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Implementing Agile Management in Space Robotics University Project: The ARDITO Rover Case Study

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Abstract

In a rapidly evolving economy where companies increasingly shift from operational to project-based perspectives, the organization and management of project teams become critical to enhancing success rates. This is particularly evident in emerging industries such as the Space Economy, where projects are characterized by high technological complexity and significant costs. Optimizing work processes is, therefore, a key factor in improving efficiency. The selection of a management approach is never straightforward, as no single model universally applies to all teams. Instead, the most appropriate system should be chosen based on the specific context. This paper explores the practical application of Agile Management Principles within DIANA, the space robotics team at Politecnico di Torino, focusing on the development of ARDITO, a Martian Rover research platform currently in its final phase. To tailor Agile methodologies to the team's unique needs, key adaptations were made to the prioritization system and sprint durations. Task prioritization was structured around a dual-factor approach, balancing both research objectives and competition requirements, while sprint durations were adjusted to align with internal team dynamics and external constraints. Additionally, to ensure compliance with space industry standards, Agile implementation was cross-referenced with ECSS-E-HB-40-01A, the Agile Software Development Handbook, considering the integration of hardware development in the project. This study provides a compelling case of transitioning from a traditional Waterfall approach to Agile within the research, development, and production of a planetary exploration rover, demonstrating the flexibility and effectiveness of Agile in complex, high-stakes environments.

Keywords: AGILE Project Management, Space Robotics, Planetary Rover Development, ECSS Standards, Team Organization.

1. Introduction

In a rapidly evolving economic landscape, many organizations are shifting from an operational to a project-based perspective, especially in sectors like Space Economy, where innovation and technological intensity are key drivers of competitiveness. Here projects are highly complex, multidisciplinary, and constrained by strict regulatory frameworks, long development cycles, and high uncertainty.

Managing projects in such environments poses significant challenges. Traditional management frameworks, such as the Waterfall model often fail to accommodate the iterative and dynamic nature of deep-tech development. As a result, a "one-size-fits-all" approach to project management is no longer viable. Instead, methodologies must be carefully tailored to the project's complexity, objectives, and organizational context.

In this scenario, Agile methodologies have emerged as a compelling alternative due to their emphasis on iteration, responsiveness to change, and stakeholder collaboration. However, applying Agile in space robotics is not straightforward. While originally designed for software development, Agile must be adapted to align with hardware development cycles and aerospace standards, such as those defined in ECSS-E-HB-40-01A. Recent experiences, such as those by NASA's OpenMDAO team and in rover prototype integration projects, have shown that tailored Agile approaches can effectively manage complex space systems [5][6].

This paper presents a case study of the application of Agile principles within team DIANA, the space robotics student team of Politecnico di Torino, focusing on the development of ARDITO, a Martian rover prototype. To adapt Agile to the specific needs of the project and the team structure, two key customizations were implemented: a dual prioritization system, balancing scientific research objectives and competition requirements, and a sprint adaptation strategy, which adjusts sprint durations to match academic cycles and external constraints while ensuring compatibility with ECSS standards.

By analysing the implementation process, the adaptations made, and the outcomes achieved, this study aims to demonstrate the flexibility and effectiveness of a customized Agile framework in a high-stakes, multidisciplinary space project environment.

2. Background and Methodological Framework

In recent years, Agile methodologies have gained increasing attention in sectors traditionally dominated by rigid planning and control structures, such as the aerospace and defense industries. These environments are characterized by high complexity, long development cycles, and strict reliability requirements, which historically led to the adoption of Waterfall or V-model approaches [3].

However, the growing need for adaptability and faster iteration cycles has encouraged the exploration of Agile frameworks even in these regulated domains [4].

To guide the integration of Agile in the space industry, the European Cooperation for Space Standardization (ECSS) published the *ECSS-E-HB-40-01A*, an official handbook outlining best practices for Agile software development tailored to space engineering contexts [1]. This document offers recommendations on how Agile practices such as iterative development, continuous integration, and flexible planning can be aligned with mission assurance requirements. It also provides guidance for integrating Agile with traditional systems engineering standards, such as those defined in the *ECSS-E-ST-40* [2].

Nevertheless, applying Agile in complex multidisciplinary projects, such as those involving both hardware and software subsystems, remains a challenge. The coexistence of iterative development cycles with fixed milestone reviews and hardware dependencies demands contextual adaptation of Agile principles [3]. As highlighted by Trimble in early NASA studies, hybrid strategies that combine the strengths of Agile and traditional methods can be effective in space missions, especially when used with small to medium-sized development teams [4].

This framework forms the foundation for the management strategy adopted by team DIANA during the development of the ARDITO rover. In the following sections, we describe how Agile methodologies were tailored and applied in this specific context, with direct reference to both ECSS standards and practical engineering constraints.

3. DIANA Environment

Born in 2008, DIANA operates within Politecnico di Torino with the goal of designing and developing rover prototypes for planetary exploration and astronaut assistance. The team embodies an innovative and non-traditional educational model, enabling students to apply academic knowledge to a highly complex, multidisciplinary project. This experience fosters both technical and soft skills, such as cross-functional collaboration, project management, individual responsibility and teamwork.

DIANA promotes strong industry collaboration, maintaining long-term partnerships with key players in the aerospace sector such as Thales Alenia Space and ALTEC, which regularly provide technical reviews, testing facilities, and expert mentorship. The team also actively participates in international competitions, public science outreach events, and collaborative research initiatives with academic and institutional stakeholders.

Over the years, the team has developed several rover platforms, most notably the ARDITO project, a high-performance research rover that has undergone extensive testing and been used as a foundation for multiple scientific contributions and technology demonstrators.

3.1 Team Structure

The team has been structured into three primary technical departments: Mechanics, Electronics, and Computer Science. Each department is co-led by two Department Leaders and subdivided into smaller work groups consisting of two to six members, each guided by a dedicated Group Coordinator. In addition to these core departments, three cross-functional units support the team's broader objectives. The Management Group oversees planning and coordination and is managed by Leader of Management. Other groups are: the Scientific Research Group, which ensures technical soundness and innovation; and the Visual Design Studio, responsible for communication, branding, and visual documentation.

Organizationally, the team follows a three-tier hierarchical model:

- **IMPERIVM** functions as the strategic board of directors and includes the Team Leader, Department Leaders, and selected former leaders who now serve as non-executive Advisors.
- **PRAETORIVM** serves as the operational support board and is composed of experienced members who typically act as group coordinators and contribute to the system-level technical integration.
- **FORVM** is the general body of team members not part of the two boards and represents the largest and most diverse component of the team.

Members of DIANA come from a wide range of academic backgrounds, primarily within engineering and design disciplines, fostering a rich interdisciplinary environment essential for complex space robotics development.

3.2 ARDITO rover

To contextualise the rationale behind our managerial approach, this section outlines the main characteristics of the rover developed within the team. ARDITO is a modular rover platform designed for space robotics competitions [16, 17]. It adopts a rocker–bogie suspension system with six independently driven wheels, four of which are also steerable, thus enabling high maneuverability on unstructured terrain.

The system architecture follows a modular design philosophy: each subsystem is implemented as a separate module with standardised interfaces. This allows individual subsystems to be upgraded, replaced, or completely redesigned with minimal integration effort. The avionics module provides command and data handling capabilities and acts as the backbone of the system. It is interfaced with the mobility module, which employs a differential mechanism to balance the two sides of the suspension. In addition, the platform is designed to host, among the payloads, a robotic arm, capable of accommodating interchangeable end-effectors to support different mission tasks.

The software stack is entirely developed in-house and relies on the MQTT communication protocol for high-level coordination. At the lower level, CAN bus communication is extensively used to interface with the motor control units. The navigation software follows the same modular paradigm: distinct components cooperate asynchronously to perform localisation, path planning, and guidance.

This modular approach is not only a design choice but also a necessity, given the operational context of a student team. Contributors typically participate for a limited period and their available time is restricted by academic obligations. The system architecture therefore supports asynchronous development and long-term continuity, allowing new members to take responsibility for individual modules without requiring complete knowledge of the overall system.

4. Case Study: AGILE implementation in ARDITO Project

The transition from a traditional waterfall approach to a tailored Agile framework was motivated by the need to better handle the iterative development and testing cycles inherent in space robotics projects. Similar transitions have been successfully implemented by NASA teams working on complex mission systems, such as the OpenMDAO project [5] and rover prototype integration programs [6], where Agile methodologies were adapted to accommodate multidisciplinary hardware and software integration and evolving system requirements.

4.1 Long Term Timeline

At the beginning of each year, an annual project timeline is developed. Although this timeline is not broken down into detailed sub-tasks nor followed with the rigidity typical of a Waterfall approach, it plays a crucial role in providing an overall view of the project. A long-term planning framework allows the management team to maintain a high-level overview, define the objectives to be achieved, structure macro-level activities based on external milestones, and meet the deadlines imposed by competitions in which the team intends to participate.

Moreover, Politecnico di Torino require a summary of planned activities at the time of funding requests. In this context, the annual timeline serves as a valuable tool to offer a structured and comprehensive overview of the project's planning status. However, this timeline is intended solely as a guiding framework and does not impose strict constraints on the actual development schedule.

Past experiences have highlighted the limitations of the Waterfall approach in highly unpredictable environments such as student teams [3]. The rigidity of predefined deadlines often resulted in misalignment with the evolving context of the project, leading to stress and friction among team members [13]. In previous years, Management Group members often found themselves pursuing department leaders to enforce deadlines established at the start of the year, leading to stress and friction during the development process. Furthermore, those deadlines were set based on a specific context that may no longer be valid as the project evolves. In such dynamic settings, where changes and new developments are frequent, a rigid management methodology proves unsuitable. In response to these issues, the team transitioned to more flexible and adaptive approaches [14], which are further described in the following sections.

4.2 Milestones

The European Rover Challenge represents the primary project deadline that the team is focused on meeting. The objective is to participate in this event on an annual basis. The competition is held in August/September, with deadlines set throughout the year. These include the submission of three reports illustrating the project (Proposal, Preliminary and Final) and a video illustrating the team and the current operational status of the rover.

These milestones are of paramount importance to the team. These elements are regarded as fixed and are consequently annotated in the project timeline at the outset, thus enabling the formulation of the entire plan around them. The following essay will provide a comprehensive overview of the relevant literature on the subject.

4.3 Stable Point

The annual student competition held in September naturally defines the pacing of the team's development activities. In earlier iterations of the project, a traditional waterfall-like approach was adopted, in which major subsystems were developed sequentially and only integrated towards the end of the cycle. This strategy revealed significant drawbacks: delays accumulated due to logistics and procurement constraints, while late-stage integration amplified the risk of unforeseen failures.

To address these challenges, the team adopted a more Agile-inspired methodology based on the concept of stable points. These represent intermediate milestones in which the rover is assembled, tested, and stabilised as a complete system. In analogy with Agile sprints, each development year is structured around approximately three stable points: one at the end of the calendar year, one in mid-spring, and one in July.

Each stable point serves as a "fallback configuration" that can be reliably restored if subsequent procurement issues or integration and verification (AIV) activities introduce delays or failures. In this way, the overall project risk is significantly reduced, since the team can always return to the last validated configuration without jeopardizing the entire development cycle.

Furthermore, the stable-point strategy also provides an incremental learning opportunity for the team. By testing the rover multiple times under increasing levels of complexity, team members progressively acquire operational expertise. This continuity of practice not only strengthens technical skills but also improves the team's readiness to face the competition environment.

4.4 Agile Sprint

Between one Stable Point and the next, the team progresses through different project phases: Development, Validation, Integration, and Testing. To facilitate coordination by the Management group and ensure clarity and consistency in execution across all team members, a standardized organizational and managerial framework is adopted.

A sprint cycle, typically lasting two weeks, is defined, concluding with a scheduled meeting. All working groups hold these meetings with more or less the same frequency. The variation in frequency depends mainly on the amount of work and the time available to participants. The aim is always to meet the needs of the student, trying to adapt the management to them and not vice versa. The duration of this meeting may vary, but it generally follows a structured format.

The first part consists of status updates, during which each participant provides a summary of their recent activities. This is followed by a collective discussion aimed at analyzing the progress, addressing issues encountered, and making informed decisions to overcome any challenges. The meeting concludes with the scheduling of tasks for the upcoming sprint and the definition of individual objectives, tailored to the availability of each member.

This approach proves particularly effective in the context of a student team, where time availability is a critical variable. All members contribute on a voluntary basis, balancing their involvement in the project with their primary academic responsibilities. Moreover, the bi-weekly scheduling structure offers the flexibility needed to adapt to unforeseen external disruptions.

This iterative and adaptive scheduling strategy proves particularly effective in highly dynamic contexts such as student teams, where member availability and external constraints can significantly affect development continuity [14]. The use of bi-weekly sprint cycles, inspired by Agile methodologies like Scrum, ensures operational responsiveness while accommodating individual constraints [5]. Furthermore, dynamic task reprioritization at the end of each sprint allows the team to quickly respond to unexpected delays caused by external bureaucratic processes, such as university-level procurement delays [15].

For instance, the procurement of materials is subject to the bureaucratic procedures of the university. This often acts as a bottleneck during the development phase, as it is impossible to predict with certainty when the ordered items will be delivered. The delay stems from the fact that procurement requests must be processed by the department's purchasing office, which handles acquisitions for all student teams and research groups, thereby introducing systemic delays. The two-week planning cycle allows the team to dynamically adjust its integration and development activities in real time, based on delays arising from the procurement process. This iterative and adaptive scheduling strategy ensures responsiveness and operational continuity despite external constraints.

4.5 Project Monitoring

The Management group, coordinated by the Leader of Management, is responsible for overseeing the team's activities with a comprehensive 360-degree perspective. Given that space robotics encompasses a wide range of technical disciplines, maintaining a transversal overview is both challenging and essential for the successful execution of the project. A horizontal vision enables streamlined project development by ensuring that the work of each subgroup progresses in parallel, ultimately facilitating effective system integration and the proper execution of testing phases.

The responsibility of monitoring ongoing activities falls to the Management group. During the reference year, the group was composed of four members, each assigned to oversee a specific macro-subsystem. This subdivision allowed the technical team to benefit from dedicated integration support, while providing the board with complete visibility over the project's progression.

The monitoring process includes regular participation in team meetings and working group sessions, allowing for direct engagement with group coordinators to understand their plans and operational workflows. To support this approach, the team adopted ClickUp as its project management tool, leveraging the Kanban interface for Agile task monitoring and the Gantt chart feature to structure and visualize the annual activity plan.

While the Management group is authorized to offer suggestions and advice regarding activity coordination, it does not hold hierarchical authority over working groups or their leaders. Within the team, the management function operates on an equal footing with other participants and does not exercise command or enforce directives.

The ideal management profile is typically a student in management engineering or an individual with a strong interest in project management. However, a foundational technical understanding is required to grasp the overall system architecture and the functionality of assigned subsystems. For this reason, new management members undergo a brief intensive training on the current project, including system-level technologies, relevant subsystems, and the methodologies in use. It is then up to the individual student's initiative and curiosity to further explore specific areas of interest.

Moreover, given the voluntary nature of student participation and the educational objectives of the project, it is neither feasible nor effective to impose strict deadlines or apply rigid, top-down project management practices.

The Leader of Management, a member of the IMPERIVM board, serves as the liaison between the executive board and the Management group. This figure is responsible for conveying key insights from the management team to the board to inform strategic decision-making. Additionally, the Leader of Management facilitates and chairs the management meetings, acting as Scrum Master and overseeing the implementation of the Agile project management process. This role is also primarily responsible for drafting reports and official documentation required for participation in student competitions.

5. Lessons Learned

Throughout the implementation of the management framework described in this paper, several key lessons emerged. One of the most significant achievements was the successful coordination of activities across a multidisciplinary team through a structured yet flexible organizational model. The adoption of Agile principles, particularly the sprint-based cycle and iterative planning, proved highly effective in maintaining momentum and operational continuity in an environment characterized by uncertainty, technical complexity, and variable availability of student contributors [13].

A particularly positive outcome was the reduction of pressure on department leaders, many of whom had previously shown resistance toward structured management practices. By shifting from a top-down enforcement model to a more collaborative and advisory approach, the Management group succeeded in improving alignment without imposing rigid controls. This alleviated friction and fostered greater trust and autonomy within the team [14].

Nonetheless, certain challenges persisted. Managing a voluntary team with no formal authority remains inherently complex. Ensuring accountability and consistent progress across all groups required continuous communication and adaptability. Additionally, the lack of institutionalized project management culture in student settings often slowed the adoption of new practices, demanding extra effort in training and engagement [13].

Despite these limitations, the Agile-based framework offered clear advantages for navigating the technical and organizational complexity of a space robotics project. Its adaptability to evolving contexts, responsiveness to delays (e.g., procurement bottlenecks), and focus on cross-functional collaboration proved critical to the project's progress [15].

7. Conclusions and Future Work

This paper illustrated how Agile-inspired project management practices were effectively adapted within a student space robotics team operating in a complex, multidisciplinary, and non-hierarchical environment. The implementation of a flexible planning framework, featuring bi-weekly sprint cycles, stable planning points, and a decentralized monitoring structure, enabled the team to maintain alignment across departments while preserving autonomy and responsiveness to change.

Key benefits observed include improved coordination, reduced friction among team leaders, and better handling of unpredictable variables such as academic constraints and procurement delays. These outcomes align with broader findings in the literature that support Agile's effectiveness in high-uncertainty, innovation-driven environments [6][14].

Furthermore, the experience contributes to the growing literature on Agile applications in educational and student-led engineering projects. It demonstrates how non-traditional teams can benefit from flexibility, adaptive planning, and a focus on human dynamics as much as on technical execution [14][15].

Looking ahead, further refinement of this management model could include deeper integration of digital tools, more structured feedback mechanisms, and comparative analysis with other similar teams. Ultimately, this approach reinforces Agile not just as a methodology, but as a mindset well-suited to fast-paced, exploratory projects typical of early-stage aerospace and space economy initiatives [1][6][9].

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Organization is fundamental within a project. And organization is not something standard and replicable in the same way for all projects (One Size does not fit at all).

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