IAC-20,D5,1,10,x60415 - A Dialogue on the Digitization of Requirements, Verification, and Test Management with Data-Driven Systems Engineering (DDSE)

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Abstract

Traditionally, hardware design has been a sequential process, requiring a specific number of deliverables, often documents, to keep track of all design data. Given the complexity, and the increase in advanced and interdisciplinary designs, the hardware design community is always looking for better ways of working, to be able to deliver higher quality products while adhering to budget and schedule constraints. Unlike the software industry, which was able to solve issues related to collaboration and traceability to remain agile, the hardware industry is reaching a limit to what is possible with the current tools and processes. This paper identifies critical key principles and practices, crucial to reinventing our way of working in the space hardware industry in the digital era. By using methodologies like Data-Driven Systems Engineering (DDSE), this paper provides solutions to modern day requirement and verification lifecycle problems, from early requirements breakdown, over test procedure definition, up to verification and validation activities, via end-to-end digitization.

Keywords: Systems Engineering, Test management, Verification & Validation

Acronyms/Abbreviations

Analysis, Demonstration, Inspection, and Testing (ADIT)
Concurrent Engineering (CE)
Data Driven System Engineering (DDSE)
European Space Agency (ESA)
Model Based Systems Engineering (MBSE)
Verification and Validation (V&V)

1. Introduction

In safety critical industries, such as space software and hardware, the end product's quality is key to an organization and mission's success and safety. Setting the right foundation, using appropriate tools and resources, and establishing good work practices, through methodology, in the digital environment can have a positive impact on the end result. If done right, large projects, such as development of satellites and rockets, can benefit from a reduction in the time and budget allocated for V&V activities, and overall test management. However, despite adoption of the latest optimized work practices, even experienced engineers find themselves struggling to adapt to projects growing in complexity.

The purpose of this paper is to summarize the qualitative data collected through an advanced workshop on Lean Requirements, Verification and Test-Management for Small Satellites, and to provide recommendations for the obstacles identified by data providers.

This paper will begin with a brief overview of the V&V lifecycle in agile, MBSE, and DDSE, under the assumption that readers have a basic knowledge of systems engineering principles. The following section will detail the methodology for data collection. Results will highlight the primary concerns identified by the participants of the workshop. Leading to the recommendation section, which provides solutions for optimization following the DDSE approach, and finally a concluding summary.

1.1 V&V Lifecycle in an Agile Process

Unlike traditional and sequential methodologies, what sets agile apart is that it is an ever evolving process. Unlike sequential methods, where a delay can have a ripple effect throughout the overall project, agile methodologies divide the development into smaller elements. These elements are subject to frequent reviews through iterations, in order to remain flexible. The end product is built incrementally, expanding upon past iterations while remaining adaptable for instantaneous changes [1].

In the V&V cycle, verification ensures the product complies to the approved high level requirements developed in the early stages of a project or mission. Requirement verification is proven through performance, commonly qualified through the ADIT methods. Validation, on the other hand, ensures the end product meets the customer's expectations. Validation of a product is proven under realistic simulated conditions. Validation tests are what helps determine the effectiveness and fitness of a product, as it is meant to be used in its intended environment. [1].

1.2 MBSE

The MBSE approach captures artifacts of systems engineering to manage complexity, and acts as a means of communication, throughout the lifecycle of a system. MBSE is a tool designed to support systems engineering processes with the objective of having a positive impact on constraints, such as cost and schedule. MBSE connects system relationships, helps control system configurations, and provides an overview of the system to all stakeholders to increase awareness while utilizing the most up-to-date information, from a single source of truth [2].

To take full advantage of what MBSE has to offer, all relevant data, documents, diagrams, models, requirements and specifications must be digitized on a platform which enables concurrent access to facilitate CE. This method of data documentation and exchange optimizes the design process, sets a common standard across the team, and enables rapid response to changes in variables and factors.

While MBSE is a powerful approach which can reduce ambiguities and inconsistencies, the tools which allow for following it have their own shortcomings. They often lack the capability to assist systems engineers with essential functions such as budget tracking, impact analysis, traceability, integration, and optimization. Furthermore, MBSE tools rely on data owned by another process or person(s), resulting in segmented and limited access [3]. Those with access have the additional burden to keep the data up-to-date, falling into a cycle of downloading, updating, and uploading for other users. In such cases several branches of a model can be created unintentionally.

1.3 DDSE

DDSE is a specific flavour of MBSE, which supports systems design and requirements management, with the key differentiation of concurrent access, so collaboration becomes a central element in the design process. Modern software and hardware projects rely on browser-based and cloud-based platforms to increase accessibility by all engineers working on a team. Companies such as Airbus, Planet, Momentus, GOMspace and OHB LuxSpace are leading in innovation through the adoption of DDSE tools.

"DDSE tools manage engineering data in the implementation phase, provide version control, make it available collaboratively and provide full traceability to the entire engineering team" [4].

2. Methodology

The qualitative data for this paper was obtained from the Advanced Workshop: Lean Requirements, Verification and Test-Management for Small Satellites, conducted during the 34th annual Small Satellite Conference. The workshop was moderated by Marco Witzmann, CEO & Co-Founder of Valispace, and Stefan Siarov, Systems Engineer & Marketing Manager at Valispace, on August 5, 2020. The workshop was conducted in the format of a social survey, utilizing the platform ahaslides.com, for participants to answer questions, anonymously and voluntarily. Two forms of questions were asked on the ahaslides platform: open ended questions with the option of providing up to three answers, and multiple choice questions. As participants answered each question they were able to view the answers from their peers and upvote the answers they agreed with. This upvoting resulted in the data discussed in the Results section.

After participants answered the questions, Siarov and Witzmann facilitated a discussion using a semi-structured interview method. The discussion presented an opportunity for the participants to voice their opinions or further expand on the answers provided by other peers. In total six core questions were asked with the purpose of identifying the current methodologies in hardware workflow planning, more specifically focusing on moving from design requirements to verification and testing (as shown in Table 1).

Due to the global COVID-19 restrictions, the 34th annual Small Satellite Conference, and this workshop, were conducted virtually, through video

conferencing, this year. The workshop had over 75 attendees in the audience. Of those who answered, the audience members reported joining the workshop from the following countries: Argentina, Bulgaria, Canada, Germany, India, Israel, Italy, Portugal, Spain, and the United States of America. Of those who answered, the occupation of the participants had the following distribution: approximately ⅓ came from professional engineering or management backgrounds, ⅓ were students, and the remaining participants categorized themselves as "others". A detailed breakdown of the results are published on the Valispace website [5].

3. Results from the Advanced Workshop on Lean Requirements, Verification and Test-Management

To obtain background information about current practices, the following question were asked of the participants:

Table 1. Workshop core questions and highest ranking responses

Questions asked to the participant	**Top Response**
What is your desired key takeaway from this workshop?	Best practices
What are your current methods of planning for testing?	Design, then a top-down planning of testing
Where do you start when doing verification?	Start with the requirements, then develop the test
What do you consider most important for requirement breakdown?	Understanding the rationale of the parent requirement
What do you consider most important for verification methods and their requirements?	Be sure that the chosen verification method is adequate to verify your requirement
What do you consider most important for test management?	Documentation

To understand what the participants valued, they were asked to identify their desired key takeaway from this workshop, the top answer was best practices (as shown in Table 1). Siarov and Witzmann asked the participants to identify and discuss what is most important for requirement breakdown, verification methods, and test management. Participants were also asked to identify the biggest pains in managing verifications and tests, to which the top response was that requirements written were not testable or verifiable.

4. Recommendations

This section provides organizations in the space industry with guidelines for end-to-end digitization of V&V activities, following the DDSE approach. These five strategies are derived from the results from the workshop, combined with the Valispace teams' years of experience helping companies make the transition to more efficient ways of working.

4.1 Recommendation: Concurrent Access

The first step in ensuring an optimized workflow is creating a stable foundation for your team to collaborate upon. That stable foundation in agile space projects is concurrent access for collaboration and management. According to the ESA, when it comes to streamlining the engineering process, collaboration tools are the backbone for every software project today [6], the same can be said for hardware projects.

Per the workshop results, the participants consider the most important aspect of test management to be documentation. Spreadsheets, disconnected databases, and fragmented access are an obstacle when it comes to modern day digital document management systems. Without concurrent access and the utilization of a single source of truth, teams risk unnecessary and costly rework stemming from human error. Platforms which allow concurrent access permit rapid reaction; users can update, change, comment, and create tasks, reducing the time wasted on unnecessary communication methods, such as phone calls, emails, and in-person meetings. CE and access, through DDSE, enables instantaneous collaboration and information exchange, leading to improved quality, development time, and workflows throughout the project lifecycle [7].

4.2 Recommendation: Task & Requirement Management

When collaboration and documentation is moved to a concurrent access platform, by design the platform (and not the individual element or segregated documents) becomes the primary means of communication. The bottleneck of waiting for an in-person or email response and confirmation are removed. Furthermore, each element of the project can be assigned to a user or a team, leaving a digital trail of historical changes and handoffs, creating continuous accountability.

One participant in the workshop spoke of the importance of having a list of actionable items to work through, and assign dates and personnel to. The participant elaborated that knowing the timeframe to obtain information regarding requirements, and which personnel will handle the requirement, is critical: simply due to its impact on testing complicated parts, interfacing with other teams on the project, and sharing of information. A point Siarov summarized as, “Essentially, it's about sharing the right information to the right people at the right point in time, and thinking ahead.” [5]. Proper task and requirement management creates a new culture of digital collaboration and information exchange.

In the workshop, a majority of the participants expressed the most important aspect of requirement breakdown is understanding the rationale of the parent requirement. Through follow up discussion, Witzmann pointed out that often these requirements are repurposed from previous projects, and continue to propagate into new projects, which they may not be appropriate for [5]. Instances such as these can lead to “childless requirements”, in which a high level requirement is not decomposed into lower level requirements [7]. It is only through proper management and bidirectional traceability, discussed in section 4.4, that a project can avoid childless requirements by linking every system element, subsystem, and component to a business, stakeholder, or system requirement, assigned to owner(s).

4.3 Recommendation: Automate What You Can

Despite making the digital transition, engineering teams often lose time on manual activities. There are several tasks which can be dramatically improved, optimized or entirely reused through the implementation of automation. Quantitative values, which are related to requirements and test-step, determine if a requirement passes or fails. By using a single source of truth as the requirement and test values, users can see a ripple effect propagated throughout documentation and simulations when a value is updated, manually or automatically. If the chosen CE platform or engineering assistant fosters an automated relationship between calculations and simulations, the end result is proper end-to-end digitization of V&V activities and monitoring of verification status.

Other beneficial examples of automation are:

- Ability to conduct multiple test runs to ensure resiliency
- Replication and reusability of specific elements from a previous project onto next generation models or a new project
- Tying outcomes of simulations, calculations, and verification outcome, to specific requirements to automatically let you know once a requirement is out of specification
- Removal of ambiguous, non-testable or non-verifiable requirement text

Furthermore, automation can alert assigned users when constraints are out of bounds or in violation. While there are limits to automation, adoption of automation frees up human capital, so your engineering team can focus on solving complex problems instead of updating files and figures.

4.4 Recommendation: Establish Digital Bidirectional Traceability

Generally, traditional document-based systems fail to ensure full traceability because of a lack of transparency, links between requirements, design, and missing engineering analysis and testing [7]. Bidirectional traceability relies on accountability to avoid cases of childless (see section 4.2) and orphan requirements, requirements not connected to a higher level parent requirement. Without bidirectional traceability, requirements may go unnoticed or not be addressed at the appropriate time, leading to unanticipated costs and/or delays. Digital tasks and requirements, combined with setting up the right accountability, allows teams and auditors to question the logic behind a requirement, as well as discuss how a requirement is derived, decomposed, managed, and verified.

By following the DDSE approach, full digital continuity and traceability are ensured. This is done by connecting data from requirements management up to testing and verification in a collaborative fashion, even across company borders. Additionally, using adequate DDSE tools to do agile test management, allows for an easy overview of testing progress and planning. From high level planning down, specific test steps, to the results of each iteration, DDSE gives users the ability to understand test data in context, which is then easily communicated to the rest of the team when design changes are needed. As a result, the time and budget for V&V and testing in complex hardware projects goes down significantly.

4.5 Recommendation: Design For Testability

Another concern the participants expressed during the workshop was ensuring the chosen verification method was adequate to verify a requirement. DDSE is the answer when classical MBSE models, which are meant to simplify the development process, meet the complexity of reality. In theory and academia, a single requirement is often associated with a singular verification method, in a one-to-one relationship, which is simply not the case in complex and integrated projects. Teams also attribute more time to reviewing requirements, but do not dedicate enough time to review the verifications which will satisfy those requirements.

Witzmann explained, “It's not about putting a “T” [for test] next to every requirement to say ‘Yes, we’re going to test this.’...If you think about testing, think ‘Is it possible to test that so that you can really close out this requirement?’ Also thinking about the question when you break down the requirements, ‘If I have verified each of the children, does that verify the parent automatically? Do I need a dedicated test for this?’ That's something that often times gets overlooked” [5].

Witzmann urged the participants to give more forethought to the relationship between requirements and verifications. In an evolving project a requirement can have multiple and varied methods of verification [5]. Dependencies are uncovered as the project continues and changes over time. It is not a linear one-to-one relationship, as presented in simplistic theory. Additionally, requirements can have multiple verification methods on multiple models, making it difficult to manage the outcome on spreadsheets. Thus, the Valispace team recommends rather than starting with the requirements, then developing the testing method, to work the other way around. Consider the potential test cases which can be conducted, before writing requirements, to ensure the team has the concise information, tools, and resources to verify the requirement [5].

5. Conclusion

DDSE is a powerful methodology which promotes concurrent access, the benefits of which are achieved by using the appropriate platform or engineering assistant. But at the end of the day, the core element of a project’s success lies in the human capital, and the approach with which it uses the tools at its disposal. It is worth taking the time in the early stages of a project to think about the relevance and testability of requirements, the appropriate verification methods, management of tasks through concurrent access and automation, and bidirectional traceability. Perhaps the most important “hack” to a successful and sustainable team is choosing approaches of design, project management and data structures which allow flexibility, so that the project and team can progress throughout development phases and face complexity head on.

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