” defects would have been found after fielding

**The simple cost Break Even Point is reached when:**

- IV&V cost = IV&V Savings
- (1)(0.3)(x/SM)(Zsize) = (100)(Y)(x/SM)
- (0.3) Zsize = 100Y
- (0.3)Zsize/100 = Y

*SM – size metric could be expressed as Lines of Code, Function Points, ...

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Some Data

• Assume 7 to 10 delivered defects per KSLOC
• Code Complete by Steve McConnell:
  • (a) Industry Average: "about 15 - 50 errors per 1000 lines of delivered code.
  • (b) Microsoft Applications: "about 10 - 20 defects per 1000 lines of code during in-house testing, and 0.5 defect per KLOC (KLOC IS CALLED AS 1000 lines of code) in released product (Moore 1992).
  • (c) "Harlan Mills pioneered 'cleanroom development', a technique that has been able to achieve rates as low as 3 defects per 1000 lines of code during in-house testing and 0.1 defect per 1000 lines of code in released product (Cobb and Mills 1990). A few projects - for example, the space-shuttle software - have achieved a level of 0 defects in 500,000 lines of code using a system of format development methods, peer reviews, and statistical testing."
• Capers Jones assumes 5 to 7 defects per function point
IS IV&V Worth the Cost

• It depends on who is paying for it, but the answer is yes.

• When critical safety and life issues are at stake (and accidents are averted), the answer is again yes.

• But what does it really cost –
  • Although numbers vary by project and environment, the costs to fix defects average what has come to be known as the "1:10:100" rule. (Achieving Software Quality Using Defect Filters; Randall Rice)
  • A defect that costs $1 to fix in requirements or design costs $10 to fix in a traditional test phase and $100 to fix after the product goes into production (live) use.

  Most ROI studies assume any defects found in IV&V would have made it to production (live usage).
NASA IV&V Benefits
So Far I have Only Looked At Benefits That Can Be Measured In $

1. The IV&V Program increases the likelihood of uncovering high-risk defects early in the development lifecycle
2. The IV&V Program provides ongoing status indicators and performance reporting to NASA program level managers
3. The IV&V Program provides stakeholders with the visibility into progress and quality of the system-software development effort
4. The IV&V Program reduces the need for rework by the developing contractor, and thereby reduces the total costs to programs and development projects
5. The IV&V Program reduces defects in delivered products
6. The IV&V Program may save lives
IV&V Life Cycle Functions

• IV&V Process provides tools and analysis procedures appropriate to each phase of the software development life cycle:
  
  • Formulation Phase:
    • Is development process sound, repeatable, and managed?
  
  • Requirements Phase:
    • Verify that system and software requirements are correct, complete, traceable and testable
    • Analyze system-level requirements: Are test plans and acceptance criteria sufficient to validate system requirements and operational needs?
    • Are testing methods sufficient to verify and validate software requirements?
    • Are the correct software development, management, and support processes in place?
  
  • Design Phase:
    • Does the design support the requirements?
    • Are test plans and test environments sufficient to verify and validate software and operational requirements?
    • Does the design have any characteristics that will cause it to fail under operational scenarios? What solutions are appropriate?
• Typical IV&V functions by Software life-cycle phase (cont.):
  
  • Coding Phase:
    • Does the code reflect the design?
    • Is the code correct?
    • Verify that test cases trace to and cover software requirements and operational needs
    • Verify that software test cases, expected results, and evaluation criteria fully meet testing objectives
    • Analyze selected code unit test plans and results to verify full coverage of logic paths, range of input conditions, error handling, etc.

  • Test Phase:
    • Analyze correct dispositioning of software test anomalies
    • Validate software test results versus acceptance criteria
    • Verify tracing and successful completion of all software test objectives

  • Operational Phase:
    • Verify that regression tests are sufficient to identify adverse impacts of changes

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IV&V Life Cycle Functions

- IV&V identifies deficiencies in program’s test planning
- Program changes their procedures to address deficiencies vice IV&V independently test
- IV&V may independently test highly critical software using an IV&V test bed
  - White box
  - Stress
  - Endurance
  - Limit
- Developer motivated to show software works
- IV&V attempts to break software
**Concerns**

- No salutatory requirement for IV&V, but probably a good policy
- $25 M to $30 M annual budget for NASA IV&V Facility – cost related to specific programs are spread over several years
- No consistent/agreed to measure of ROI – this would be helpful
- Most analyses of ROI assume that defects would not have been found until fielding – therefore they apply the 100 rule (see slide 9)
Closing Thoughts

- No software is delivered defect free
- The larger/more complex a system is the more likely IV&V will result in positive outcomes
- It is about critical safety and functionality more than cost
- Key Benefits:
  - Early detection.
  - Improved quality
  - Lower Total Cost of Ownership (TOC) cost
  - Reduced management burden
- IV&V is hard work that takes expertise independence, and a degree of rigor
- There is no professional certification of IV&V “engineers”
- Understand you need competent, experienced professionals but this is not a mystical art.

Bottom Line: IV&V is worth the cost

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