Università degli Studi di Palermo
AREA RICERCA E TRASFERIMENTO TECNOLOGICO
SETTORE DOTTORATI E CONTRATTI PER LA RICERCA
U. O. DOTTORATI DI RICERCA

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NEW SPACE ECONOMY: THE SOCIO-CULTURAL REVOLUTION OF THE SPACE RACE INTO A NEW EARTH RACE AND THE NEED FOR THE PUBLIC SECTOR TO MODERNIZE ITS PROCESSES AND WORKING PRACTICES TO ADAPT TO THE NEW FAST-CHANGING ENVIRONMENT

THE CANDIDATE

CHIARA MARIA COCCHIARA

THE COORDINATOR
AND SUPERVISOR

PROF. GIOVANNA LO NIGRO

TUTOR

PROF. PAOLO ROMA

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1. Introduction

a. Background and Scope of the Research Problems

The last decades have shown a transformation of the Space Sector under multiple aspects, such as the number and typology of the main players and investors, the space applications, its economic impact, old objectives linked to science and the Space Race, together with new objectives such as tourism and the general space commercialization.

Similar to what happened to other products and services, the space sector began a new phase of globalization: currently it includes a larger geographical distribution, private and public presence, and also emerging economies started to get involved, despite the initial important economic effort to enter the space business [1] . Between 1957 and 2021 the number of Countries that participate to space programs, grew from two (Soviet Union and United States) up to almost ninety [2] , and went from being solely public to both public and private sector [3]

The Space Economy has brought the broad humanity closer to the Space sector: the approach went from dealing with a fascinating sector, but fully separated from non-space related activities, into a sector that is changing and contributing to the way traditional sectors work (from agriculture, to food, medicine).

One of the most important aspects of the new Space Economy is linked to the birth of multiple Start-ups around the world, which challenged the traditional approach to Space. With their operations, they are contributing to the technological evolution, to the societal contribution and to the economic impact at worldwide level. As Start-ups, they are strongly interested in the commercialization of their products/services, they are pushing for the acceleration of processes, project management and development cycles, and this has changed the approach that governmental agencies traditionally had with the Space sector.

The first one of the two research questions addressed as part of this PhD concerns the characterization of the Space Economy. This characterization will lead to the second research question, addressing the need for the Public Sector to modernize its processes and working practices, whose core element has been identified to be under the Project Management working practices.

The characterization has been structured using the theory-development building blocks identified with “What”, “How”, “Why”. In the theory, the “what” aims at identifying which factors (variables, constructs, concepts) logically shall be considered as part of the explanation of the phenomena of interest. The “how” serves to identify how are they related. Lastly, the “why” aims at identifying what are the dynamics (e.g. economic, social) that justify the selection of factors and the relationships [217] . If I “translate” the theoretical approach to this specific research question on the Space Economy, it derives thar:

- The “what” aims at identifying what are the main elements building up the Space Economy, meaning what is within the Upstream Segment and the Downstream Segment. The “What” is important because it gives an understanding to why so many new players entered the space market, showing also the importance of Space commercialization.
- The “Who” leads to the identification of the differences between public and private players, from big companies to small start-ups, all playing a role in the transformation of the Space sector.
- The “How” addresses how the public sector needs to modernize its working practices, and management of projects, to remain competitive in this fast-evolving market.

Starting from the characterization of the Space Economy, it was clear that not only new products and services push for a modernization of internal working practices to supply the new demand, but also the new regulations, the new contracts, investors and new players that generated the need for a modernization in the “way” that things are done [4]. This shows itself to be especially important for the public Space Agencies, that traditionally were the ones driving the Space Sector in the past and that have well established processes and working practices. Public Space Agencies are the ones facing the most difficult challenges caused by the entrance of numerous new competitors, mostly made of private players, with their products, processes and times: they move much faster than the ones of the public sector [5] . Start-ups and private industries beat the competition assuming a higher level of risk, establishing multiple partnerships (both between private companies as well as between public and private), exploring new geographical markets and leading to the need of new regulations in the sector [6] . Figure 1 shows the characterization of the Space Economy by Euroconsult in 2022 [7].

Figure 1: Space Economy value and main markets and applications in 2022 [7]

Characterizing the Space Economy is of paramount importance in understanding the intricacies and potential of the Space sector. Despite the growing significance of space activities, there has been a notable lack of comprehensive characterization in the existing literature.

The second one of the two research questions focuses specifically on the “how” aspect, with the need for public Space Agencies to modernize their processes and working practices, and the starting point has been found to be in the Project Management (PM) and Knowledge Management (KM) guidelines used in these agencies.

With new needs and requirements from the scientific community, investors, and satellite data end users, the Space Agencies keep increasing the number of Space Missions that they plan to launch in the next decade.

PM and KM are critical components within the operations of any organization, and space agencies are no exception. As space exploration and research continue to expand, the need for effective PM and KM becomes increasingly essential. Effective PM is demonstrated to bring benefits to the organization both in tangible (e.g., costs and schedule) and intangible ways (e.g., corporate culture and organizational efficiency) [12]. Space missions with their systems and subsystems are unique projects, undergoing long development cycles with complex procedures that include participation and contribution of the member States [13]. The analysis, design, and development of a Space Mission are intended as an iterative and recursive process. Numerous new missions are about to join the current portfolio, pushing project managers and organizations to continuously refine the requirements and constraints and improve processes and tools [14]. Each mission, as a standalone project, is developed following the ECSS (European Cooperation of Space Standardization) standards, with the ECSS being a set of guidelines in the fields of Space Project Management (SPM), Product Assurance (PA) and Engineering. With a focus on SPM, these standards indicate the guidelines to comply with when developing a new Space Programme [15]. Within each project, ECSS leads towards a complex development, implementation and controlling of all major project parameters, including those typical of PM (cost, schedule, risk, and technology).

With the evolution of project complexity as well as the introduction of new missions, an attempt was performed in the past to develop a platform specification of a SPM Handbook [16]. The need for the evolution of PM and KM working practices in space agencies is certainly also led by the numerous new private players that entered the market, especially from the private sector.

While the private component needs to adopt, at least at some level, the ECSS Standards, to be able to work together with public agencies, at the same time private companies develop internal PM and KM policies that often result faster and more efficient than those adopted in the public sector [13]. The private sector is certainly pushing the public agencies to change and improve their PM and KM policies to become more efficient and faster, in the attempt to remain competitive in the global market and keep a key role.

Some progress has been made over the years, although the PM and KM approaches in public space agencies still show a scattered picture with single experiences, single missions, meaning single projects, that are not coordinated/harmonized among each other. Therefore, in this research, I aim at identifying the gaps in PM and KM as applied today in European space agencies, and look for ways of improvement in their working practices. Starting from the fact that each mission is a stand-alone project, I seek for ways of harmonization among projects (i.e., among space missions), with the objective of finding in this harmonization a powerful tool for improving the PM and KM processes.

The research study starts with the analysis of PM and KM, encompassing an overview of the existing literature explaining the current working practices in space agencies and the need for a Project Management Office (PMO). To gain a deeper understanding of PM and KM practices within space agencies, I employ a case study approach relying on a strict collaboration with a European public space agency. Information is collected by direct observations and document analysis. The case study explores the specific PM and KM practices, tools, and techniques employed by the considered space agency. The findings are then compared to the state-of-the-art practices identified in the literature review.

Afterwards, grounding on the analysis of the literature, comparative study, and case study findings, we draw the conclusions and recommendations for improving the working practices of space agencies with respect to PM and KM. A deep analysis of new technologies and in particular AI, is addressed to support improvements in PM practices through the PMO adoption.

The importance of studying current PM and KM practices within public Space Agencies is highly relevant in today' s Space Economy. This study aims at analyzing the urgency for reform within the public sector and suggest a possible way forward. Firstly, it is crucial to recognize that the existing PM and KM methodologies employed by public space agencies are often deeply rooted in decades-old practices.

Furthermore, the influence of the private sector and startups in the space industry has introduced a new paradigm. Private companies are operating with agility and innovation, establishing partnerships, and pushing the boundaries of space exploration at a pace that often surpasses that of public agencies. Finally, the benefits of improving current PM and KM practices within public Space Agencies are multifaceted. Enhanced project management can lead to reduced costs, improved timelines, and a higher success rate in mission execution. Meanwhile, robust knowledge management ensures that valuable insights are retained and shared, preventing the loss of institutional knowledge and facilitating continuous improvement [28]. Moreover, modernized practices make public space agencies more attractive partners for collaborations with the private sector, academia, and international organizations, fostering innovation and resource-sharing that can drive the space industry forward collectively.

To better understand the needs for this research study, I would also like to expand and anticipate the needs from the literature review and the gaps that I aim to cover.

The literature review on the Space Economy reveals significant gaps, reflecting a profound lack of comprehensive academic research in this burgeoning field. Despite its rapid and continuous growth, the Space Economy remains difficult to characterize, largely due to its multifaceted nature encompassing various industries, technologies, and global markets. The existing literature often fails to keep pace with the rapid developments and innovations, resulting in a fragmented understanding of the sector. Industry reports offer some insights, but from a scientific and academic point of view, the real literature gap exists. The Space Economy is not only witnessing the emergence of new products and services but also the entry of diverse new players, including private companies, international agencies, and new spacefaring nations. This influx of new actors further complicates the landscape, making it challenging to create a cohesive narrative or analytical framework.

Compounding these challenges is the pressing need for new regulatory frameworks to govern activities in space. Current regulations are often outdated, originally designed for an era dominated by a few governmental entities. The proliferation of private enterprises and international collaborations necessitates a re-evaluation and restructuring of space law and policy to address issues such as space traffic management, resource utilization, and the mitigation of space debris. The academic discourse around these regulatory needs is sparse, further highlighting the gap in literature.

Furthermore, the absence of a coherent structure and organization within the research hampers the ability to derive meaningful insights and comprehensive frameworks. Existing studies are often solo-studies, focusing on specific aspects such as satellite technology, space tourism, or space mining, without integrating these components into a unified whole. This fragmentation prevents a holistic understanding of the Space Economy and its broader implications for global economic systems.

To address these challenges, it is imperative to adopt a systematic approach utilizing the "What," "Who," and "How" building blocks of theory. This methodology provides clarity by defining the scope and elements of the Space Economy ("What"), identifying the key stakeholders and their roles ("Who"), and elucidating the mechanisms and processes that drive the industry ("How"). By structuring the research in this manner, it becomes possible to create a robust theoretical foundation that can better accommodate the dynamic and evolving nature of the Space Economy.

Specifically, the "What" component involves a detailed exploration of the products, services, and economic activities that constitute the Space Economy. This includes traditional sectors such as satellite communications and navigation, as well as emerging areas like space tourism, asteroid mining, and in-orbit manufacturing. The "Who" component focuses on the actors involved, ranging from established space agencies like NASA and ESA to private companies such as SpaceX, Blue Origin, and a myriad of startups. It also considers the roles of international organizations, regulatory bodies, and new spacefaring nations. The "How" component examines the processes, technologies, and business models that underpin the Space Economy, including launch systems, satellite deployment, and space-based research and development.

By addressing these elements systematically, I aim to develop a more organized and comprehensive understanding of the Space Economy. This approach will facilitate the identification of key trends, challenges, and opportunities, providing valuable insights for policymakers, industry stakeholders, and academic scholars. It will also help bridge the existing gaps in literature, fostering a more integrated and coherent body of knowledge that can support the sustainable growth and development of the Space Economy.

In addition to the primary gap in the literature concerning the overall characterization and organization of the Space Economy, there is a pronounced lack of scientific research on Project Management (PM) and Knowledge Management (KM) within space agencies. This gap is becoming increasingly critical as the Space Economy evolves and expands. The rapid proliferation of new collaborations between public entities and private companies, alongside the initiation of numerous new missions, necessitates a re-evaluation and modernization of PM and KM approaches within public space agencies.

Traditional PM methodologies in space agencies have often been tailored to long-term, government-funded projects with well-defined scopes and timelines. However, the current landscape is characterized by a mix of shorter-term, commercially driven initiatives and complex international collaborations. This shift requires more flexible and adaptive PM strategies that can accommodate the varying scales and scopes of contemporary space projects. The literature on this subject is scant, with few studies addressing how public space agencies can integrate agile methodologies, risk management frameworks, and collaborative tools to enhance project outcomes.

Similarly, the domain of KM within space agencies has not kept pace with the rapid changes in the Space Economy. Effective KM is crucial for capturing, sharing, and utilizing the vast amounts of knowledge generated through space missions and research activities. With the increasing involvement of private companies and international partners, there is a growing need for robust KM systems that facilitate seamless knowledge transfer across organizational and national boundaries. The literature currently lacks comprehensive studies on how space agencies can implement advanced KM practices, such as leveraging big data analytics, fostering organizational learning cultures, and utilizing digital platforms for knowledge sharing.

Addressing this gap involves formulating a second research question that focuses on the development of new PM and KM approaches suitable for the dynamic environment of contemporary space exploration and commercialization, specifically with the introduction of a PMO. This question should explore how public space agencies can adopt and integrate innovative PM and KM strategies to improve efficiency, collaboration, and knowledge retention.

To effectively tackle this research question, it is essential to examine the specific challenges and opportunities presented by the current space exploration landscape. This includes understanding the unique project management needs arising from public-private partnerships, such as coordinating between entities with differing objectives, timelines, and resource availabilities. It also involves investigating the best practices for knowledge management in a context where the rapid pace of technological advancement and mission diversity requires continuous learning and adaptation.

In conclusion, the lack of scientific literature on PM and KM in space agencies presents a critical gap that must be addressed to support the sustainable growth of the Space Economy. By developing new, tailored PM and KM approaches, public space agencies can enhance their ability to manage complex, multi-stakeholder projects and effectively harness the collective knowledge generated by their activities. This research will not only fill a significant void in the academic discourse but also provide practical frameworks that can be adopted by space agencies to navigate the evolving challenges of the Space Economy.

b. Structure of the thesis

This thesis is structured into five chapters. The first chapter, the Introduction, addresses the background and scope of the research problems, introducing the two research questions and the importance of the study. Starting with the Space Economy, it addresses the need for the characterization of this worldwide phenomenon, and structure it through three main parameters: the "what", "who" and "how". From the "how", it derives the second research question, that addresses the PM and KM in public space agencies and addresses the need for modernization through PMO. The second chapter analyzes the Space Economy phenomenon and explains the literature review that has been carried out to address both the research questions introduced in the first chapter.

The third chapter then deeps into the characterization of the Space Economy, extensively structuring the phenomenon into three groups, assigned respectively to three parameters: the "what", the "who" and the "how". Per each of this group, the key elements of both the upstream and downstream are allocated, with the objective of compensating the current knowledge gap in the literature related to the Space Economy in general. The fourth chapter deeps into the "how" aspect that has been previously explained. In particular it focuses on the PM and KM in public space agencies, and the need for improvement introducing the

PMO. This chapter makes use of a Case Study, and then focuses on the benefits that new technologies (e.g. AI, ML,..) can bring to the PM in public space agencies, when joined with PMO. The fifth and last chapter describes the conclusions of the research study and address future works, showing how this phenomenon is continuously growing and that updates in both the characterization as well as new working practices in public space agencies, will certainly need to be studied in the near future.

2. Space Economy

a. Introduction to the Space Economy

The Space Economy is growing at an exponential rate, with new investors, companies and end users, both in the public sector and the private sector. From the Space Industry, it generates an impact on the global economy, becoming one of the main economic engines at worldwide level. According to the OECD, the Space Economy is defined as "the full range of activities and the use of resources that create value and benefits to human beings in the course of exploring, researching, understanding, managing, and utilising space" [2] . With its exponential growth and new players, products and services arising on a continuous basis, it is difficult to completely characterize the Space Economy. Among the main elements, one could certainly include satellite manufacturing and operations, space tourism, asteroid mining, space-based research, and more, seeking not only an economic return, but also a social and environmental benefit. One of the fundamental facets of the Space Economy is its substantial economic impact. As of 2022 the global space economy was estimated to be worth over $464 billion [214], reflecting its remarkable growth trajectory.

Beyond its intrinsic scientific and exploratory value, space-related activities have far-reaching economic implications. Investments in space programs and technologies generate jobs, drives technological innovation, and fosters economic growth. Additionally, space applications like satellite-based telecommunications, Earth observation, and navigation systems, such as GPS, have become integral to modern life, underpinning industries like agriculture, logistics, and telecommunications, further amplifying its economic significance [19]. **Errore. L'origine riferimento non è stata trovata.** shows the estimated growth of the Space Economy in the next 15 years [20].

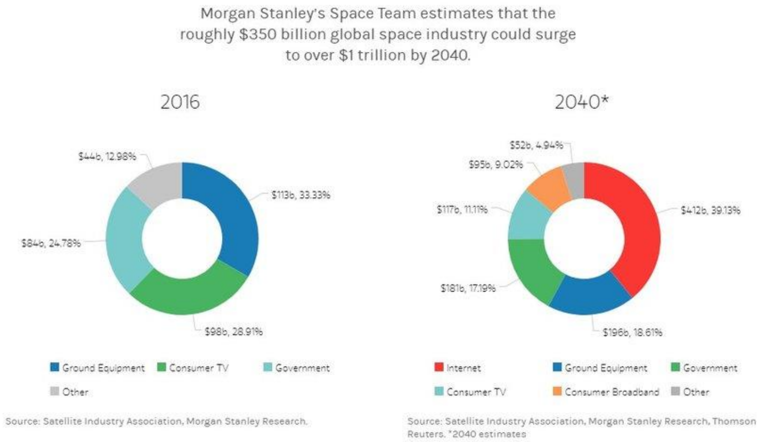


Figure 2: Morgan Stanley estimation for the Space Economy by 2040

To delve deeper into the Space Economy, it is useful to categorize its activities into two primary segments: downstream and upstream. The downstream sector encompasses applications and services derived from space assets. Typical examples include satellite television, telecommunications, weather forecasting, disaster management, Earth observation for environmental monitoring, and navigation systems. On the other hand, the upstream sector focuses on the development, manufacturing, and launch of space assets. Examples include satellite manufacturing, launch services, space exploration missions, and space infrastructure development. The upstream sector is characterized by its high technological complexity and capital-intensive nature, requiring significant investments and expertise in fields such as rocketry, materials science, and propulsion systems [21].

The growth of the Space Economy is strictly linked to a diverse array of players from both the public and private sectors. Governments, through space agencies like NASA (United States), ESA (Europe), CNSA (China), and ISRO (Indian), continue to play a pivotal role in space exploration, scientific research, and international collaborations. These government agencies often drive ambitious space missions, such as Mars exploration, lunar missions, and interplanetary exploration.

The private sector has increasingly asserted its influence and innovation within the Space Economy. Companies like SpaceX, Blue Origin, Virgin Galactic, and Boeing have taken significant strides in commercializing space activities. Nevertheless, smaller companies, the so-called Start-Ups, also play a major role in the Space Economy.

Despite their size, they push for the highest level of innovation, specializing in applications, products and services normally new to the market. Collaboration agreements between Start-Ups and bigger companies, as well as public sector, drive the Space Industry of the 21st century [3] . While further addressed below, under the second research question, it emerges already from these considerations that with the transformation and growth of the space sector, new Project Management and Knowledge Management needs start to arise. While change is always challenging, especially in public agencies, I will explain later how new PM and KM approaches need to be imported and used.

Mainly driven by the new players around the world and their missions, the Space Economy also faces complex challenges that necessitate robust regulatory frameworks. With the increasing deployment of satellites and the growing problem of space debris, space traffic management and debris mitigation have become critical concerns. In 2021, the United Nations adopted the "Artemis Accords" [22] to establish a framework for responsible and sustainable space exploration, outlining principles such as transparency, interoperability, and the utilization of space resources for the benefit of humanity. International cooperation and clear regulations are vital to address these challenges and ensure the long-term sustainability of space activities.

With numerous private players that entered the Space Industry, Space commercialization represents a significant aspect of the Space Economy, with companies exploring innovative revenue streams beyond traditional government contracts. Activities such as asteroid mining, internet, the development of space-based manufacturing, and even the establishment of permanent lunar or Martian colonies for scientific research and commercial exploitation provide a big contribution to the economic aspect of the Space Industry. The impact of the Space Economy extends far beyond national borders, contributing to a global reconfiguration of economic dynamics. International collaborations, such as the International Space Station (ISS), demonstrate the potential for countries to work together on ambitious space projects, fostering diplomatic ties and advancing scientific knowledge. Furthermore, the development of space technologies often results in spin-off innovations that benefit various industries and sectors worldwide, enhancing the commercialization aspect of the Space Industry [23].

b. Literature Review

The foundation of this research is rooted in a thorough examination of existing literature pertaining to the space sector, project management, and organizational efficiency. A systematic review of peer-reviewed articles, books, and conference proceedings provided a holistic understanding of the challenges faced by the space industry. The synthesis of this knowledge identified gaps in current practices and established a theoretical framework upon which the subsequent phases of the research were built.

The literature review also included an exploration of methodologies employed in similar studies across various industries, enabling the identification of best practices and theoretical models applicable to the space sector. This fusion of theoretical insights formed the conceptual underpinning for the research, guiding the subsequent stages of empirical investigation.

Recognizing the inherent value of cross-disciplinary insights, this research adopted a proactive approach to identify successful practices in non-space industries. Organizational strategies, project management methodologies, and technological innovations from sectors such as aviation, manufacturing, and information technology were scrutinized for their adaptability to the space domain.

By benchmarking against proven solutions in diverse industries, the research aimed to introduce fresh perspectives and novel approaches to long-standing challenges in the space sector. This cross-pollination of ideas not only enriched the proposed solutions but also fostered a culture of innovation within the research framework.

Complementing the insights gained from the literature, the researcher actively engaged in the space sector to garner firsthand experience. This involved collaborative efforts with industry professionals, participation in workshops, and immersion in relevant projects. By immersing oneself in the day-to-day operations of the space sector, a nuanced understanding of the challenges and intricacies emerged, informing the development of practical solutions.

Direct experience served as a reality check, bridging the gap between theory and application. It allowed the researcher to identify nuances that might not be apparent in scholarly works and facilitated the fine-tuning of proposed methodologies based on real-world constraints and opportunities.

A pivotal component of the methodology was the in-depth analysis of a carefully chosen case study within the space sector. The selected case study represented a paradigmatic example of operational efficiency and innovation, serving as a benchmark against which proposed solutions could be evaluated. The case study approach enabled the exploration of context-specific factors influencing success, extracting valuable lessons for application in the broader space industry.

The analysis involved qualitative and quantitative data collection methods, including interviews, document analysis, and observation. This multifaceted approach ensured a comprehensive understanding of the case study, facilitating the extraction of transferable insights and actionable recommendations. In the context of the evolving Space Economy, the literature review illuminated the intricate interplay of economic forces, policy decisions, and technological advancements that influence the dynamics of the space industry. It helped to dissect the main business applications, such as commercial satellite communications, space tourism, and resource utilization beyond Earth, which are reshaping the landscape of space-related activities.

Furthermore, a comprehensive literature review highlighted the evolving challenges and opportunities within the space sector. By identifying gaps in the current knowledge base, the research study tried to understand way forwards to support the available scientific literature.

The literature review has been an indispensable component of research and decision-making in the realm of this study related to the Space Economy and Project Management at public Space Agencies.
The first part of the literature analysis focuses on the definition of the Space Economy phenomenon and its structure. A comprehensive literature review played an instrumental and multifaceted role in guiding this research and shaping critical decision-making processes. The literature review included a systematic examination of a vast array of scientific articles, technical reports, industry publications, and case studies that pertain to space projects and the intricacies of managing these complex endeavors. This review serves as the intellectual scaffolding upon which further research and policy formulation stand. It aimed at elucidating the current state of knowledge in these specialized fields as well as at providing crucial insights into resource allocation strategies, risk mitigation, and the dynamics that underpin space-related activities.
The second part of the literature analysis focused on space project management: a thorough literature review served to unearth best practices and lessons learned from past missions and projects in the public sector. It was also used to compare with the latest PM practices used in the private sector or other specialized public sectors (e.g. the defense industry), with the scope to understand how to fine-tune space agencies' project management methodologies and techniques. In particular, the case study, aimed at identifying critical success factors and potential pitfalls, facilitating more efficient and effective project execution.

b.1 Critical Review of existing literature about the Space Economy

A detailed analysis of the literature related to the Space Economy on the Elsevier library showed 134 articles under the category "Space Economy" within the "Space industry". Most of these papers are published in space-related journals, and in particular by the Space Policy journal and the Acta Astronautica journal, followed by the Journal of Space Safety Engineering and the Advances in Space Research journal. Few articles could be found in journals that do not treat directly space-related topics, but whose downstream applications impact a different specific field. This shows that while the Space Economy has an enormous impact on multiple other sectors, the research in these fields, related to the space applications is still very much limited (see **Errore. L'origine riferimento non è stata trovata.**).

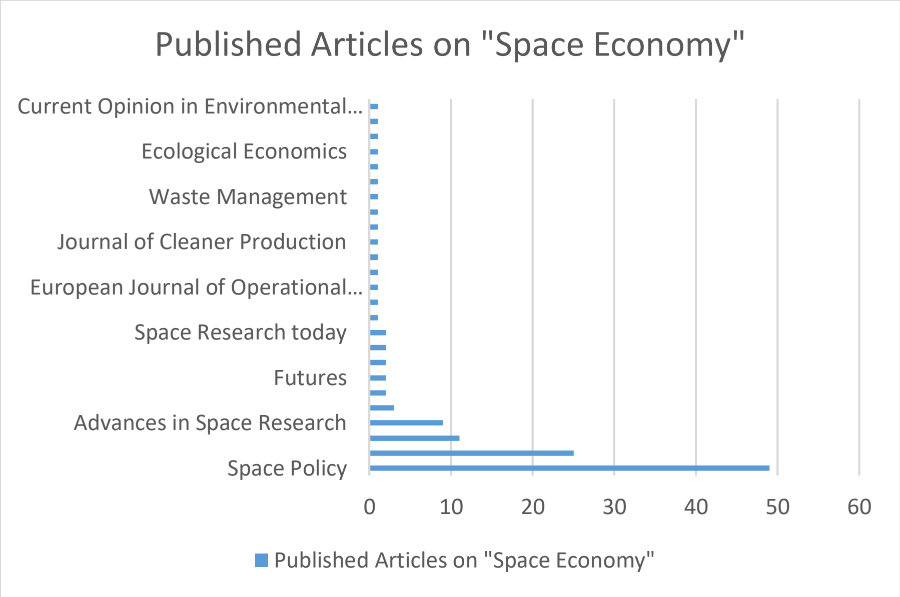


Figure 3: Publications of "Space Economy" articles by Journal

A careful analysis of these papers shows that none of these papers describe the Space Economy as a phenomenon per se. None of the papers is for example addressing all the main elements together characterizing the Space Economy, its structure, inputs and outputs. Very few papers address the Space Economy, but only from a geographical perspective, addressing for example the phenomenon specifically in India [37], or in the United States [38] or in Italy [39]. A. Paravano [19]addresses the benefits of the Space Economy from an end-users perspective, studying the value perception of satellite data from the end-users' point of view, showing for example how and why end-users adopt satellite data in tactical and strategic choice. The impact of the Start-Ups and new entrepreneurs is definitely an important element shaping the Space Economy, and it drives the so-called astropreneurial ecosystem, grouping all the new generation of entrepreneurs in this field [4].
When relating to the new Space Economy, with many new players, new technologies and applications, Space is becoming a very busy place. The space debris issue and other collaboration/competition situation arise on a regular basis, calling for a regulatory framework, which is addressed as separate topic in few other papers relating to the Space Economy. Space policies is a delicate topic touching both the global phenomenon, especially with the growth of the commercialization aspect of the sector [41], or specifically with the interaction of local governments and regulation [42]. Next to the players, the geographical distribution, national and international policies, certainly the biggest reason for the Space Economy to grow at this exponential rate is its economic impact at global scale. On one side the lowering of costs, brings a new economic infrastructure for the Space

Industry [43], on the other hand new technologies, missions and frontiers are driving the next steps of the Space Economy, including for example the Lunar economy [44], [45]. One last portion of the articles in the existing literature addresses other applications deriving from the Space Industry, new Business Models, new technologies (e.g. Artificial Intelligence (AI)) and sustainability. Sustainability, despite being a more recent topic, is among the most relevant for the future of the Space Economy. The rapid growth on multiple aspects of the Space Economy, leads both governmental agencies and private companies to the understanding of the value of new business practices which are environmentally responsible [46]. The complexity of the Space Economy structure requires a transdisciplinary approach to explore the definitions and values at various scales, including certainly sustainability frameworks and environmental legislation [47].

The previous paragraphs show how the scientific literature focuses on specific aspects on the Space Economy, and no general characterization of the Space Economy is available. This is an important gap in the literature, especially considering the impact of this sector at worldwide level. The purpose of this research was to try to fill the gap and provide an overall characterization of the Space Economy, under the “What”, “Who” and “How”, and in particular focusing then on the “What” aspect.

b.2 Critical Review of existing literature about PM in public Space Agencies

If the characterization of the Space Economy showed a gap in the scientific literature, when focusing on the Project Management working practices and guidelines in public Space Agencies the literature showed similar limitations. Most of the documentation developed for this aspect was produced as part of Industry or Agency documentation, or Conference papers, while very limited one is available as part of the scientific literature. Possibly this limitation is also due to limited interaction between the Industry and the academic world till recent time.

For the purpose of this research, the literature review examines PM and KM with a focus on the space sector, encompassing agile and waterfall PM in space agencies, the role of ECSS standards, an analysis of risks, limitations, and challenges associated to PM and KM in space agencies.

Agile and Waterfall PM in space agencies

Public space agencies normally apply a combination of waterfall and agile PM approaches to their projects. The classic waterfall approach is based on the importance of planning, execution, and expected results. They are based on the end-user requirements that have been established at the beginning of the project [60]. Space agencies' missions are commissioned by the Member States that express the requirements on the desired data collected by the satellites. Based on those, the projects are developed in a goal- and plan-oriented manner (work packages, roles and responsibilities, and deadlines in the form of reviews) in order to deliver the expected data, with expected timeliness to the end users [61]. Waterfall approach is highly supported by documentation, and is certainly a classic methodology that confers stability to the project.

Within the project lifetime, it is normal that missions undergo modifications through the project lifecycle, for which the agile method is applied: high-level requirements are defined at the beginning of the mission, but the implementation from an operational perspective could be challenging to be clearly defined during Phase 0 or Phase A, which are described below in support to the case study. In this situation, the agile approach is applied, where for example, at any point in time, a team manager may ask for a request for waiver (RFW), to include products/processes that in the first place were not taken into consideration, but that in a second moment were considered to be useful for the operational implementation. The agile approach allows for higher flexibility, but cannot be used for long-term goals: it is rather implemented for small projects or individual tasks within a bigger project. This is for example the case for space agencies working with outsourced solutions, where external companies need to develop parts of their systems. In this case, agile methods, such as Scum or Kanban are applied [62].

Agile and waterfall approaches in a hybrid combination are normally the preferred option used by space agencies: high level requirements and a mission lifecycle schedule is defined using a waterfall approach, while sub-projects are managed in an agile manner. This helps maximize the benefits from both methodologies [63].

KM in public Space Agencies

KM is a key element of business strategy, which may have an impact on the efficiency/success of product/process development in tech organizations [205], including Space Agencies. While KM is a key element, normally the associated strategies adopted by organizations are not sufficiently reliable [206]. Also, the literature examining the implementation of KM practices is still limited, especially in the public sector [207], [208], thus suggesting the need for a focus on the improvement these practices.

To classify knowledge is quite a complex task in itself, and shall be divided into "explicit" and "tacit or implicit" knowledge [209]. The explicit knowledge is available through the usage of tools available in the organization, where documentation, lessons learnt, and other materials is collected and made available for the employees. The implicit or tacit knowledge instead is acquired by employees through work and years of experience. It is an intuitive knowledge, which is very difficult to transfer, not only because of its nature itself, being a natural knowledge acquisition of employees, but also because of the lack of willingness among employees to share knowledge [210].

KM covers an important role in public space agencies to ensure effective capture and share of knowledge to achieve mission objectives. KM shall ensure that knowledge and expertise are shared across departments, teams and projects within the space agency, and lessons learnt and practices shall be disseminated throughout the organization [211]. To these scopes, some agencies have developed some structures for managing and sharing knowledge, with the use of a centralized KM system, and the use of collaborative tools, such as wikis and online forums [212]. As an example, EUMETSAT has created a Document Management Tool (DM Tool) to facilitate knowledge sharing among members of dedicated teams, a tool that will be soon replaced by a more advanced software platform in the upcoming years [213]. Another example is ESA with its dedicated KM Portal, which has the objective of providing timely information about all activities related to KM, as well as to serve as a repository and sharing platform [58].

The relationship between PM and KM

In public space agencies PM and KM, and their interconnections, are vital elements for both short-term and long-term activities, and they are necessary for ensuring the success of the missions and the entire organization.

PM includes activities such as planning, executing, and controlling of a project. On the other hand, KM is responsible for the creation, capturing, sharing and, certainly, management of knowledge for a project or, in general, for the organization itself. They both represent a powerful tool for the success of space mission design, implementation, and operation. They are both input and output of each other: effective PM relies on access to relevant knowledge, provided in an organized manner by KM. On the other hand, successful projects contribute to the organizational knowledge collection. KM supports PM by providing the means to access the information, at any time, needed by the project teams. This includes documentation such as working practices, project documents, lessons learnt from other space missions, etc. Alavi and Leidner **Errore. L'origine riferimento non è stata trovata.** suggest that "knowledge management is a critical enabler of project management, and project management is a vehicle for knowledge management". Project success depends on the proper and regular integration of KM into PM, through the full project lifecycle. In the case of a space mission, this becomes even more relevant, due to the regular handover of systems and knowledge from one team to another, in multiple departments, across the organization. As a good working practice, KM should be integrated in all processes and activities from project planning to team management, risk management, and project evaluation [139].

ECSS Standards

ECSS provides the standards for space activities that are used in European space missions, encompassing three main groups of standards: SPM, product assurance, and engineering. For the scope of this article, we focus on the SPM branch, which collects the requirements for project planning, quality management, and risk management. The SPM branch of the ECSS standards is used to manage a mission effectively, while ensuring safety and reliability of the space systems. These standards are largely used in the European space framework for current and future missions and are equally applied across the European space agencies [170]

The project planning provides the top-level guidance on the management of a space mission, detailing aspects such as scheduling, risk management, quality management, and configuration management [63]. Some of these are then detailed under the ECSS-Q-ST-10C [64], which provides the know-how and tools related to quality management, and specifically quality assurance, quality planning, and control. The scheduling and controlling aspects are detailed under the ECSS-M-G-11 [65] , while risk management is further detailed under the ECSS-M-G-20 [66].

3. Space Economy Characterization: What, Who and How: A triple perspective and a research agenda for the new Space Economy in the 21st Century

The usage of the building blocks of theory for this research study has been introduced above, and under this chapter, I expand on the characterization of the Space Economy indeed through three parameters: What, Who and How.

Under the "What" characterization, three groups have been identified, in terms of products (Manufacturing), usage (Services) and new applications needs (Commercialization).

The Manufacturing branch includes the contribution from both public, but above all private players in the development of space infrastructure. This includes both the Ground and the Space segments. Where the Ground Segment includes the full infrastructure which is based on Earth and is used for all the activities in support of a space missions, such as the production, monitoring and control, the data processing, ground stations, etc. The Space Segment includes the full infrastructure flying in space, such as satellites, with their subsystems and instruments.

The Services branch includes the services derived by the usage of space infrastructure and organization, and that is used on Earth. Services involve both physical and human resources. From physical point of view, meaning the usage of data, these are mainly used to provide large-scale commercial services, such as internet, or other applications available to the mass market. Services with respect to the space sector also include the provision of human know-how through service contracts normally offered between private and public entities, bigger and smaller companies.

The Commercialization branch includes the commercial activities that are developed in Space or for the Space Sector. This branch is used by companies which perform experiments in Space in order to study and improve a product to be commercialized on Earth, as well as the latest touristic space trends, and the rising mining activities in Space. Many Space Agencies changed their organizational culture to embrace the new Commercialization approach to Space. One among others, NASA went from its original hierarchical model into intergovernmental model and currently working with the newest commercialization network model, where contracts and partnerships with external players, such as SpaceX are now part of routine work [77]. Within the New Space Economy Commercialization is probably the one characterizing this phenomenon the most, and that, indirectly includes the above two, where the players tend to deliver manufacturing and services in order to commercialize solutions (e.g. standardization and production of products for multiple applications).

The “What” aspect of the Space Economy includes therefore multiple sub-branches, and as further expanded below, it is characterized by numerous components, that continuously grow and add up to the Space Economy. While the PM and KM are more linked to the “how” aspect (see below), it is worth noting that such a complex development of components of the Space Economy certainly are leading to an higher complexity from the management point of view, requiring a more advanced PM and KM approach to be used in the public space agencies.

Under the “Who” category, three groups have been identified: the Public and the Private (including Big Industries as well as Start-ups). The participation of Private players in the Space Sector has changed the work approach and speed up the Development and Operations times.

The appetite for risk has increased enormously, and more challenges have been taken, leading to increased innovation and entrepreneurship in the sector: the so-called New Space started already in the early 2000s, where the Space Sector saw the introduction of new companies that directly started to operate, innovate and invest in the Space Sector.

Moreover, investments need to take into account the newest Crowd-funding mechanism, which is financing the space sector across the globe. Crowd-funding is pushing towards the democratization of the access to space, and new policymakers and individuals are using the Crowd-funding to access Space [78] .

The Public sector includes the governmental expenditures and institutions that contribute to Space Programs. With an incredible evolution on their number, these players represent the bone structure of the Space Sector, and traditionally are the players that contributed to the first epoch of the so-called Old Space Economy, also known as Space Race. Space agencies are more and more open to value the public opinion as strategic partner: open innovation and crowdsourcing are becoming key elements of space agencies’ work [79] .

Big industries are the players that initiated the transformation of the New Space Economy. They are the ones that first started to establish partnerships with the public sector, starting a new approach to the Space Industry, and bringing a push to the development of new technologies, services and commercialization of Space.

Start-Ups are the latest trend of new industrial players all around the world. They are smaller entities, but whose importance is not less than the other two players mentioned above. They characterize the current evolution of the New Space Economy, and will cover an even more important role in the so-called Emerging Space Economy. New Business Models and new regulations that have transformed the traditional approach to the Space

Sector characterize the Space Economy. Space agencies are opening more towards commercialization and introduce new business models including B2B and B2C, to work with other companies, as well as directly with customers. The models introduced by the Start-Ups are in line with the development of these small and innovative Businesses in other fields, but their impact became more evident in the Space Sector, because traditionally it was a priority accessible only to public institutions and space agencies [80] . Start-Ups also highlights the importance of the contribution of the Young Generation in space matters: with new ideas, understanding of Space and development of new businesses, the young generation is shaping tomorrow's space sector [81].

The "How" addresses the different approaches to the Space Economy with respect to regulations, and the different types of public-private partnerships.

With the growth of Space Programs, Space players and investments, it became necessary to introduce Space Regulations that guide operations for old missions, as well as the new missions, including international standards. While the need of regulation is a key element in the Space Economy, as of today, it was still difficult to establish worldwide rules, and multiple Countries according to local culture and regulation, approach the Space Policy in different ways. One of the most important need in terms of regulation refers to the usage of Earth Observation data, which currently are regulated only in five Countries, namely Canada, France, Germany, Japan, and the United States [82].

New players raise the question for space security, and regulations address the needs for transparency and confidence-building measures (TCBMs) with respect to space activities in our day-to-day lives [83]. TCBMs could take multiple forms, such as the elaboration of key elements related to the exploration and usage of space, political measures, information-sharing activities, operational practices or consultative mechanisms [84].

The importance of Public-Private Partnership is a key aspect of the Space Economy: different players working together in Space Programs characterize the New Space phenomenon. If individual entities may specialize to some elements of the Space Economy, the importance of agreements between multiple entities is a key element to succeed. No player, whether public or private, is capable to develop the full end-to-end chain of a Space Mission, including the manufacturing, services and commercial aspect of it, by remaining updated with the latest technology, commercial, social and political trends. Similar to the International Space Policy, different approaches are encountered between players in different Countries, including limitation imposed at political level.

a. Space Economy: the "What" aspect

Three umbrella segments characterize the Space Economy: the so-called Upstream and Downstream Segments, and the independent-space related segment.

The Upstream Segment is represented by all those technologies that go in the direction from Earth to Space. Its main elements include: Space Manufacturing (e.g. Satellites and their instruments and subsystems), Launchers and their infrastructure, Ground Segment Manufacturing (e.g. Mission Control Centres, Data Processing and Dissemination infrastructure, Ground Stations with TM, TC capabilities).

The Downstream Segment is represented by all those technologies that go in the direction from Space to Earth. Its main elements include: Space Operations for Terrestrial use (e.g. GNSS data), Products and Services delivered for Earth Applications, based on Satellite technology (e.g. satellite broadcasting, internet) [85].

The Upstream Segment is the one that is the easiest to be associated to the Space Sector, and at a first sight, it would be spontaneous to entitle it as the leader of the Space Economy. In reality its contribution to the creation of job places, its economic impact, as well as its innovative component are much more limited with respect to other segment. When analysing the list of elements characterizing the Upstream Segment, one could immediately observe that the Manufacturing activities are the main ones linked to the Upstream Segment, while we have limited presence of services and applications targeting the benefits for the Humankind. This results in a strong limitation of this Segment with respect to other one.

The Downstream Segment seems to be the real leader driving the Space Economy, according to the EUSPA. Innovation is a key element of the Downstream segment, and its impact goes beyond the Space Sector itself, and is of interest for numerous traditional industries, from the Agriculture, to Healthcare, to transportation and infrastructure, and much more. The job creation within the Downstream Segment supersede the one created by the Upstream sector. As an example, the GNSS Space Agency (GSA) alone generates over fifty thousand jobs on a yearly basis. The GNSS global revenue is forecasted to reach three hundreds-twenty-five Billion of EUR by 2029. Over 50% of the GNSS revenue comes from benefit services [86]. Figure 4*: The "What" aspect of the Space Economy* summarizes the "What" aspect of the Space Economy.

Between Upstream and Downstream, there are also combination of technologies that combine both the segments for delivering a specific product or service. To give an example, certainly is worth mentioning the Space-based solar power [215] , aiming at collecting solar energy in space and through a wireless connection and ground antennas receive it for Earth applications.

Together the Upstream and Downstream continuously change a re-shape the space sector that we are used to know. New products, services are continuously enhancing the capabilities of the space sector. In this respect Knowledge Management certainly plays a key role in retaining old knowledge, provide lessons learned and build up the knowledge for the future development. A proper Project Management will then ensure improved management of both upstream and downstream components that form the basis for the new Space Economy.

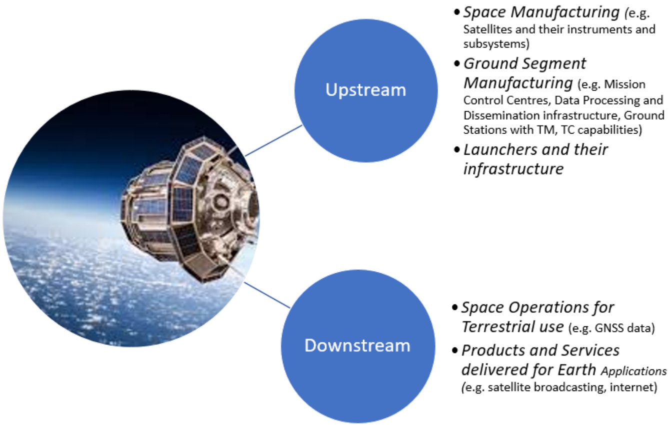


Figure 4: The "What" aspect of the Space Economy

Manufacturing

Both Private and Public players contribute to manufacturing in the Space Industry. Most of the manufacturing is to be found within the traditional Space Industry, and is reflected as part of the Upstream Segment [87].

While Manufacturing is an element traditionally present in the Space Sector, its key elements and objectives have evolved over the years. New technologies, in particular for the hardware components, characterize the Manufacturing in the 21st Century, such as miniaturization, nanotechnologies, as well as new Artificial Intelligence applications. The newest target and trends in the Manufacturing side of the Space Economy is to reduce the costs of satellite manufacturing and launch vehicles. As an example, the European Commission, as part of the Horizon Prize on a Low Cost Space Launch, awarded € 10 million to Isar Aerospace Technologies GmbH in January 2022 [88], for the development of Spectrum, a high-performance launch vehicle based on clean propulsion and specifically designed for light satellites [89].

The main elements of the manufacturing branch feature Satellites, Ground Stations, Mission Control Centers, Launchers and Launching sites, Probes and Landers, as well as crewed missions.

A Satellite, more specifically for the interest of this research study an Artificial Satellite, is a body that orbits a planet or a star. The Satellite Manufacturing, which falls under the Upstream Segment, is a strategic element of the Space Economy. This element is among the most important ones in the Space Economy, as most of the other ones are connected to and derived from it (Data and Services use Satellites in orbit) [90]. The value of the satellite industry accounts for about 80% of the full economic impact of the Space Economy: as an example in 2017, the full value of the Space Economy accounted for EUR 308.7 billion, of which EUR 238.2 billion derive from the satellite industry.

While traditionally, Space Agencies and companies would work with Large Satellites (mass bigger than 1000 Kg) and Medium Satellites (mass between 500 and 1000 Kg), the importance of satellites grew over the years, especially with the introduction of smaller scales satellites. Most of the Start-ups players, as well as Universities and individuals have initiated the usage of CubeSats, which then became also part of the satellite fleet of big companies and Space Agencies. The commonly known CubeSats include those Small Satellites with a mass between 0.2 and 40 Kg [91] , which include Minisatellites, Microsatellites, Nanosatellites, Picosatellites, Femtosatellites, Attosatellites and Zeptosatellites.

A Ground Station is to be intended as the mean of communication between the ground segment on Earth and the satellite in Space. The communication occurs with the exchange of telecommands (uplink) and telemetry (downlink) [92]. More details are available in Appendix A.

With the evolution of Space Missions and research in Space, as well as with the introduction of SmallSats in the Space panorama, also the Ground Stations infrastructure have evolved over the years. A key approach to ground stations in the 21st Century shows the evolution from single Ground Stations to Ground Station Networks, with complex software and hardware to operate multiple missions [93].

The Mission Control Centres are the facilities from where satellites are launched, operated or de-orbited, together with all the subsystems able to support all the activities related to Satellite Operations. Together with the Ground Stations and other support centers they represent the core of the Ground Segment of a Space Mission. The three main blocks according to the ECSS Standards [94] of a Mission Control Center include the Mission

Operations Systems (used for activities such as the Mission Analysis, Operations Preparation, Mission Planning and scheduling,..), the Payload Operations and Data Systems (used for activities similar to the ones of the Mission Operations Systems, but with the focus on the Payload), and the Ground Communication Systems (used for all the communications within and interfacing with the Mission Control Centers). Within each subsystems a series of software and hardware is developed in order to ensure the correct functionalities. All together, they represent the Mission Control Center Manufacturing elements.

In order to launch a satellite mission, Launchers and their associated Launching sites and infrastructure are used. Launchers and Launching Sites Manufacturing include not only the rocket itself, but also the ground equipment to perform the launch, such as the Launch Control Center, the Launch Pads, the Communication links. It also includes the Integration equipment to mount the rocket on the launch pads, with all the comms links. While launchers are owned by both public and private entities, currently launch pads are primarily owned and operated by national government [95]. The biggest contribution to the transformation of the Space Economy is provided by new commercial players that started to build rockets and provide the service of commercial launches, especially thanks to the newest technology which uses reusable rockets [96] (e.g. SpaceX).

When exploring the Manufacturing segment, the launchers clearly represent a niche market within the Space Sector. If one would compare the number of Countries with a satellite in space, with respect to the ones able to perform independent launches, the ratio is about 8:1 (see Figure 5)

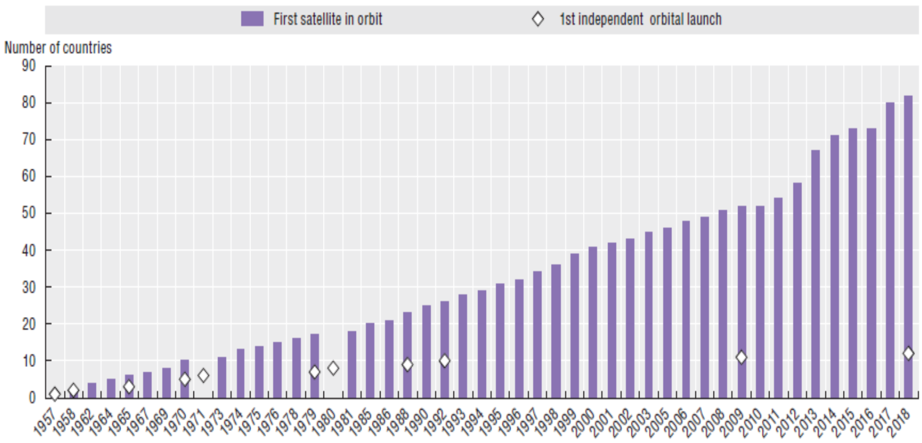


Figure 5: Number of Countries with the first satellite in orbit vs. independent launches over time [2]

Even if is considered to be a smaller contribution to the Space Economy, it is important to mention Probes and Landers. These are proper elements of interplanetary missions and for this reason, the manufacturing results in a smaller amount with respect to other missions such as the Earth Observation ones. Nevertheless, the technology around probes and landers, similar to satellite instruments, require high precision hardware, software, integration with the satellites, data collection, transmission and processing. The classical subsystems, such as power, thermals, thermal protection, structure, require major engineering for the design and operations of these machines [97].

Crewed Missions represent one last important contribution to the Manufacturing Segment. Once again, traditionally this was a segment which was only a priority of Space Agencies and public entities, but within the last years, an important transformation and the perception from private companies, such as Virgin Galactic to mention one, and individuals, is growing the contribution within the Manufacturing Branch. The importance is growing in the last decade and is expected to expand further in the upcoming years, with new international missions (e.g. Gateway) [98] and the Space Tourism. The elements of a crewed mission are similar to the ones previously described, and include a space segment and a ground segment, a launcher and launching facility. Nevertheless, the engineering behind each of them present different requirements with respect to unmanned missions and the manufacturing adds on top of the satellite infrastructure.

Often a Space agency is a central point managing all the above together. An excellent PM working practice adoption is certainly a solid basis to run smoothly operations in the organization.

Services

The second (not in order of importance) big contribution to the New Space Economy, is represented by the Services. These derive from both the application of the Space and Terrestrial infrastructure. The main contribution to the Services comes from the utilization of data, which are used for mass markets and commercial services. Mass commercialization became very common in the last decade, and it affected the Space Sector: mass customization implies the development strategy and the delivery of products and services to end users [99], which in the space sector is found among Earth Observation satellites. Data applications are the main driver for the impact of the Space Economy in traditional sectors. Earth Observation (EO) data are key in the cross-fertilization between economics, social sciences and remote sensing science, and justify a large socio-economic impact of the Space Sector in the 21st Century [100].

A list of Services includes Commercial Services, Scientific Services and Contractual Services. Commercial Services include Direct Data Application (such as the launch of satellites specifically to provide a service like Internet, Satellite TV, Global Positioning System) and Data and Infrastructure Application for Traditional Industries (such as the usage of satellite data and satellite infrastructure to support other industries, like Agriculture, Medicine,..). The value of satellite data is increased by crowdsourcing, where customers (end users) and providers (space agencies and industries) work together for new products and services [101].

The development of infrastructure and applications to serve human needs, also from the Space Sector, can be linked to the so-known Compassionate Operations, which connect social issues, from healthcare to education to sustainability [102]. Scientific Services include Satellite data used for Scientific Purposes. These services include Earth Observation Data Acquisition, to support scientific research such as Climate Change and not only: EO data are mostly used nowadays also in support to the Sustainable Development Goals (SDGs). The United Nations Member States and not only, invest into the utilization of space infrastructure and its applications, in order to implement the SDGs and to benefit society [103].

In the Industrial terminology, Services acquired a new important meaning, which is linked to the so-called Service Level Contract (SLC). In this case, the Service is provided in the form of infrastructure or of human resources, providing the know-how to the Industry. This form of Service certainly requires a set of other activities linked to it, such us, in particular also the need of regulation and the intervention of the legal departments during the exchange of resources between two parties. These Services fall under the above called Contractual Services.

The main applications in the group of Commercial Services include common technologies that are used on a daily basis by humans on Earth: e.g. Satellite Television, Internet via Satellite and GNSS technology.

Satellite Television is one of the most known services that uses space infrastructure, specifically communication satellites, to deliver television channels to the end users.

Contrary to what one could think, Satellite Television is not a recent application, and instead it was used for the first time in October 1967 by the Soviet Union, with the satellite “Orbita”. The Russian State Company “Space Communications” used this satellite to transmit TV Signal of the Central Television of Russia and domestic communication [104.

Nowadays the number of users has grown enormously, and the technology now includes 5G and B5G (beyond 5G), and 6G to deliver high quality service to the end users, avoiding issues like traffic congestion due to the large number of users [105].

Internet became a key element of everyone's daily life in the 21st Century. Multiple companies are improving the way and the quality of internet, by using satellite infrastructure. The new network is based on the usage of thousands of satellites, which together with the support of ground infrastructure are able to provide internet globally. Among the providers, four big companies took the leadership of the internet satellite infrastructure: SpaceX, Amazon, OneWeb and Telesat. The number of satellites is different and so are the elevation angles of the orbits where they are placed. Among those, Amazon is the one that achieves the highest throughput of about 53.4 Tbps [106].

GNSS stands for Global Navigation Satellite System. This is a constellation of satellites that provide time and position from space to end users on Earth worldwide. The output of the GNSS satellites is often combined with other constellations of satellites which improve the performances. The combination of multiple satellite constellations is not new in the Space Segment, and many private players are developing constellation of satellites to improve the performances of the public agency's satellites [107].

As already mentioned, one of the main characteristics of the Space Economy is given by the application of Space Infrastructure and Data in order to provide a benefit to other fields, also those that traditionally were not linked to Space Technologies. The database of industries and Start-ups using satellite infrastructures and data to support other sectors, is very large. Among the services provided to other fields, one could find: Agriculture, Health, Finance, Investment, Insurance, Energy, Tourism, Maritime, Aviation, Transport, Logistics, Media, Culture, Sport, Infrastructure, Smart Cities, Safety, security, Environment, Wildlife and Natural Resources.

Commercialization

Commercialization is the last but not least of the three branches under the "What" category. This branch is used under multiple aspects and partially includes what is already explained under the Manufacturing and Services Branches. While the Commercialization is a key element very common nowadays when talking about the Space Sector, it shall not be considered as a big umbrella under which we can find everything else. The Space Sector still includes the scientific research as one of its priorities, and in that case, space exploration, or utilization of data to monitor our Planet, remain outside the

Commercialization Sphere. Scientific research includes the development of telescopes, manned missions, research stations on Mars and on the Moon and much more [108] . When talking about scientific research, certainly human research plays a key role, which helps understanding the sustainability of human spaceflight and Space Tourism [109].

Commercialization uses mainly LEO (Low Earth Orbit) satellites and constellations. In the last decades, it also included the missions to the Moon, and a large part of services and manufacturing.

The Lunar activities attracted the interest of fourteen space agencies. It includes both large satellites and crewed missions, as well as lunar CubeSats missions [110].

Bryce Tech performs routine surveys among Space companies, and despite some areas have more transparency than others, it is estimated that in 2020 alone, the revenue of the satellite industry amounted for more than 270 B USD. New Start-Ups emerge on a regular basis, in multiple fields, in particular remote sensing and services. This is achieved with the launch of numerous CubeSats every year [111].

Among the most emerging topics in the Commercialization aspect of the Space Economy, is the Space Tourism. Commercial Space Flight is becoming a reality, also thanks to the development of infrastructure able to support this new sector. One of the main drivers of Space Tourism, is certainly the possibility, now reality, of reusable rockets, like the ones from SpaceX, which are able to go to space and then safely land back on Earth [112].

Currently the costs related to Space Tourism are incredibly high. A way for companies to mitigate costs, is to avoid orbital flights (speed around twenty-eight-thousand Km/h), and instead perform suborbital flights (speed around six-thousand Km/h), although clearly the heights which could be reached are lower with respect to the first one. The main companies providing Commercial Space Flights are Blue Origin and Virgin Galactic, although investments are coming from all over the world (e.g. Saudi Arabia invested one Billion USD into Virgin Galactic for this purpose) [113].

Constraints linked to Space Tourism are also linked to Regulations, other than the costs associated to a trip to Space. Space Tourism could be seen as an open door to popularization of the Space Sector, and it is argued whether regulations should be different from current air space and outer space rules, and instead a dedicated legal framework shall be established [114].

No international consensus and regulation have been reached as of today with respect to Space Tourism, which is a field developed between air and Space. No formal boundaries have been decided yet, and this leads to the need for further discussion among parties around the world. This is especially because while U.S.A are the leaders in the race, all around the world individuals are already paying large amount of money to experience a Space Flight, from Russia to Japan. This shows that Space Tourism is becoming more and more a reality, with the objective to reach one day the mass market [115].

Space Mining is an emerging topic within Space Commercialization. Space Resources raise questions for applications on Earth, as well as economic impact and property. Space Mining is still a new topic, and many private players are investing in infrastructure aiming at collecting space resources [116]. Space Resources are still considered to be "common", although their belonging is under discussion in terms of regulations and ownerships. Currently the Outer Space Treaty (OST) declares that no government can own celestial bodies or outer space, but economic profitability is becoming clearer, and the new question raised is about the exploitation of resources, public or private, that can benefit the entire humanity [117].

With the Commercialization aspect becoming more and more present, the relationship between public and private organizations is a central aspect of the new Space Economy. It will be further expanded hereafter, under the who aspect, with the need of a good PM approach, which includes also the needs for advanced space regulations.

b. Space Economy: the "Who" aspect

In the grand cosmic tapestry of space exploration, the space industry is a realm where a multitude of players, each unique in their character, purpose, and motivation, have joined hands to unravel the Space market and science. These players have been classified into several distinct categories: the steadfast public entities, visionary private corporations, audacious start-ups, and the venerable halls of academia. The space industry, once dominated by a few key actors, has witnessed a transformation that now includes a vibrant ecosystem of diverse contributors.

Public Entities

Since the inception of the space age, public entities have served as the vanguards of space exploration. Funded and overseen by governments, these organizations carry with them a legacy of pioneering achievements, which started with scientific research, and continued with commercial activities and missions in collaboration with the private sector. Among the main players, certainly the National Aeronautics and Space Administration (NASA), is perhaps the most iconic name in space exploration. Established in the wake of the Cold War space race, NASA has a legacy that spans over six decades. It was NASA that masterminded the awe-inspiring Moon landings of the late 1960s and early 1970s, and it's NASA that continues to spearhead missions like the Mars rovers and the Hubble Space Telescope. With the Artemis program, NASA has renewed its commitment to return humans to the lunar surface, setting the stage for humanity's first steps on Mars. Outside from the United States, certainly Russia played historically an important role and keeps playing it today, with Roscosmos, Russia's space agency, carrying a rich history of cosmic exploration. It was the launch of Sputnik, the world's first artificial satellite, in 1957 that marked the commencement of the space age. The agency's pioneering efforts also saw Yuri Gagarin's historic journey as the first human in space in 1961. Today, Roscosmos maintains a strong presence in crewed spaceflight and remains a key partner in the operation of the International Space Station (ISS). The third, not for importance, public Space Agency worth mentioning, is certainly the European Space Agency (ESA), which epitomizes the power of international collaboration. Consisting of 22 member states, ESA operates on a cooperative model that shares resources, expertise, and responsibilities. Their missions encompass a broad spectrum, from Earth observation satellites to ambitious interplanetary exploration endeavors, and they serve as a testament to the potential of uniting nations in the pursuit of cosmic understanding. In the last decades, new public Space Agencies are covering more and more important roles. The Indian Space Research Organization (ISRO) has been steadily emerging as a prominent player in the global space arena. Established in 1969, ISRO has made remarkable strides in space exploration, satellite technology, and space science. One of its most significant achievements was the Mars Orbiter Mission (Mangalyaan) in 2013, which made India the fourth space agency globally to reach the Red Planet and the first to do so on its maiden attempt. ISRO's Chandrayaan missions have also significantly contributed to lunar exploration, with Chandrayaan-2, in particular, gaining international attention. Beyond lunar and planetary missions, ISRO plays a vital role in providing satellite services for communication, earth observation, and navigation, benefiting both national and international users. Emerging space agencies like the United Arab Emirates' UAE Space Agency and the Israel Space Agency have also successfully entered the space exploration domain. The UAE's Mars mission, the Hope Probe, and Israel's Beresheet lunar lander mission are notable examples of their growing impact on space science and exploration. These agencies are forging partnerships, sharing expertise, and contributing to the global effort in space research and development.

In addition, several other space agencies around the world have been making significant strides in space exploration. The Canadian Space Agency (CSA) has been increasingly active in both national and international space endeavors: it has contributed to a range of important missions, including the Canadarm robotic systems used on the Space Shuttle and the International Space Station. They have also been involved in Earth observation and climate monitoring through the RADARSAT program.

China's space agency, the China National Space Administration (CNSA), has become a major player in space exploration. Their missions to the Moon, such as the Chang'e series, and Mars exploration, with the Tianwen-1 mission, have garnered global attention. CNSA's ambitious plans for space station construction and deep space exploration indicate China's growing influence in space.

Japan's space agency, the Japan Aerospace Exploration Agency (JAXA), has also been instrumental in various missions. JAXA's Hayabusa missions brought asteroid samples back to Earth, advancing our understanding of the early solar system. The agency's involvement in the International Space Station and plans for lunar exploration show Japan's commitment to space research and development.

In the last decade, also pushed by the increased importance of thematic like Climate Change and Weather forecast, numerous public Space Agencies specialized in the operations of satellites carrying meteorological missions. Two of the most important examples are EUMETSAT and NOAA, respectively in Europe and the United States, followed by numerous other such as CMA and JMA, respectively in China and Japan.

EUMETSAT, short for the European Organization for the Exploitation of Meteorological Satellites, is a key player in the world of meteorology. It is an intergovernmental organization with 30 European member states, founded in 1986. EUMETSAT's primary mission is to gather, process, and distribute data from meteorological and environmental satellites. The origins of EUMETSAT can be traced back to the early days of space exploration and meteorology. In 1977, the European Space Agency (ESA) and the European Meteorological Satellite (EUMETSAT) organization were established. They aimed to collaborate on the development and operation of meteorological satellites, marking the first steps towards EUMETSAT's formation. It was officially established as an intergovernmental organization in 1986. EUMETSAT's headquarters are located in Darmstadt, Germany. EUMETSAT plays a crucial role in collecting data from a constellation of geostationary and polar-orbiting satellites, such as the Meteosat and Metop series. These satellites provide real-time meteorological and environmental information, including weather forecasts, climate monitoring, and disaster management. EUMETSAT also operates ground stations, data processing centers, and delivers products and services to its member states and international partners.

One of its flagship programs is the Copernicus program, which includes the Sentinel series of Earth observation satellites. EUMETSAT collaborates with the European Space Agency and the European Centre for Medium-Range Weather Forecasts (ECMWF) to provide data and services for this program, supporting applications in various fields, from agriculture to environmental protection. EUMETSAT's contributions to meteorology and environmental monitoring are of paramount importance. Its satellite data and services are critical for weather forecasting, severe weather warnings, climate research, and disaster management. The organization's international partnerships further enhance its global impact, as it works with entities like the World Meteorological Organization (WMO) to share data and expertise.

The National Oceanic and Atmospheric Administration (NOAA) is a renowned institution in the United States, dedicated to the study and understanding of the Earth's oceans and atmosphere. NOAA's work encompasses a wide range of areas, from weather forecasting to marine conservation. NOAA has a rich history dating back to the early 19th century when President Thomas Jefferson founded the Survey of the Coast in 1807. This marked the beginning of a long lineage of organizations and agencies that would eventually merge to create NOAA. In 1970, President Richard Nixon officially established NOAA as a federal agency under the Department of Commerce. NOAA's mission is broad and multifaceted. It is responsible for weather forecasting, monitoring and predicting severe weather events, managing the nation's fisheries, conducting research on climate change, and protecting marine and coastal ecosystems. NOAA operates the National Weather Service (NWS), which provides weather forecasts, warnings, and other critical information to the public and various industries.

The China Meteorological Administration (CMA) is the national meteorological agency of the People's Republic of China. As one of the world’s largest and most influential meteorological organizations, CMA plays a pivotal role in weather forecasting, climate research, and disaster management within China and beyond. CMA's history can be traced back to the early 20th century when meteorological services were first established in China. It underwent several organizational changes over the years before being officially named the China Meteorological Administration in 1994. Today, CMA operates under the Ministry of Emergency Management of the People's Republic of China. CMA's primary responsibilities include weather forecasting, monitoring and warning of extreme weather events, climate research, and environmental protection. The agency maintains a network of meteorological stations and radar systems across China, providing real-time weather information to the public and various industries.

CMA also actively participates in international collaborations and contributes to the World Meteorological Organization (WMO). The agency operates its own satellites and has launched programs such as the Fengyun (FY) series, which includes geostationary and polar-orbiting satellites for meteorological and environmental monitoring. CMA's significance goes beyond serving the Chinese population. China's geographical size and diversity of climate zones make accurate and timely weather forecasting crucial for the nation's agriculture, transportation, and disaster preparedness. Moreover, CMA's contributions to climate research and environmental monitoring have a global impact, especially in the context of climate change and its consequences.

As China continues to grow as a global economic and political power, CMA's role in sharing meteorological data and collaborating with international partners is increasingly important for addressing global challenges and enhancing our understanding of the Earth's climate systems.

The Japan Meteorological Agency (JMA), is the national meteorological organization of Japan. JMA's history, functions, and contributions are integral to the nation's safety, agriculture, and disaster preparedness. JMA is responsible for a wide range of meteorological and environmental services. These include weather forecasting, monitoring of earthquakes and tsunamis, typhoon tracking, climate research, and the management of Japan's extensive network of meteorological stations. JMA also operates its own satellites, such as the Himawari series, for meteorological observations.

One of JMA's critical functions is providing early warnings and emergency information for natural disasters, including earthquakes, tsunamis, and typhoons. The agency's role in disaster preparedness and response is essential for saving lives and minimizing the impact of such events. JMA's significance extends to the safety and well-being of Japan's population. Its precise weather forecasting, earthquake monitoring, and tsunami warnings are crucial for disaster mitigation. Additionally, JMA's research and observations contribute to our understanding of climate patterns, which is vital for agriculture and long-term environmental planning.

JMA actively collaborates with international organizations, such as the WMO, to share its expertise and data. The agency's contributions to global climate science and disaster management have far-reaching effects, making it an important player in the international meteorological community.

In conclusion, these four meteorological organizations - EUMETSAT, NOAA, CMA, and JMA - each play a unique and vital role in monitoring and understanding our planet's weather and climate. Their efforts save lives, protect the environment, and contribute to the collective knowledge of our planet's ever-changing meteorological systems.

These agencies, are collectively advancing human knowledge and capabilities in space exploration and monitoring our Planet, often through international collaboration and the pursuit of innovative technologies and missions.

Private entities

In recent years, the landscape of the space industry has undergone a profound transformation, with private corporations increasingly taking the reins alongside their public counterparts. Public-private partnerships have emerged as a pivotal force, where governmental space agencies and private companies collaborate to achieve common cosmic objectives.

The Commercial Crew Program is one such groundbreaking partnership spearheaded by NASA. This initiative has forged alliances with private companies such as SpaceX and Boeing to transport astronauts to the International Space Station (ISS). By outsourcing low Earth orbit activities to commercial partners, NASA has been able to concentrate its resources and focus on more ambitious deep space exploration goals, such as missions to Mars.

The Artemis Program, NASA's ambitious project to return humans to the Moon, highlights a similar spirit of collaboration. This endeavor unites traditional aerospace giants like Boeing and Lockheed Martin with emerging players like SpaceX and Blue Origin. Together, they work in tandem to create a new chapter in lunar exploration, setting the stage for the next giant leap of humankind.

Pioneering entrepreneurs, inspired by their audacious visions and armed with cutting-edge technology, have become a driving force in reshaping the space industry. These private corporations have introduced a sense of competition, efficiency, and innovation that is breathing new life into the cosmos.

SpaceX, founded by the charismatic entrepreneur Elon Musk in 2002, stands as a paradigm-shifting entity in the space industry. Their groundbreaking Falcon rockets and Dragon spacecraft have drastically reduced launch costs, thereby enabling a thriving commercial space industry. However, their ambitions extend far beyond Earth's orbit; SpaceX's Starship project aims to make humanity a multi-planetary species, with Mars as their ultimate goal. Blue Origin, led by Jeff Bezos, has cast its sights on the lunar surface. Their New Shepard suborbital vehicle is designed not just for space tourism but also for launching scientific experiments and educational payloads. Blue Origin is committed to aiding NASA's efforts to return humans to the Moon, thereby rejuvenating the cosmic frontier.

Virgin Galactic, helmed by Richard Branson, is pioneering the space tourism sector with their SpaceShipTwo suborbital vehicle. It offers paying customers the unique opportunity to experience a few minutes of weightlessness at the edge of space, bringing a taste of the cosmos to a broader audience. Virgin Galactic envisions a future where space tourism is accessible to the masses.

Even startups, traditionally perceived as small players in the space arena, have started to leave an indelible mark on the industry. These audacious newcomers leverage cutting-edge technology and novel approaches to stake their claim in the cosmic frontier.

OneWeb, a startup founded in 2012, is on a mission to provide global internet coverage through a constellation of small satellites in low Earth orbit. Their vision is to bridge the digital divide and connect underserved regions through the power of space.

Rocket Lab, a New Zealand-based startup, has disrupted the space launch market with their Electron rocket. Tailored for small payload launches, Rocket Lab has made access to space more affordable and accessible. They have garnered attention from a wide range of clients, from governments to private companies.

While the limelight often shines on the public and private players in the space industry, academia silently plays a pivotal role in advancing our understanding of the cosmos. Universities and research institutions contribute to the intellectual framework of space exploration, conducting groundbreaking research, nurturing the next generation of space scientists and engineers, and often collaborating with both public and private entities on innovative projects.

Something worth mentioning, and that will be listed as one of the limitations at the end of this research study, is that these different players, all having shared projects with each other, are often subject to proper internal regulations, working practices and directives from their member states or directive boards. With programs becoming more and more international, it is always more evident the need for standardization in working practices for example related to project management and knowledge management. This certainly would bring a more homogeneous approach not only within an organization but also when working with each other.

c. Space Economy: the “How” aspect

The dynamics of the Space Economy are characterized by a multifaceted and rapidly evolving landscape driven by a convergence of various factors. At its core, the "how" dynamics of the Space Economy are influenced by the public and private players now regularly working together (e.g. through PPPs and Outsourcing business models), leading to a complex interplay of regulations, new agreements, technological advancements, and their profound impact on the space sector.

The growing number of players in the space industry has far-reaching consequences. The consequences of this new age of space exploration are multifaceted:

- Faster Technological Advancement: The fierce competition in the space industry is driving rapid technological advancement. As private companies compete for contracts and market share, they are developing cutting-edge technology at an unprecedented pace.
- Reduced Costs: The entry of private corporations has significantly reduced the cost of space access, making it more affordable for both governments and commercial entities to participate in space exploration.
- Democratized Access: Space has become more accessible, allowing smaller nations and private startups to participate in cosmic endeavors that were once the domain of superpowers.
- Global Collaboration: The space industry has witnessed a surge in international collaboration, with governments and private entities collaborating on projects that transcend borders and national interests.
- Commercialization of Space: The commercialization of space, driven by private corporations, has the potential to open up new revenue streams and industries, from space tourism to asteroid mining.
- Inspiration and Education: The growing diversity of players in the space industry has inspired a new generation of scientists, engineers. It serves as a testament to the boundless possibilities that await those who dare to venture beyond Earth.

The cosmic frontier, once the exclusive domain of superpowers and governmental agencies, has now become a dynamic landscape where public and private entities, startups, and academia converge to redefine our place in the universe.

In the following paragraphs, I will address PPPs and Outsourcing and then the international regulations.

Public-Private Partnerships (PPPs) and Outsourcing

The two business approaches, i.e. set up a Public-Private-Partnership and Outsourcing, are well established since the 1980s, with their usage becoming more and more common in all the sectors, including the space sector.

Public-private partnerships can be defined as a relationship between a public and a private entity that share risks to reach a shared objective. PPPs are a powerful tool that helps government and public agencies to leverage the expertise and efficiency of the private sector, raise capital, and spur development. PPPs become also a very powerful tool to manage and ensure an improved resources management, with resources that are allocated to address the most urgent development needs. Normally this is a contractual-based relationship between a private entity and the state for a publicly funded service [118].

On the other hand, outsourcing is defined as that business approach where a company or a public agency in our case, subcontracts with a provider to perform a pre-defined service, handle operations or perform specific tasks. In the space industry, as well as in other sectors, normally the company providing the service (also identified as service provider or third-party provider) can either place a resource within the commissioning company/public agency (perform the work onsite), or to perform the tasks within its own facility or another external location. This shall be predefined in a contract between the two entities [119].

Both Public-Private Partnerships (PPPs) and outsourcing are largely used in Space Agencies, with Outsourcing being the most regular contractual approach with resources located both within the agency as well as outside, especially following COVID and the increase of the teleworking practice. They both play crucial roles in the contemporary space sector, facilitating collaboration between governmental space agencies and private entities. The present several commonalities, from enhancing efficiency and reducing costs, as well as several differences, in their scope, structure and objectives.

Table 1 shows a comparative analysis between the two business approaches in the context of the space industry.

	PPP	**Outsourcing**
Nature of the agreement	PPPs are characterized by a more comprehensive and strategic collaboration between the public	Outsourcing is typically transactional and task-specific. It involves contracting specific

	and private sectors. The partnership extends beyond specific tasks, with both parties sharing responsibilities, risks, and benefits. PPPs often involve a long-term commitment to achieve common objectives.	components or services to external entities without the same level of shared responsibility or long-term commitment seen in PPPs. The focus is on achieving efficiency in the execution of particular tasks.
Funding	PPPs involve shared funding, with both the public and private sectors contributing financial resources to the project. The funding structure is often more complex, with various models such as build-operate-transfer (BOT) or revenue-sharing arrangements.	Outsourcing may involve a simpler financial arrangement, where the contracting organization pays the external entity for the specific services or components provided. The financial relationship is more transactional, with less emphasis on shared investment in the broader project.
Risk and Responsibility	PPPs emphasize shared risk and responsibility. Both public and private partners bear the consequences of project success or failure. Risk mitigation strategies are collaboratively developed, and the partnership model encourages joint problem solving.	In outsourcing, the external entity assumes responsibility for specific tasks outlined in the contract. The contracting organization retains overarching responsibility for the success of the project but may have less direct control over the detailed execution of outsourced functions.
Flexibility and Innovation	PPPs often provide a more flexible and innovative environment. The collaborative nature allows for the integration of diverse expertise, fostering innovation in technology, project management, and problem	Outsourcing can promote efficiency and cost-effectiveness but may have limitations in terms of fostering innovation. The focus is primarily on delivering specific services or components as outlined in the contract.

	solving throughout the project's lifecycle.	

Table 1: Comparison of PPP and Outsourcing in the Space Industry

International Regulations

Regulations in the space domain are central to maintaining the responsible and sustainable use of space resources. Governments around the world have established comprehensive space policies and regulatory frameworks to ensure the safety of space activities, the protection of orbital environments, and the equitable use of space resources. These policies often include licensing requirements, spectrum allocation for satellite communications, and guidelines for space debris mitigation. Furthermore, international bodies like the United Nations Committee on the Peaceful Uses of Outer Space (COPUOS) play a crucial role in developing guidelines and norms for space activities, such as the Space Debris Mitigation Guidelines and the Outer Space Treaty.

New agreements have emerged in response to the increasing role of private entities in space activities. Public-private partnerships have gained prominence, as detailed in the previous paragraph, enhancing improvements and developments in areas like satellite deployment, Earth observation, and space transportation.

The advance of space technologies has been a driving force behind the expanding space economy. The development and commercialization of technologies like reusable launch systems, miniaturized satellites, and in-orbit servicing have made access to space more cost-effective and efficient. Artificial intelligence and machine learning have enhanced satellite data analysis, revolutionizing Earth observation and remote sensing. Advancements in propulsion systems, such as electric propulsion, have enabled extended mission lifetimes and increased efficiency. Moreover, the emergence of space tourism and asteroid mining technologies foreshadows entirely new sectors within the space economy.

The impact of these dynamics is profound, extending across a multitude of sectors. The space economy's growth and diversification have created new jobs, fostered economic development, and driven innovation. Space-based technologies, such as GPS and Galileo, as well as Beidou and GLONASS, have become indispensable for telecommunications, navigation, and disaster management. Earth observation data is used for agriculture, environmental monitoring, and urban planning. The potential for space-based solar power generation, lunar resource utilization, and interplanetary exploration holds promise for addressing energy needs and expanding human presence in space. However, these developments also raise concerns about orbital congestion, space debris, and the militarization of space, necessitating continuous collaboration and regulation to ensure the responsible and sustainable development of the space economy.

Space Law is certainly a critical component of the Space Economy, regulating the activities and interactions of spacefaring nations, private companies, and international organizations. The dynamics of Space Law vary significantly across different countries and continents, reflecting distinct legal traditions and priorities. Meanwhile, international treaties and agreements play a crucial role in shaping global space governance. The increasing prevalence of space debris necessitates new regulations to address the challenges posed by orbital congestion and the sustainability of space activities. It is interesting to note that different countries take different Approaches to Space Law. This is mainly because space regulations are strictly linked to national regulations, which differ from Country to Country. As an example, the United States has a market-oriented approach to space law. The Commercial Space Launch Competitiveness Act of 2015, often referred to as the "Space Act," promotes commercial space activities, including asteroid mining. It emphasizes a light-touch regulatory framework to encourage private investment and innovation. On the other hand, the European Union has taken a coordinated approach to space law through its Space Strategy and Space Surveillance and Tracking (SST) program. The program aims to ensure space security, sustainability, and competitiveness, fostering cooperation among its member states and regulatory bodies.

Very different is what happens in Russia with a more state-centric approach to space law, where the government maintains a strong presence in space activities. It has expressed reservations about the commercialization of space and emphasizes national sovereignty over space territories. Looking more towards the East, China has rapidly expanded its space capabilities and has enacted laws to regulate its space activities. The country's space law emphasizes national security, resource exploration, and cooperation, demonstrating a hybrid approach that combines state control with commercial objectives. Despite national differences, an attempt has been made to adopt International Space Treaties, consisting of the following:

- Outer Space Treaty: The Outer Space Treaty, adopted in 1967, forms the cornerstone of space law. It prohibits the militarization of space, establishes space as a global commons, and lays out principles of peaceful exploration. However, it lacks enforcement mechanisms, and interpretations of its provisions can vary (see Figure 6).

- Liability Convention: The Liability Convention of 1972 establishes the liability of states for space activities, including damage to other nations' space objects. It ensures that victims of space incidents can seek compensation.
- Registration Convention: The Registration Convention of 1976 requires states to register their space objects with the United Nations, enhancing transparency in space activities.
- Moon Agreement: The Moon Agreement of 1984 emphasizes the common heritage of humankind and the equitable sharing of lunar resources. However, it has not been widely adopted and faces challenges in aligning commercial interests with its provisions.

Figure 6 : Signing of the Outer Space Treaty in 1967(Credit: United Nations)

Next to the international Treaties, a series of "Principles" have been established. The five declarations and legal principles are:

- The "Declaration of Legal Principles"
    - Declaration of Legal Principles Governing the Activities of States in the Exploration and Uses of Outer Space
    - General Assembly resolution 1962 (XVIII) of 13 December 1963
- The "Broadcasting Principles"
    - The Principles Governing the Use by States of Artificial Earth Satellites for International Direct Television Broadcasting
    - General Assembly resolution 37/92 of 10 December 1982
- The "Remote Sensing Principles"
    - The Principles Relating to Remote Sensing of the Earth from Outer Space
    - General Assembly resolution 41/65 of 3 December 1986
- The "Nuclear Power Sources" Principles
    - The Principles Relevant to the Use of Nuclear Power Sources in Outer Space
    - General Assembly resolution 47/68 of 14 December 1992
- The "Benefits Declaration"

- The Declaration on International Cooperation in the Exploration and Use of Outer Space for the Benefit and in the Interest of All States, Taking into Particular Account the Needs of Developing Countries
- General Assembly resolution 51/122 of 13 December 1996

Space debris is probably the most pressing issue that requires new regulations. The increasing number of defunct satellites, rocket stages, and fragments poses a risk to operational spacecraft. Countries and organizations are exploring debris mitigation guidelines and debris removal technologies. There is a need for binding agreements to tackle space debris, promote responsible space behavior, and reduce collision risks.

Space traffic management is another area where regulations are evolving. The proliferation of satellites in low Earth orbit (LEO) has heightened concerns about collision avoidance and safe orbital operations. Collaborative efforts are underway to establish norms and best practices for space traffic management.

Furthermore, as commercial space activities expand, issues related to property rights, resource utilization, and the definition of celestial bodies as "territories" require careful consideration. New legal frameworks are needed to address these challenges and promote sustainable space exploration and utilization.

Analysis: “Who”, “What” and “How” as the drivers for the need of modernization of the public Space Agencies

Over the years, the Space sector has undergone a transformative shift, with public space agencies, particularly in Europe, finding themselves at a crossroads. The need for modernization has become paramount to stay competitive, foster innovation, and collaborate effectively in a rapidly evolving space industry. The “who”, “what” and “how” are the drivers of the needed change of the public Space Agencies, with the constant injection of new private players, the technological advancements and new international agreements. Figure 7 summarizes the three aspects of the Space Economy:

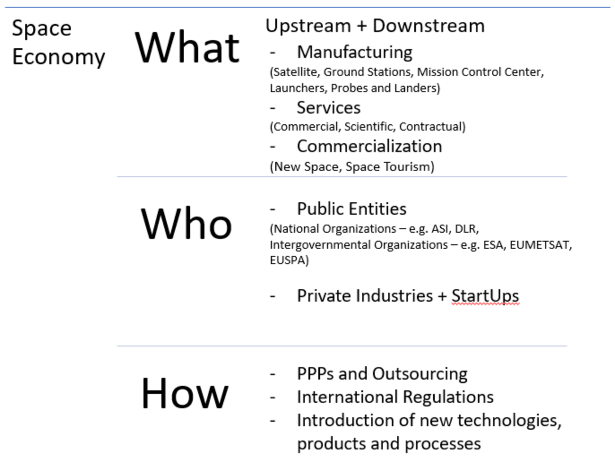


Figure 7: Summary of the three aspects of the Space Economy

Certainly, the most important impact comes from the new players that continuously change the needs, the rhythms and the competition of the space sector. While traditionally, governmental space agencies led the space industry across the world, over the past years it witnessed the emergence of private entities as major players. Companies like SpaceX and Blue Origin, together with many others, have demonstrated the capability to innovate rapidly, reduce costs and push the boundaries of space exploration. Space agencies, understanding the importance of these new players, they started multiple collaborations to leverage their expertise and resources. In response to this shift, European space agencies are reevaluating their strategies to incorporate more flexible and collaborative approaches. PPPs became a key component, allowing for shared risks, costs and expertise. The biggest advantage from these new competitors is the push towards innovation that is making the space industry more and more a dynamic environment.

Not only driven by new players, the modernization of the space agencies is driven every day more, by the technological advancements that are spreading within the space industry and not only. If the United States are the leaders in competitive technologies and developments, also, Europe shows a rich history of contributing cutting-edge technologies especially to the space industry, and now it faces the challenge of staying at the forefront. Innovation is accelerating under multiple areas, with Artificial Intelligence being the focus of the attention of the tech world, leading development towards autonomous spacecraft to data analysis, enhancing efficiency and enabling missions that are more ambitious. In the past years, European space agencies, especially ESA, are investing in research and development to integrate AI and other emerging technologies (e.g. Blockchain, Natural

Language Processing - NLP, computing paradigms, etc.) into their programs, ensuring they remain competitive in an era defined by technological progress.

From the above, it becomes clear that new partnerships and international collaboration become a key element of the modernization efforts. The main example that we can see in Europe is the ESA phi-lab [120], representing the center of innovation, with focus on the Earth Observation (EO) domain, of the European Space Agency. The ESA phi-lab, made of two offices (Explore Office and Invest Office), accelerate the future of EO by mean of transformative innovation, with the establishment of numerous partnerships with industries, academia and other research institutions. The Invest Office represents the ESA PPP investment opportunity for external entities. The modernization of European space agencies involves adapting to the changing landscape of global cooperation in space.

In general, it emerges that the imperative modernization in European public space agencies is multifaceted. What is clear is that the general space agencies policies and working practices are undergoing a strong transformation, with the organizations philosophy and mindset being pushed towards new directions that were not necessary before.

An adequate Project Management and Knowledge Management that shall be carefully applied across the full organization shall lead the full modernization. PM and KM are very well known practices within the space agencies, that are today making use of both internal and external tools and guidelines. Nevertheless, as will be further detailed hereafter, the working practices often have been established decades ago, and while processes have been slightly improved over the years, they are not yet developed enough to make space agencies competitive in today’s Space Economy and especially in tomorrow’s Space Economy. In the following chapters and sections, it will be addressed the issue of Project Management and Knowledge Management within one particular European space agency, with the objective of improving current working practices by introducing a Project Management Office (PMO), and identifying three main areas of improvement.

4. Project Management and knowledge management at European public space agencies: the need for a three-dimensional Project Management Office

The space agencies are responsible for the management of numerous and complex projects, related to research and space exploration, that involve multiple stakeholders, within the agencies, as well as external partners and contractors. Such a complexity and the involvement of thousands of people working across multiple disciplines generate the need of effective PM to ensure the success of individual projects (e.g., missions) and of the entire agency [48].

European space agencies are strongly dependent on the usage of standards. In particular, the ECSS standards are the most powerful tool to support their PM processes. Some agencies like the European Space Agency (ESA) have developed their own PM guidelines, based on the ECSS standards, to cover the main topics from project planning to risk management, quality management and reporting [49]. The PM approach in space agencies is based on the international standards, such as ISO 21500 [50] and PMBOK, which have both been tailored to the specific needs and requirements of space projects. In particular, standards and guidelines are applied to individual space missions, which are viewed as a stand-alone project, namely “a temporary organization that is created for the purpose of delivering one or more business products according to a specified business case” [51].

ECSS are equally applied to all the projects across the space agencies, but certainly, each space mission has some specific requirements that impose a dedicated tailoring to suit the needs of individual projects [52] . Based on the ECSS Standards, the space agencies dealing with multiple projects break down the latter into smaller manageable phases, allowing multiple project teams to focus on dedicated aspects of a project at a time [53]. Projects are regularly reviewed and audited during the full mission lifecycle in compliance with the ECSS standards, where the project team prepares series of documentation to be carefully reviewed by peers and steering committees [54]. Dedicated project boards carry out reviews of the progress of the projects and are responsible for the identification of issues, challenges, and risks. These should be properly documented [55], following the ECSS guidelines.

Main risks, limitations and challenges associated to PM and KM at European public space agencies

Space agencies currently deal with the management of large-scale complex projects, linked to space missions. Each of these missions requires a significant investment of resources, time, and money and involves very large teams, both staff across the organization, contractors, scientists, and other stakeholders. The management of such complex projects shows important limitations in current PM processes in space agencies [68]. Projects complexity often leads to delays and cost overruns, together with challenges associated to risk management and uncertainty, for which space agencies are not yet well prepared and need to improve their PM practices [69].

Another important limitation is linked to the knowledge sharing and communication processes. Public organizations deal with the issue of knowledge transfer and retention, sometimes also linked to large number of retirements that may lead to the loss of institutional knowledge. Currently space agencies are hiring numerous positions dedicated to the young generation to mitigate this issue for the future, as well as introducing new tools like mentoring and succession planning to transfer the knowledge [70]. Issues are linked also to the large number of people involved in each individual project, which makes the implementation of an efficient KM policy even more complex [71]. The biggest problem is also related to the structure of the human resources within public Space Agencies, which are divided into staff and contractors. The organization of resources between staff and contractors is a crucial aspect that ensures the successful execution of ambitious space exploration endeavors. Staff members, often consisting of skilled scientists, engineers, and administrative professionals, represent the core workforce of the agency, responsible for project planning, design, and execution. Concurrently, contractors, comprising external entities and specialized companies, bring additional skills, technologies, and resources to the organization, and deal more with the testing and technical support. Staff and contractors work closely with each other, as part of the same teams, and this dynamic resource allocation ensures that public space agencies can leverage a diverse skill set and optimize efficiency, ultimately advancing humanity's exploration of the cosmos. On the other hand, both staff and contractors often have limited duration contracts. In Space Agencies, this translates normally into four or five year’s contracts, that sometimes are converted into permanent contract after two renovations, and in some other cases they are not. For contractors this is always the case, where permanent contracts for employees are normally guaranteed with their own external companies, but not with the Space Agencies. This limited duration contracts have a big impact on the knowledge transfer and communication of lessons learnt, as the turnover of people may result a bit higher than for a situation with a permanent contract.

As mentioned above space agencies have developed KM databases, but a big limitation is related to the fact that access to the information is normally restricted to the people working within a specific project. Limitations normally are imposed due to different reasons. First, certain information is confidential and as such must be restricted to a limited group of people. Second, it can also happen that, to simplify its search, documentation is classified and assigned to groups of people belonging to a dedicated project, making it easier for them to access the information. As a consequence, those that do not belong to that project (and normally their names do not belong to that project list) do not have visibility of that set of documents, even if no confidential information is listed. Therefore, in general, knowledge is not easily transferred from one project to another.

One last limitation on knowledge sharing is due to the lack of a common naming convention within the agency [58]. To bring an example from the Copernicus program, if we look at the Sentinel-3 Ground Segment, we find that the data acquisition and processing falls under the PDGS (Payload Data Ground Segment) while if we look at Sentinel-5, the data acquisition and processing falls under the PDAP (Payload Data Acquisition and Processing) [71]. This is just one of the numerous differences in the taxonomy in different missions.

Need for PMO in space agencies

In many large organizations, projects become integrated organizational structures, making these organizations project-based ones [72]. Among those, space agencies kept increasing their size over the last decade[1], with the consequence that informal mechanisms of smaller organizations, such as centralistic decision-making approaches, are no longer effective. Space agencies are big project-based organizations, where a space project normally includes both a space segment and a ground segment, which are implemented in parallel, with a necessary interface with a launch segment. The space projects are born through a proposal typically raised by governments (alone or in cooperation), national space agencies (alone or in cooperation), scientific communities or commercial space players, and are considered unique projects, making the space agency a project-based organization.

Due to the large number of projects, we witness an important power decentralization, which, in return, leads to further complications for the alignment among projects, departments, and processes, also increasing the risk of failure [73].

With continuously new missions joining the current operational set of satellites, and the growth of the departments, human resources, services, and processes, the generation of a new entity established into the governance system is needed: the Project Management Office (PMO) [74]. According to the Project Management Institute (PMI), the PMO is: ‘‘an

[1] Space agencies can be national entities (e.g., ASI in Italy, DLR in Germany, etc) or intergovernmental (e.g., ESA; EUMETSAT; EUSPA). They all use typical outsourcing contractual terms to manage the relationships with external partners and contractors.

organizational body or entity assigned various responsibilities related to the centralized and coordinated management of those projects under its domain. The responsibilities of the PMO can range from providing project management support functions to actually being responsible for the direct management of a project''[60].

The need for the introduction of PMO into space agencies is supported by the analysis performed by Badewi [75]. He surveyed 130 firms, showing that transformation projects are more successful in organizations that have institutionalized their PM. PMO supports organization to solve inconsistencies in PM processes across different departments and projects, improving project outcomes and reducing duplication, which is one of the crucial issues in space agencies [76].

Proejct Management

From the literature definition, Project Management is the systematic application of processes, methods, skills, knowledge, and experience to achieve specific project goals while managing constraints such as scope, schedule, budget, quality, and resources. It involves planning, executing, monitoring, and controlling all aspects of a project to ensure its successful completion [60]. No industry or agency, including those belonging to the space sector, can run their business without a good and regulated application of Project Management working practices. Before addressing the PM working practices specifically in public Space agencies, at its core, project management involves the following key components [60]:

1. Scope: Clearly define the project's objectives, requirements, and deliverables. What needs to be achieved, and what are the boundaries?
2. Schedule: Develop a timeline, including milestones and deadlines, to ensure that tasks are completed in a logical sequence.
3. Resources: Identify and allocate the necessary people, equipment, and materials to carry out the project.
4. Cost: Establish a budget and manage expenses to keep the project within financial constraints.
5. Quality: Set quality standards and measures to ensure that the project's outcome meets or exceeds expectations.
6. Risk: Identify potential risks, assess their impact, and develop strategies to mitigate or manage them.
7. Communication: Establish clear channels for communication among team members, stakeholders, and partners.

8. Integration: Ensure that all project components work together seamlessly and align with the project's objectives.

Projects typically go through a series of stages, known as the project life cycle. The stages may vary depending on the project management methodology used, but they generally include [60]:

1. Initiation: This phase involves defining the project's purpose and objectives. It answers the "why" and "what" questions and assesses the project's feasibility.
2. Planning: During this phase, project managers and their teams create a detailed plan that outlines the scope, schedule, resources, budget, and risk management strategy. Planning is critical for success and provides a roadmap for the project.
3. Execution: This is where the project comes to life. It involves carrying out the activities outlined in the project plan, coordinating team members, and managing resources to achieve the project's goals.
4. Monitoring and Controlling: Continuous oversight and measurement of project performance are vital. This phase ensures that the project remains on track and within the defined constraints. If deviations occur, corrective actions are taken.
5. Closure: The project is officially completed during this phase. It includes handing over deliverables to stakeholders, evaluating the project's success, and documenting lessons learned.

Important to highlight, is the differences between the possible PM methodologies. A Project Management methodology is a set of standardized processes, techniques, tools, and best practices used to plan, execute, and control projects. It provides a structured framework for managing projects efficiently, ensuring that they are completed on time, within budget, and with the desired quality. Despite all the best effort and strict application of PM working practices, 45% of projects suffer schedule delays, about 38% is not completed with the initially allocated budget, and 27% of projects do not reach business objectives [121]. Several reasons may cause these low success rates, among which certainly are the changes in project objectives when the project is in progress, inaccurate requirements gathering and estimation, undefined opportunities and risks [122].

PM methodologies serve as guidelines and roadmaps for project managers and their teams, helping them to make informed decisions, allocate resources effectively, and mitigate risks. These methodologies often include specific phases, tasks, roles, and deliverables to follow throughout the project's life cycle, and aim at enhancing project effectiveness and increase chances of success [123]. The choice of a PM methodology depends on various factors, including the project's scope, complexity, industry, and the organization's culture. Common

PM methodologies include Waterfall, Agile, Scrum, Kanban, PRINCE2, and more. Rapidly changing conditions, such as new players, new technologies, new needs for example for short time-to-launch cycles and many other factors influence how projects are managed. Different types of projects require the application of different procedures for successful execution [124]. Each methodology has its own set of principles and practices, making it suitable for particular types of projects or work environments. Adhering to a PM methodology promotes consistency and ensures that projects are well managed from initiation to closure. It provides a structured approach to project planning, execution, and monitoring, improving the chances of successful project delivery and customer satisfaction.

The Waterfall methodology is a traditional and linear approach to project management. In this method, the project is divided into distinct phases, and each phase must be completed before the next one begins. It follows a well-defined sequence: initiation, planning, execution, monitoring and controlling, and closure. Waterfall is suitable for projects with well-understood requirements that are unlikely to change during the project's course. It provides a structured and predictable path, making it easier to manage and estimate timelines and costs [125][126][127]. However, its rigidity can be a drawback in situations where requirements evolve, as changes can be costly and time-consuming to implement. Waterfall is commonly used in industries like construction and manufacturing.

Agile is an adaptive and iterative project management approach that prioritizes flexibility and collaboration. The first adoption of the Agile methodology could be found in projects focusing on software development, although it slowly started to be used in numerous other industries. It finds the main applications in projects with evolving requirements and dynamic environments. Agile emphasizes delivering small, incremental improvements to the project at regular intervals, known as sprints or iterations. The teams involved in projects driven by the Agile methodology work closely with stakeholders to understand their changing needs and adjust the project accordingly, and this is done on a regular basis (e.g. in multiple phases of a mission life-cycle). Scrum and Kanban are two popular frameworks that fall under the Agile umbrella. [128][129].

Figure 8 shows the comparison between the Waterfall model and the Agile Model.

Scrum is a specific framework within the Agile methodology that organizes work into short time periods called sprints, typically lasting 2-4 weeks, and during a sprint, a cross-functional team works collaboratively to complete a set of tasks or user stories. These short follow-ups make Scrum methodology suitable for handling projects with high level of complexity, where for example requirements change rapidly. Typically, Scrum methodology also includes daily meetings in order to keep the team aligned and focused on their objectives, as well as increase a positive team-environment aiming for improved productivity. Scrum methodology relies on three key roles: the Product Owner (responsible for defining requirements), the Scrum Master (responsible for facilitating the process), and the Development Team (responsible for executing the work). [130].

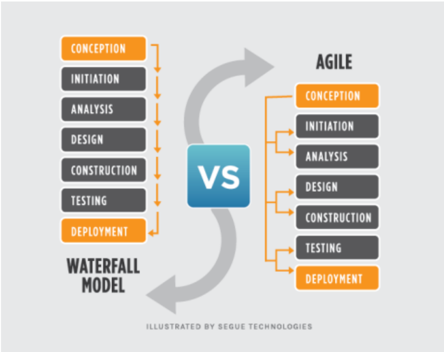
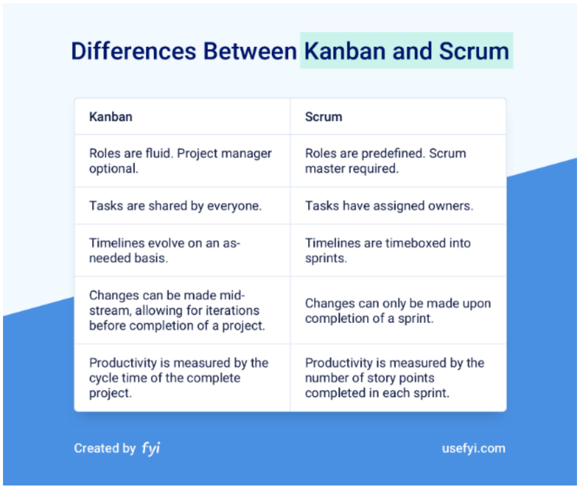


Figure 8: Waterfall Model vs. Agile (credit: Segue technologies)

Kanban is another Agile framework that emphasizes visualizing workflow, reducing work in progress, and optimizing the flow of work items. Like for other Agile methodologies in general, Kanban was used mainly for software development, but it slowly started to be used in other fields, such as customer support and manufacturing. In Kanban, work items are represented on a visual board with columns (e.g., "To Do," "In Progress," "Done"). As team members complete tasks, they move them across the board. The focus in Kanban is on maintaining a steady flow and balancing workloads. Unlike Scrum, Kanban does not use fixed time frames like sprints. Instead, it allows for a continuous flow of work, making it suitable for projects with variable and unpredictable workloads [131].

Figure 9 shows the differences between Kanban and Scrum methodologies.



Kanban	Scrum
Roles are fluid. Project manager optional.	Roles are predefined. Scrum master required.
Tasks are shared by everyone.	Tasks have assigned owners.
Timelines evolve on an as-needed basis.	Timelines are timeboxed into sprints.
Changes can be made mid-stream, allowing for iterations before completion of a project.	Changes can only be made upon completion of a sprint.
Productivity is measured by the cycle time of the complete project.	Productivity is measured by the number of story points completed in each sprint.

Figure 9: Kanban vs. Scrum Methodologies (credit: Nira)

One of the most used methodologies worthies recalling here, is PRINCE2. PRINCE2, which stands for "Projects IN Controlled Environments," is a structured project management methodology widely used in various industries and organizations around the world, but mainly in the United Kingdom and Europe. PRINCE2 provides a comprehensive and flexible framework for managing projects. It is process-driven and focuses on key project management principles, such as continuous business justification, clearly defined roles and responsibilities, and effective project control. PRINCE2 divides a project into manageable stages, each with its own set of processes, activities, and deliverables (Figure 10 shows the process model diagram). It emphasizes the importance of tailoring the methodology to fit the specific needs of the project, ensuring that it is scalable for both small and large endeavors. One of the distinctive features of PRINCE2 is its emphasis on clear documentation, which helps in tracking project progress and decision-making. Additionally, PRINCE2 defines roles such as the Project Manager, Project Board, and Project Assurance, making it clear who is responsible for what within the project.

PRINCE2 is known for its flexibility, which allows organizations to adapt the methodology to suit their unique project requirements. This adaptability, along with its focus on control and accountability, makes PRINCE2 a valuable choice for organizations seeking a structured approach to project management [132].

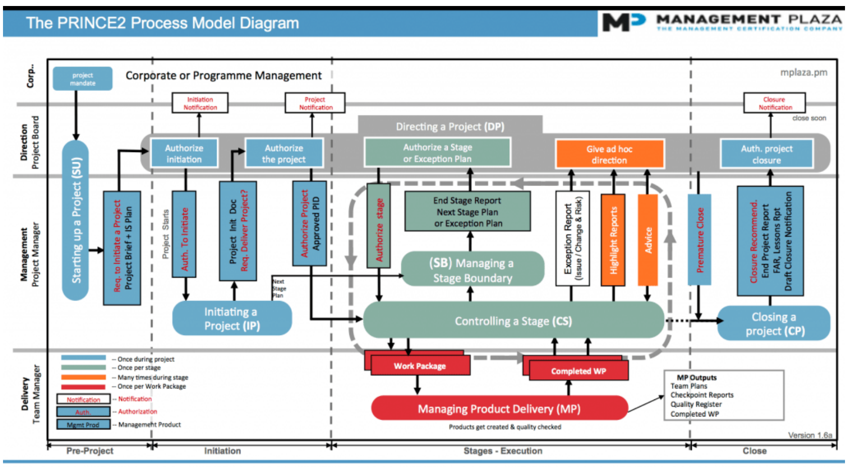


Figure 10: PRINCE2 Process Model Diagram [132]

Knowledge Management

In the intricate organizational dynamics, the relationship between Project Management (PM) and Knowledge Management (KM) is a symbiotic alliance needed for ensuring projects success. PM focuses on the efficient execution of projects, managing resources, timelines, and deliverables. In this context, KM serves as the guardian of the intellectual capital generated throughout the project lifecycle. As projects unfold, knowledge is created, including lessons learned, and innovative solutions, which need to be documented. KM ensures capturing of these nuances and transforming them into explicit knowledge. Conversely, PM benefits immensely from KM's insights, utilizing past project data, best practices, and lessons learned to optimize current and future endeavors [133]. The relationship between PM and KM enhances project efficiency, mitigates risks, and fosters a culture of continuous improvement. The fluid exchange of information between PM and KM is the cornerstone of an organization's ability to navigate the complexities of project landscapes, ensuring that each project becomes a stepping stone in the ever-growing repository of organizational knowledge [134].

Knowledge Management shall be analyzed as both within its tacit and explicit forms. Tacit knowledge is deeply embedded in individuals' experiences, insights, and intuition, often challenging to articulate. Explicit knowledge, on the other hand, is codified and easily transferable through documents, databases, or any tangible medium. KM seeks to bridge the gap between these realms, creating a seamless flow of insights across the organizational landscape. According to Clemente [135] KM can be measured through a model listing four steps of a lifecycle: Capture, Sharing, Storage and Application. The first step involves capturing tacit knowledge and converting it into explicit forms. Achievement of this “translation” could be done through interviews, documentation, or the development of knowledge repositories, ensuring that valuable insights are not lost when individuals leave the organization. The second step (sharing) makes use of an environment that encourages collaboration. Platforms for sharing ideas, lessons learned, and best practices foster a culture of continuous learning. Whether through intranets, collaborative tools, or regular knowledge-sharing sessions, organizations reap the benefits of a collective intellect. Certainly, when talking about KM Taxonomies, search functionalities, and intuitive interfaces play a crucial role in ensuring that employees can quickly retrieve the information they need, transforming data into actionable knowledge [136]. Despite the important need of KM, organizations face numerous challenges in performing a correct implementation. Amon the main reasons that challenge a successful KM, are certainly Cultural Resistance, new technologies with new associated knowledge, and what became more and more important lately, Data Security and Privacy.

In a public space agency PM and KM, and their interconnections, are vital elements for both short-term and long-term activities, and they are necessary for ensuring the success of the missions and the entire organization.

PM includes activities such as planning, executing, and controlling of a project. On the other hand, KM is responsible for the creation, capturing, sharing and, certainly, management of knowledge for a project or, in general, for the organization itself. They both represent a powerful tool for the success of a space mission design, implementation, and operation, being strictly connected, given that each one serves as input of the other one, and vice versa. If PM provides the support for the management of knowledge-related activities in a specific project, KM supports PM by providing the means to access the information, at any time, needed by the project teams. This includes documentation such as working practices, project documents, lessons learnt from other space missions, etc. In an article by Alavi and Leidner [138], it is reported "knowledge management is a critical enabler of project management, and project management is a vehicle for knowledge management". The success of a project (space mission), depends on the proper and regular integration of KM into PM, through the full project lifecycle. In the case of a space mission, this becomes even more relevant, due to the regular handover of systems and knowledge from one team to another, in multiple departments, across the organization. As a good working practice, KM should be integrated in all processes and activities from project planning, to team management, risk management and project evaluation [139].

Needs and applications of PM and KM in public Space Agencies

Project management plays a key role in public space agencies, at all phases, and in particular when dealing with Space Operations activities. The inherent nature of space missions demands a systematic and disciplined approach to planning, organizing, and controlling resources to achieve specific objectives within defined constraints. One of the primary needs for project management in public space agencies is linked to the high level of complexity, which is associated to the preparation, and then operation of a Space Mission, including the interaction with other partners and contractors contributing to the success of the mission. Space missions involve an intricate web of interconnected tasks, ranging from spacecraft design and construction to launch logistics, orbital maneuvers, data acquisition, processing and dissemination, etc. Moreover, Public Space Agencies work closely with other public entities as well as with private players: outsourcing is nowadays something very common for space agencies, with the externalization of parts of the services or products to external contractors. The sheer complexity and interdependency of these tasks require a structured project management approach to ensure that timelines are met, resources are efficiently utilized, and risks are effectively mitigated. Budget is also a major part of the Project Management for Space projects: both the financial and technological investments associated with space exploration underscore the necessity for effective project management. Public space agencies operate within budgetary constraints, and the allocation of resources shall be meticulously managed to maximize efficiency and minimize waste. Project management methodologies, such as the Project Management Body of Knowledge (PMBOK) or the PRINCE2 framework, are applied also to Space Agencies. In addition, the dynamic and rapidly evolving nature of space technology necessitates adaptability, and project management provides a structured approach to change management. Unforeseen challenges, advancements in technology, and shifts in mission objectives can occur during the course of a space project. A robust project management framework enables space agencies to respond agilely to these changes, ensuring that projects remain on track and adaptable to emerging circumstances. Collaboration and coordination among diverse teams and stakeholders are also critical aspects of space missions, involving scientists, engineers, technicians, and administrators. Project management methodologies facilitate effective communication, team integration, and the establishment of a common understanding of project goals. Clear lines of communication are essential in ensuring that all stakeholders are aligned, potential issues are identified and addressed promptly, and that the project progresses harmoniously towards its objectives. Moreover, the international and collaborative nature of many space missions amplifies the need for effective project management. Public space agencies often collaborate with other countries, space organizations, and private entities on joint ventures. Managing these complex partnerships requires a systematic approach to project management, as it involves navigating diverse cultures, legal frameworks, and technical standards.

PMO as a tool for improved organizational management

By observing the organizations structure, their evolution in the last ten years, and the future needs, it shows a scenario where increased competition, number of projects and time to market require a transformative change also in terms of project management. Most organizations started to develop more flexible organizational forms, moving more towards being project-based organizations [140]. To respond to the new challenges and the increased number of projects and their importance within the organizations, they have implemented a new entity that goes under the name of Project Management Office (PMO). To better explain, organizations are keen to implement a larger number of PMOs, with various forms and functions [141]. As it normally happens in the normal evolution of an organization, also PMOs, when established need to be constantly revised, wither as a period re-structuring of the organization, or because of organizational experimentations or due to external inputs requiring a new adequate structural arrangement [142].

The implementation of a PMO or the restructuring of an existing one, is an important organizational change, being itself a complex project.

PMO usage in public administrations

Development and success of projects within an organization lay their basis on an efficient project management. This is especially true when dealing with large projects (such as could be those in a space agency), where a strong PM structure becomes an essential need to cope with the complexity of the projects [143]. Organizations around the world attempt to cope with parallel complex problems trying to manage all activities, meeting evolving requirements, risks, responsibilities, costs and other aspects [144]. Despite the effort, the development of effective and efficient PM guidelines within the organization remains a major challenge. Project Management Office can certainly help, providing support to innovate, develop competitive advantage and reduce uncertainty for the success of the projects [145].

A public institution’s work is mainly driven by the delivery of services within a certain period of time and making use of the available funds. In the case of a space agency, for example with Earth Observation missions, the objectives rotate around the delivery of EO data to the Member States that are funding the missions. With routine operations, bureaucratic activities carried out by public institutions, including budgetary management on functions, planning, risks and other challenges seem to be regularly addressed. However, we witness over the years an increase on complexity related to the implementation of projects, especially when dealing with large and parallel projects [146]. Complexity in dealing with projects in public organization is a big combination of multiple components, going from the technical aspect (e.g. different missions, different instruments, and other technologies) to human resources aspect (e.g. experience of the team members, background, etc), as well as a continuous political interference, being the funds public funds.

When dealing with multiple projects, shared services shall be seen as the most powerful tool to solve PM issues, with shared services being the consolidation of specific activities under a single area of an organization [147. Sharing services normally apply in order to reduce or eliminate a duplication of efforts among different business units [148]. While the private sector embraced more easily this concept, the public sector is still going through a learning curve.

While still not many examples from the public sector are available, hereafter a few examples from the PMO integration in public organizations are listed. These examples have been carefully studied in order to get lessons learned and examples for the implementation of a successful PMO at European space agencies.

Tsaturyan and Mueller [72] analyzed the integration and governance of a PMO in large organization making use of a case study from a European bank. They analyzed a concept for a four-dimensional framework of PMO governance, addressing the following areas: structures, procedures, relationships, and regulations, and applying the four dimensions to a large European bank. In general, if PMOs are still poorly used in public sectors, when they are applied, they often appear as a single PMO, while there is an emerging trend and need for establishing multi-dimensional PMO within larger organizations and at several levels in the management chain, although this is leading to further complications related to project decision-making processes [149]. The European bank which has been studied, is a clear example of a project-based organization, showing a very large number of parallel projects (about 100 at the time of the study) and also for the working practices, that show a project-oriented approach, distributed to several teams within the organization. The bank uses a multilevel project governance structure, consisting of:

- Business Project Office (BPO): an umbrella organization of all PMOs in the bank, fostering communication between business and IT and other activities such as portfolio management and follow-up on projects
- Project Management and Strategic Integration Office (PMSI): a dedicated PMO for IT projects, providing the interface between business and IT
- Local IT Project Office: a PMO that coordinates and tracks the largest cross-organizational IT projects
- Strategic Project Office (SPO): a PMO dedicated solely to the Operations and Technology aspects.

The four PMOs activities intertwine with each other, with several relationships at both hierarchical as well as at the peer level. The study case at the bank shows that a four-dimensional PMO makes the organization more focused on the long-term strategic goals rather than focusing on the daily operational objectives, increasing the value provided to all the involved stakeholders. It also improves the management of human resources and foster effective cooperation across teams.

Another example of successful PMO application, comes from the study conducted by Paton and Andrew [29] at multi-national defense organization, that associated to the PMO role of integrator aiming at facilitating, coordinating and supporting project activity across organisations and portfolios, also the role of parallel integrator of activity across the product lifecycle, especially to bridge the interface gaps that exist between product lifecycle phases [150]. The study highlighted that project development is already a complex and challenging activity, and each project present an inherent challenge. Nevertheless, multiple studies started to suggest also issues going from one phase to another, such as connectivity and knowledge management [151].

Among many industries, the defense sector is one that uses a lifecycle approach to structure all the activities, based on the carrying out of projects, as the dominant form of organizational work. The companies and organizations operating in this sector can typically be identified as Project Based Organizations (PBOs) [152]. In the defense sector, the work transition between phases in the product lifecycle could be very challenging and present interface gaps, especially as each phase is often further segmented into sub-phases. Moreover, the defense sector is mainly dominated by the public-sector procurement strategies, where funding is typically released in multiple stages rather than at the beginning of the full project. All this, together with the inherent complexity of the defense technologies, lead to a scenario likely to experience phases gaps.

By observing the work of multiple defense organizations, it emerged that interface gaps, both within phases and within sub-phases, seem to be unavoidable in this sector, therefore, I analyzed how the introduction of a PMO can improve the situation and favor success within the organization, both from a strategic perspective and an operational perspective. In particular they show that an effective PMO shall deal with the correct deployment of human resources across phases, to help the transition between one phase to another: the ownership of two consequent phases, by the PMO, brings coherency in the lifecycle of the project, resulting in coherency towards the longer-term objectives, with less focus on the shorter-term objectives that shall be dealt with within the team. PMO shall be used for both personnel allocation and consistency between phases, as well as to perform process control and knowledge management, to smoothen activities across the organization.

Case Study

The case study is a research strategy, which focuses on understanding the dynamics present within single settings [153]. For the purpose of this article, the Case Study is used to analyze two unique, real and similar space missions focusing on earth observation from the same European space agency. For reasons of confidentiality requested by the space agency, these missions are indicated respectively with Mission A and Mission B. The two missions have a launch date that is three years apart. At the time of this study, Mission A has recently been launched, while Mission B just suffered a further delay, leading to the three years expected separation. The characteristics of the two missions have been highlighted in Table 2.

Characteristic	**Mission A**	**Mission B**
Type of Mission	Earth Observation, specifically Geostationary (GEO)	Earth Observation, specifically Low Earth Orbit (LEO)
Mission Objectives	Deliver new data for advancing weather, climate and Earth system research, as well as to enhance operational forecasting	Deliver new data for advancing weather, climate and Earth system research, as well as to enhance operational forecasting
Number of Satellites per Mission	Six Satellites	Six Satellites
Number of Instruments on board the satellites (per pair of satellites)	Five instruments	Ten instruments
Measurement Domains	Five measurement domains: Atmosphere, Ocean, Land, Snow & Ice	Five measurement domains: Atmosphere, Ocean, Land, Snow & Ice
Copernicus participation	Yes	Yes
Financial approach	30% assumed by the Space agency in question, while the rest if shared between partner agencies, the European Commission, or other contributing stakeholders	30% assumed by the Space agency in question, while the rest if shared between partner agencies, the European Commission, or other contributing stakeholders

Budget	Confidential information, but the two missions have a comparable budget.	Confidential information, but the two missions have a comparable budget.

Table 2: Mission A and Mission B characteristics comparison

Based on what described above, I decided to compare the two missions based on the following:

- development of the operational scenario validation campaign (OSVC);
- development of tracking tools and associated methodologies for operational items;
- Human resources issues.

Before addressing the three aspects above, I recall that both missions followed the mission lifecycle, inclusive of all the reviews, as described in the ECSS Standards, going from Phase 0 to Phase F, (see Table 3) [64], where:

- Phase 0, Phase A and Phase B include the set of activities necessary for **i.** Elaboration of system functional and technical requirements and identification of system concepts to comply with the mission statement, **ii**. Initial assessments of technical and programmatic risk, **iii.** Initiation of pre-development activities.
- Phase C and Phase D include the set of activities necessary for the development and qualification of the space and ground segments and their products.
- Phase E includes the set of activities necessary for the launch, commissioning, utilization, and maintaining of the orbital elements of the space segment and the utilization and maintaining of the associated ground segment.
- Phase F includes the set of activities necessary for the safe disposal of all products launched into space as well as ground segment.

At the time of this study, Mission A is within Phase E, whereas Mission B is still within Phase D. The study focuses on the Phase D of the mission lifecycle for both the missions, and particularly between two key reviews: the SVVRR (System Verification and Validation Readiness Review) and the SVVR (System Verification and Validation Review). During this phase, the project team is preparing the operational scenario validation campaign (OSVC), developing the test specification (a document identifying the timeline, content, roles, and responsibilities of a dedicated campaign), and collecting test cases (steps of a validation) and test procedures (procedures to validate a dedicated step, and aiming at becoming operational procedures).

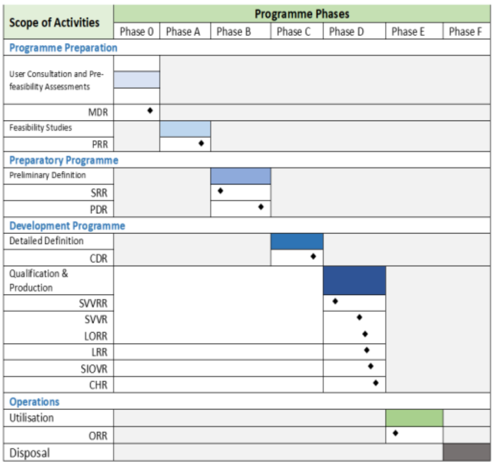


Table 3: ECSS Project Lifecycle [64]

The OSVC includes a series of activities aiming at validating operational scenarios, addressing both nominal and contingency configurations. It makes use of ground-based tests and simulations to measure the satellite performance in multiple scenarios, with respect to pre-established operational requirements [154].

The OSVC aims at validating both the space segment and the ground segment of a mission, and in particular at developing the end-to-end system operations. This is necessary to simulate and prepare for the operations phase that will occur after launch. Due to the complex nature of a space mission, project teams of both Mission A and Mission B broke down the testing activities into multiple sub-campaigns with different focuses. The two project teams, though, performed a different breaking down, but both with the common objective of validating the full set of operational scenarios, as defined in each respective Reference Operations Plan (ROP), which is a document describing operational activities of a specific mission.

The organization of the validation campaign of Mission A and Mission B has been developed independently and without, or just little, exchange between the two missions. Moreover, Mission A started the validation campaign closer to the satellite launch date (about two years before the launch date), while Mission B started the organization of the OSVC earlier, about four years before launch.

Development of the OSVC

Due to the development occurring relatively closer to the launch, Mission A took an "operational" approach from almost the very beginning. Systems from both the ground segment and the space segment needed to be tested together, in parallel where possible, with the objective of validating, almost from the beginning, a final configuration scenario. Test specification and test cases have been developed directly to simulate end-to-end scenarios, including the development of system procedures and system activities.

On the other hand, Mission B started the validation campaign with more margin from the launch date, with systems availability very much reduced. Therefore, while the final objective was to test end-to-end system scenarios, the Mission B's OSVC campaign started as a more "subsystem oriented" campaign, rather than "end-to-end scenario" oriented. The setup of the first validation campaign of Mission B included three separate campaigns, involving "satellite operations", "ground stations", "data processing", with no or very little interaction between subsystems. Only when closer to the launch, the Mission B' s started to merge all the components and the individual campaigns in order to test the end-to-end scenarios.

As a result, Mission A became very efficient in the testing of the systems already in an "operational configuration", which was a positive approach showing immediately positive and negative systems behavior. Nevertheless, it lacked testing for individual subsystems per se, and introduced numerous patches to "make the systems work", due to less individual testing of the subsystems.

On the other hand, for Mission B, a detailed testing of individual subsystems could be carried out before the testing of the end-to-end scenarios, but this led to investing more time and resources already at an earlier stage, continuously looking for "what can be tested", without the possibility of simulating real operational scenarios till a much later stage. A summary of the timeline for the two missions is shown in *Figure 11*.

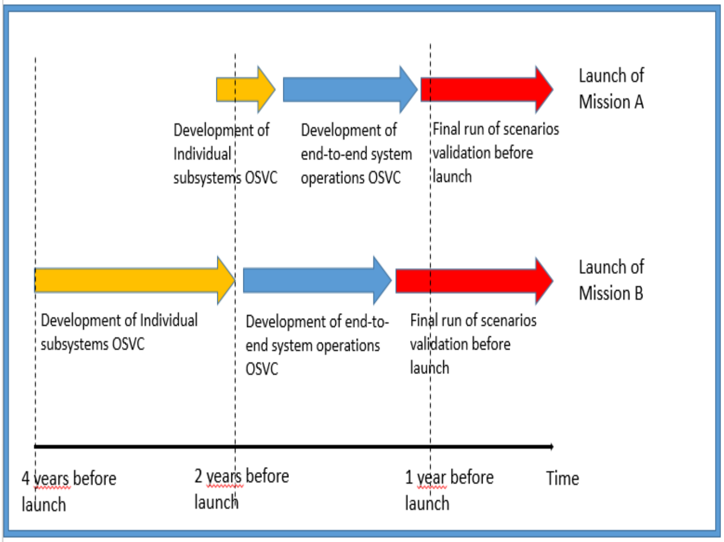


Figure 11: Operational Scenario Validation Campaign for Mission A and for Mission B

Tracking tool and associated methodology

At the time of a mission to be declared operational, numerous operational items, such as operational procedures, must be in place, in order to support real time operations, both in nominal and contingency configurations. The development of these operational items occurs during the OSVC conducted by the project team.

The project team is responsible for ensuring the adequate development and validation: a set of procedures is allocated to each test specification and test case. The project team is also responsible for ensuring that no procedure is missing to support real operations, and this is done with the usage of a dedicated tracking tool. To ensure this, each mission developed an independent methodology, including the tool aiming at tracking the development and validation process. Since in the space agency under consideration a standard approach and a dedicated tool are not available for this purpose, the two missions took two different ways.

While Mission A decided to allocate one human resource, for a period of about one year, to the development of a detailed and comprehensive tracking tool. The tool in the end was a complex combination and usage of three tools: the agency's KM tool integrated with two commercial software solutions.

On the other hand, Mission B took a simpler approach, giving the task (i.e., development of tracking tool) to a human resource who was also dealing with other activities, and for a period of time much shorter compared to the Mission A (only a few months). The output was a tool that was making use of the agency's KM tool and that was developed with Excel.

As a result, Mission A invested a much bigger amount of time into the development of a complex tool and took the approach of allocating one resource almost entirely to this task.

On the positive side, it was a very precise tool, able to deliver a picture of the tracking at any specific time, with multiple requests, in an immediate manner.

On the other hand, Mission B did not invest the same amount of time into the tracking tool development, which allowed for the resource allocated to this task to support other activities in parallel. However, the tool was not as precise as the one of Mission A, although still able to deliver the expected tracking and ensure operational readiness.

Human Resources issues

Due to the lack of a shared project team between projects, a dedicated project team was allocated to the Mission A and a separate one to the Mission B. The preparatory phase of a space mission takes a long period of time, and within the Phase D, which was the focus of our case study, both teams happened to encounter difficulties due to lack of resources at a specific moment in time.

Lack of human resources was caused by various reasons: in some cases, members of the project team reached the retirement age and left the team, in some cases there were sickness reasons or parental leave, or other reasons, or simply, team members left for a different job position. Lack of human resources is the main cause for increased workload for the remaining team members, loss of expertise within the project and in some cases delay in the completion of dedicated tasks.

Moreover, during the Phase D, the project team underwent multiple reviews, with the need of defining, updating, and publishing documents addressing validation activities, verification activities as well as the design. In each mission, the resources invested a large amount of time to study and understand the documentation. Although they were different missions, many documents were similar. Therefore, the agency invested almost double effort to carry out project reviews.

Table 4 hereafter shows a summary of the above-discussed aspects used for this case study, compares the approaches of Missions A and B, and highlights the positive and negative aspects of each of them.

Aspects	Mission A	Mission B	Comments
Development of operational scenarios	Direct development of end-to-end operational	1st step: Development of broken operational	**Mission A:** Positive: very efficient in the testing of the systems already in an “operational configuration”

	scenarios for validation campaign.	scenarios addressing individual subsystems. 2nd step: merging of sub-system individual campaigns into end-to-end testing of operational scenarios.	<u>Negative:</u> lacked testing for individual subsystems per se, and introduced numerous patches to "make the systems work", **Mission B**, <u>Positive:</u> detailed testing of individual subsystems. <u>Negative:</u> need for investing more time and resources already at an earlier stage, continuously looking for "what can be tested", without the possibility of simulating real operational scenarios till a much later stage.
Tracking of procedures and other operational items	Over one year for setting up a complex, tracking methodology.	Simpler tracking methodology developed in parallel with the testing campaign.	**Mission A:** <u>Positive</u>: it was a very precise tool, able to deliver a picture of the tracking at any specific time, with multiple requests, in an immediate way. The tool is capable of creating interconnected Structures that represent the OSV, allowing to drill down to the Test Specification, Test Cases, Test Procedures and Operational Static Data associated to it, getting the latest status of a specific set of items (using filters) with a finger click. It is also possible to select all the details of interest in dedicated viewers in order to

			export them and use them for low detailed level of reporting. Negative: invested a much bigger amount of time into the development of a complex tool, allocated one resource almost entirely to this task, and long time required also to populate the database once created. **Mission B**: Positive: required less time for the development, with resource allocated to this task also supporting other activities in parallel. The database is relatively easy to be used by all team members, also those not having a lot of experience with the tool. Negative: tool not as precise as the one of Mission A. The tool allows for tracking of operational static data with respect to a specific OSV, but it does not go down to the details of Test Cases. It provides a general picture in time of what has been run, when and in which campaign, but without too many insights about the exact test where they have been run. Therefore, only a general picture is available with the sole purpose to track

			validation of the items, providing a general report to management.
Human Resources issues	Lack of resources closer to the launch.	Lack of resources closer to the launch date.	**Mission A and Mission B:** <u>Negative:</u> lack of human resources is the main cause for increased workload for the remaining team members, loss of expertise within the project, and in some cases delay in the completion of dedicated tasks.

Table 4: Case study key aspects and comparison between Mission A and Mission B

While the two missions followed different approaches, and the unofficial work and workload was different, from an official point of view, the ECSS milestones and guidelines have been followed in terms of checkpoints, reviews and milestones for both missions.

Analysis and proposal for an improved PMO solution for the public space agencies

The three-dimensional PMO framework

The case study brought up some limitations deriving from the application of individual project management at the Space Agencies.

From the case study, the two missions, both based on the ECSS standards, are expected to reach the final objective successfully. Results are in line with the expected requirements, but different resources, methodology, time, and tools have been used and changed over time to reach the same objectives. We are therefore not questioning the outcome of the project, but rather the working practices adopted at the space agencies. Was it possible to manage these projects more efficiently? How can SPM be improved for future missions?

With new missions joining the space agencies' portfolio, the latter are witnessing an increased presence of 'projectification', leading to an increased need of sharing of project work [155]. Although not part of this study, it is worth mentioning that projects complexity is increased by the outsourcing approach, which is today a normal working practice at space agencies, where the latter combine their expertise with that of other contractors, to deliver a solution in line with the mission requirements [156].

When examining the number of missions under development in the top public agencies, it is clear that agencies work on many parallel missions at the same time. In the case of EUMETSAT, they are all earth observation missions, at EUSPA they are all constellations of satellites for global navigation system (GNSS), and ESA shows the highest complexity with missions covering multiple areas, from earth observation to deep space or human spaceflight. While the variety and classification of the missions differ from one agency to another, they all face a similar issue of working in parallel projects, at the same time. Learning from the past is something that could be more easily implemented, using sequential projects strategically [157], but documentation from previous missions is not easily available, and would make this a project within a project, with the need of investing further resources. Therefore, knowledge sharing and learning need to be implemented between simultaneous projects, for missions undergoing similar phases at similar times, allowing for the possibility of technology and knowledge transfer during their implementation [158].
The three aspects addressed during the case study are for us the starting point to analyze and propose an improved approach based on a three-dimensional framework of PMO governance. The three-dimensional PMO aims at improving the PM and KM at space agencies, addressing the need for a centralized and coordinated management of the projects under three areas: Strategy, Resource, and Knowledge (see Figure 12).

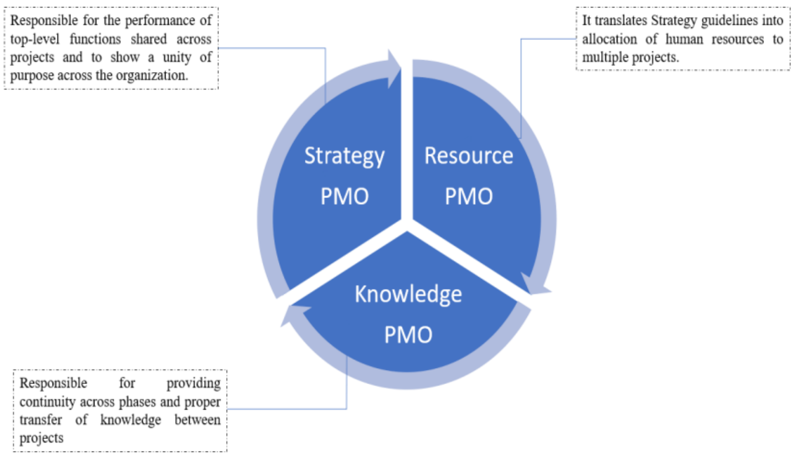


Figure 12: Three-dimensional PMO - Strategy, Resource and Knowledge

- Strategy PMO

The main objective of this area is to identify within multiple projects, happening in parallel, those autonomous activities that act in the same goal-directed manner [159]. A centralized governance must be implemented to manage multiple parallel projects, address their commonalities and differences. In other words, this area is responsible for the performance of top-level functions shared across projects, and that show a unity of purpose.

Strategy is one of the most challenging activities in a space agency, especially in the presence of numerous projects. PM is strictly linked to the organizational culture, as well as the size of the organization, the environment, and the context [160]. Managing a project is per se a difficult task, and shared management of multiple projects, with their needs and differences, could be even more challenging. In the case of space agencies, each mission is commissioned by the member States as a unique mission, with specific requirements, that makes sharing PM approaches more difficult [161]. The Strategy PMO is not responsible for a project from a technical point of view, but it should rather use the technical requirements, especially those that are repetitive and high level within multiple projects, and be responsible for the overall management and working practices that could be shared across missions and project teams [162]. The strategy PMO should be considered as place for centralization of all the agency's PM practices, enforcing further standardization and PM across the organization [163]. It should also be continuously improved bringing lessons learnt from other projects, collecting both success and failure perspectives [164].The strategy area is expected to be responsible for tasks such as inter-organizational risk mitigation, replicated structures and responsibilities, and control mechanisms [165].

- Resource PMO

The Resource PMO translates Strategy guidelines into allocation of human resources to multiple projects. The focus of this PMO is certainly on the technologies used within the projects, but also, in a space agency, the delivery of a mission is strictly linked to the human capital [166]. That is, the successful delivery of a project crucially depends on the human resources capability. The Resource PMO would have the objectives of standardizing human resource management practices and would be an integrated tool across multiple projects [167]. In this respect, the Resource PMO would represent a powerful tool to bridge the gaps that exist between multiple projects and within multiple phases of the same project, best achieved through continuity of deployed human capital [29]. This PMO would act as an overall management of all the resources and have visibility of them as well as the ability to deploy them into a dedicated project in a specific phase of the lifecycle. It would also need to ensure enough human resources to deliver, in a successful manner, the expected outputs based on the requirements for that specific mission and phase [168].

- Knowledge PMO

Knowledge management and sharing is a key aspect of each project-based organization. Each project input and output need to be properly documented, and should serve as a basis for other projects. While this is a policy commonly understood at each organization, practically when it comes to multi-projects organization there are still many limitations and challenges linked to the application of an efficient KM policy [169]. Public space agencies have implemented KM systems, such as the document management (DM) tool implemented at EUMETSAT [57], but access rights are normally project-specific. Therefore, only team members working on a dedicated project can access specific documents. This implies that sharing with other projects is very limited. We recall once again that each mission development till operations follows the lifecycle as described in the ECSS standards [139]. Along the lifecycle, there are six phases, and within each phase, a dedicated project team works on specific activities. At the end of each phase, we can identify gaps due for example to inconsistency in processes and methodologies, lack of knowledge transfer between one team working in a phase and the one working in the following phase, as well as poor general KM [130].

The KM PMO would be responsible for providing continuity across phases and proper transfer of knowledge between projects (e.g. detailed collection of lessons learned, working practices, technology adoption, outsourcing-related documents, etc, easy availability and sharing of information across different projects, structured knowledge organization).A lifecycle-based KM PMO becomes a powerful tool to improve the integration between other PM activities. KM PMO would extract from individual projects common organizational knowledge, and put it at the service of every future mission. One of the main outputs, as will be described hereafter, is the definition of a common naming convention, as a first step for projects KM harmonization.

Measuring PMOs' good practices

The three PMOs would need to oversee the overall PM and KM of the full organization. Here we try to identify the most powerful solutions to measure efficiently the application of good practices of the above PMOs. In particular, we link the three PMOs to the three aspects analyzed as part of the case study (OSVC, development of tracking tool and associated methodology for operational items, and resources issues). Obviously, the three PMOs are viewed as strictly connected with each other, and the work of one PMO certainly affect and is affected by the work of a second PMO. Therefore, we identify three solutions whose responsibilities fall within more than one PMO and whose management needs be shared among the responsibilities of the PMOs. This certainly highlights the complexity for the establishment of PMOs within an organization.

The three solutions that have been identified and that aim at improving the efficiency of space agencies' missions if guided by the PMOs are: sharing of human resources, sharing of technology, and common naming convention across projects.

- Sharing of Human Resources

All the three PMO need an effective human resource management that could become one of the most powerful tools within the organization. The challenges linked to retain knowledge as well as the need of sharing with other projects is a key aspect within an organization and its projects. Human capital in a project requires time and other resources that need to be invested to train new people in multiple phases of the project. An effective solution is the introduction of a horizontal human resources approach into the vertical project approach, where a vertical approach follows the project lifecycle from Phase 0 to Phase F according to the ECSS standards. We suggest the sharing of human resources between multiple projects, where they are allocated to the same phase (e.g., Phase D in our case study) of multiple projects (horizontal approach). Human resources allocated to a specific phase and only to this one, become expert of the activities that have to be carried out during that time of the mission lifecycle. The sharing among multiple projects allows them to learn from failures and successes of other missions and continuously improve the working practices and efficiency of that phase. In the case study, the sharing of resources is a powerful solution for multiple reasons. First, the expertise is shared across missions, improving the efficiency and the speed of the projects. As an example, during the project reviews, if a common team was allocated to both missions, it would have improved the efficiency of the project review (documents can use lessons learnt from the other missions and improve the quality of the review), as well as reduction of time, and thus costs. Moreover, a large team dedicated only to specific tasks across missions, would reduce the risks associated to loss of expertise, for example in the case of people leaving, permanently or temporarily. Experts allocated to each phase of the mission through this approach would improve the efficiency of the full mission as well as reduce risk and time. The approach also reduces risks associated to human error and human knowledge and experience, which is not the same for all projects, and provides greater flexibility for the agency. Sharing of resources results into an easier adjustment to changes in project priorities, needs, and other factors that could affect timeliness or project requirements.

- Sharing of Technologies

This solution is more specific for the Resource PMO, although certainly has an impact on the other two. Similar to human resources sharing, which improves efficiency and time while reducing risks of multiple projects, also sharing of technologies and tools leads to similar outcomes. Development, integration, and testing of a ground segment element require time and effort, and, of course, introduces risks. In addition, the development and tracking of operational items, as shown in the case study, could be challenging if each project adopts different strategies. Multi-mission technologies and tools represent a more robust solution, reduce direct PM dependency on a specific project and is a powerful tool for improving the quality of the systems. A shared technology means to run the above cycle only once and apply to multiple missions. In addition, if a bug, a failure is identified in one project, it reduces the risk for it to be repeated into other projects. Sharing of technologies is certainly a powerful tool for a more effective PM, as well as increasing the sharing of KM across projects. In the case of Mission A and Mission B, they both have system elements that are outsourced, and in some cases by the same manufacturer. The sharing of resources would certainly benefit the agency that would procure a single set of systems and perform tailoring only to adapt them to Mission A and Mission B. This would certainly lead to a more robust system, where the lessons learnt from Mission A would be beneficial for Mission B and vice versa. Sharing of technologies would introduce a more standardized approach, where both missions could adopt same processes, as they are using the same systems. In terms of time and costs, a shared technology would be reviewed only once and then adopted by both missions. Moreover, in the long term, in the transition from Phase D to Phase E (operations), it would be much easier to operate a single system through a shared infrastructure, and would be more beneficial in terms of maintenance activities.

- Common Naming Convention

Effective PM and KM are highly challenged when projects do not speak the same language. Each project, with different human resources and (partially) different systems, leads for example to the definition of different acronyms. If the project terminology is not well understood by the parties involved, it becomes difficult to communicate, learn, and compare with other projects where products and processes are not well understood. The application of a common taxonomy ensures consistency in the way that information and knowledge are organized and categorized across multiple projects. Not only this is beneficial for projects running in similar phases at the same time, but also it makes it easier to find, retrieve, and use information from previous missions, reducing possible risks. A common naming convention is facilitated by the horizontal allocation of human resources to multiple projects, making it easier to apply the same language across projects, and consequently it becomes easier to organize and categorize information and knowledge. In the case of Mission A and Mission B, the project teams could have easily shared knowledge if they had talked the same language. During the reviews, this would have facilitated the sharing, understanding, and review of the documents. Common naming convention would improve the understanding of the mission as well as their future operability. During Phase D, in fact, multiple operational documents are created, and each of them is developed according to the naming convention of a specific mission. When handing over to the operational team, this is forcing into a lack of understanding between teams in the subsequent phase. While the case study focuses on Phase D, the earliest adoption of a common naming convention would be beneficial for all subsequent phases, including Phase D.

The introduction, or where needed an improvement, of a Documentation office, is expected to be a powerful tool to improve this lack of consistency across the organization and would tackle issues of naming conventions, standardizing processes and aggregating lessons learned in a common information platform.

Transformative technologies within and outside the Space Industry and applications to the discussed PMOs

In the ever-evolving landscape of technology, a wave of transformative innovations continues to redefine how we navigate our daily lives, reshape industries, and connect with the world. At the forefront of this rapid transformation are startups that serve as vanguards, introducing groundbreaking applications across diverse sectors. These startups are driven by a relentless pursuit to address the dynamic needs of the market. Traditional industries are increasingly adopting technology to streamline operations, enhance efficiency, and meet evolving consumer expectations. From agriculture to healthcare, from finance to space, the infusion of technological advancements is becoming a cornerstone for sustainable practices and improved outcomes. Interdisciplinary collaboration lies at the heart of the innovation models fuelling these transformative technologies. The new industry are breaking free from traditional silos and are thriving on the convergence of ideas from diverse fields. The amalgamation of biotechnology, nanotechnology, and artificial intelligence, for instance, is giving rise to applications that redefine personalized solutions and treatment plans.

The impact of transformative technologies extends far beyond individual sectors, encompassing a myriad of fields. While transformative technologies are influencing various industries, one sector stands on the brink of significant change – the Space Industry.

The Space Industry, historically known for its high entry barriers and substantial costs, is undergoing a profound transformation facilitated by transformative technologies. Innovations are paving the way for increased accessibility and affordability, democratizing space exploration and commercialization. Startups in the space sector are challenging traditional norms. Advancements in reusable rocket technologies, for instance, are not only reducing launch costs but also are also fostering competition and innovation. The advent of these technologies is making space missions more frequent and accessible, opening up new possibilities for exploration and utilization of space. The demand for Earth observation satellites has surged as real-time data becomes crucial for climate monitoring, disaster response, and resource management. Remote sensing technologies, driven by transformative innovations, are providing accurate and timely information that has far-reaching implications for environmental sustainability and resource optimization.

Space exploration itself is undergoing a paradigm shift. The development of autonomous spacecraft leveraging artificial intelligence is revolutionizing how we explore and understand celestial bodies. These spacecraft, equipped with advanced autonomy, can operate independently, making decisions in dynamic environments and conducting experiments without constant human intervention. This autonomy enhances the efficiency and adaptability of space missions, allowing exploration in conditions previously considered inhospitable. Transformative technologies have made it possible for civilians to engage in commercial space travel, signaling a shift from government-dominated space missions to a more inclusive and commercially driven space industry.

Among the main technologies that will shape the future of the tech world and not only, certainly it is worth mentioning Artificial Intelligence (AI), Machine Learning (ML), Blockchain, Big Data (BD), Computing Paradigms and Advanced Digital Technologies (ADT), together with Natural Language Processing, Augmented and Virtual Reality and many more. Some of these technologies are more advanced, while others are still at an early stage (e.g. quantum computing, especially applied to the space sector).

Hereafter a short description of the main technologies advances are explained, together with their applications to the Space sector and in particular to the PM aspect, in support to the PMO strategy.

Artificial Intelligence (AI) – Generative AI

The interest in Artificial Intelligence has been growing over the past years, mainly supported by the increase in the availability of large amount of training data, computational power and the needs of applications coming from multiple sectors [172]. Today's AI applications are based on developed cognitive functions, such as perceiving, learning, reasoning, planning, and lately even memory capabilities [173]. If Artificial Intelligence is becoming more popular in general, multiple branches are created, among which the one related to Generative AI. This branch refers to deep-learning models that, based on the data they were trained on, are able to generate new outputs such as high-quality text, images, and other content. More than a language, generative models are also capable of learning the grammar of software code, molecules, natural images, and a variety of other data types [174]. While actual business value from the implementation of AI-enabled systems are becoming a key element of any private business, this remains a challenge for many organizations, especially in the public sector [175].

AI plays a vital role in multiple fields and multiple applications. In the dynamic realm of space exploration, project management plays a pivotal role in orchestrating complex missions and ensuring their success. The infusion of Artificial Intelligence (AI) has brought about a paradigm shift in the way space projects are planned, executed, and monitored. Hereafter is an analysis of AI applications in the Space Sector and in particular related to Project Management.

- **Autonomous Mission Planning**

Traditionally, mission planning in the space industry involved meticulous coordination and human oversight. AI is revolutionizing this process every day more, by introducing autonomous mission planning systems. These systems leverage machine learning algorithms to analyze vast datasets, including celestial dynamics, fuel constraints, and mission objectives. The result is an optimized and dynamic mission plan that adapts to real-time variables, ensuring efficient resource utilization and mission success [176].

- **Predictive Risk Analysis**

Space missions are fraught with risks, ranging from technical malfunctions to unpredictable cosmic phenomena. AI-driven predictive analytics enables project managers to assess and mitigate risks more effectively. Machine learning models analyze historical mission data, identify potential risk factors, and predict the likelihood of specific challenges. This proactive risk analysis empowers project managers to implement preemptive measures, ensuring a higher probability of mission success [177].

- **Resource Optimization with AI**

Efficient resource allocation is a cornerstone of successful space project management, and a key aspect of the proposed PMO strategy. AI algorithms have the capability to analyze project requirements, resource availability, and historical data to optimize resource allocation. Within the space sector, whether it's fuel for spacecraft, computing resources for data analysis, or personnel for mission control, AI shall ensure that resources are allocated judiciously, maximizing efficiency and minimizing unnecessary expenditures [178].

- **Dynamic Schedule Management**

Space projects often encounter unforeseen challenges, such as weather events or technical glitches. AI enhances schedule management by incorporating dynamic adjustments. Machine learning algorithms assess real-time data, predict potential delays, and automatically optimize project timelines. This agility in schedule management ensures that space missions can adapt to changing conditions while maintaining overall project coherence [179].

- **Continuous Performance Monitoring**

Monitoring the performance of spacecraft, systems, and personnel is critical for mission success. AI applications provide real-time monitoring and diagnostics, enabling project managers to identify and address issues promptly. Whether it's monitoring the health of spacecraft components or assessing the efficiency of team members, AI ensures continuous performance monitoring, enhancing the overall reliability and success rate of space projects [180].

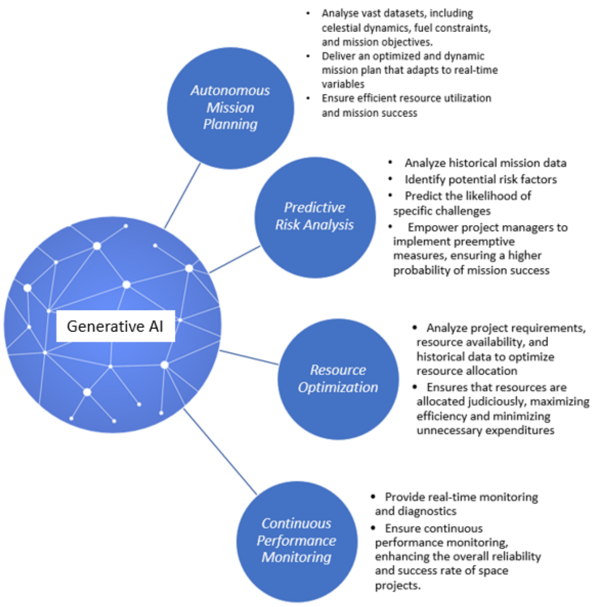


Figure 13: AI applications in the Space Industry with focus on Project Management

Blockchain

Blockchain, well known as the technology behind Bitcoin, is becoming more popular in multiple other sectors [181]. At its core, it is a decentralized and distributed ledger technology. It operates on a peer-to-peer network, where each participant, or node, has a copy of the entire ledger. This ledger, comprised of blocks linked through cryptographic hashes, ensures transparency, security, and immutability of data. The key features of Blockchain – decentralization, transparency, security, and immutability – make it an ideal candidate for transforming various industries, including space exploration. [182]. The benefits of this technology extend much further than the financial sector, and the tech sector, including the space industry is opening up to this technology, with Blockchain becoming part of business processes [183]: it shows an enormous potential in terms of optimization of business operations efficiency, improving for example cycle time, productivity and quality of business processes [184].

Blockchain has been proved also to bring improvements to internal organization synergy efficiency and optimize external collaboration, based on some intrinsic characteristics, where a Blockchain database is an open distributed ledger. Copies of all on-chain information are shared between multiple stakeholders that can validate this information without a centralized authority. This decentralization, combined with the real-time updating of information, makes Blockchain useful in networks involving different departments and organizations [185].

As the space industry propels itself into an era of unprecedented exploration and innovation, the integration of cutting-edge technologies becomes imperative. Among these, Blockchain stands out as a transformative force, revolutionizing not only financial systems but also how space projects are managed and executed. The space sector, with its complex missions, collaborative endeavors, and critical data transactions, finds an ally in Blockchain technology. Several key applications of Blockchain in space have emerged, offering solutions to longstanding challenges. Hereafters are a few applications of Blockchain technology applied to the Space Industry, with particular focus on the Project Management aspect in support to the proposed PMO strategy.

- **Decentralized Satellite Communication**

Traditional satellite communication networks often rely on centralized systems, making them susceptible to single points of failure and vulnerable to cyber threats. Blockchain introduces a decentralized approach, enabling secure, tamper-proof communication channels among satellites. Smart contracts embedded in Blockchain facilitate automated communication protocols, reducing the risk of communication breakdowns and enhancing the overall reliability of satellite networks [186].

- **Secure Data Exchange and Storage**

Space missions involve the exchange and storage of vast amounts of sensitive data. Blockchain provides a secure and decentralized solution for managing this data. The distributed ledger ensures the integrity and authenticity of data, while cryptographic encryption secures it from unauthorized access. This decentralized approach minimizes the risk of data breaches and ensures that critical mission information remains confidential and unaltered [187].

- **Smart Contracts for Mission Automation**

One of the most impactful applications of Blockchain in space project management is the use of smart contracts. These self-executing contracts, encoded on the Blockchain, automate and enforce predefined rules and conditions. In space projects, smart contracts can streamline various processes, from procurement to mission execution. For instance, they can automatically trigger payments, verify milestones, and regulate access to sensitive information, reducing manual intervention and the risk of human error [188].

- **Transparent Supply Chain Management**

Space missions involve intricate supply chains with components sourced from various vendors. Blockchain provides transparency and traceability across the supply chain by recording every transaction and movement of components. This ensures the authenticity of materials, reduces the risk of counterfeiting, and enhances the overall reliability of mission-critical systems [189].

- **Tokenization for Funding and Resource Allocation**

Blockchain introduces the concept of tokenization, enabling the creation of digital tokens representing real-world assets. In the space sector, this can revolutionize funding models. Tokenization allows for fractional ownership of space assets, facilitating decentralized crowdfunding for missions. Moreover, these tokens can represent access rights to specific data or resources, providing a novel way for transparent and fair resource allocation within a project [190].

- **Decentralized Identity Management**

Ensuring the authenticity of participants and devices within a space project is crucial for security. Blockchain's decentralized identity management capabilities offer a solution by providing secure and verifiable digital identities for spacecraft, personnel, and ground systems. This mitigates the risk of unauthorized access, streamlines authentication processes, and enhances the overall cyber security posture of space projects [191].

Challenges and Considerations

While the integration of Blockchain in space project management offers promising solutions, it is not without challenges. Issues such as scalability, interoperability, and regulatory frameworks need to be addressed. Moreover, the energy consumption associated with some Blockchain networks poses environmental concerns. As the technology matures, collaborative efforts between the space industry and Blockchain developers will be essential to overcome these challenges. The marriage of Blockchain technology and space project management represents a pioneering frontier. As the space industry embraces decentralized, transparent, and secure solutions, Blockchain will play an increasingly vital role in shaping the future of space exploration. Collaborative missions, automated processes, and enhanced security are on the horizon, driven by the transformative power of Blockchain.

Case Study: Blockchain-Enhanced Project Management in Space

Hereafters it is considered a typical scenario where a collaborative space mission involving multiple space agencies and private entities leverages Blockchain for project management. Multiple aspects will be considered as all being part of the scenario, from mission planning to resource allocation, decentralized communication network, etc.

All of these elements are interconnected with each other towards successful scenarios operations and summarized in Figure 14.

- **Mission Planning with Smart Contracts**

Smart contracts are deployed for mission planning, automating the negotiation and agreement processes between participating entities. These contracts define roles, responsibilities, and milestones, ensuring that every participant is aligned with the mission objectives.

- **Transparent Resource Allocation**

Tokenization is utilized for funding the mission. Digital tokens representing ownership or access rights are issued to contributors, providing a transparent and traceable record of financial transactions. These tokens can be traded on a decentralized exchange, fostering a liquid and efficient funding ecosystem.

- **Decentralized Communication Network**

Satellites equipped with Blockchain-enabled communication systems autonomously form a decentralized network. Smart contracts govern communication protocols, ensuring secure and reliable data exchange. Any disruption or attempted interference triggers automated responses, enhancing the network's resilience.

- **Secure Data Transactions**

Blockchain ensures the security and integrity of mission-critical data. Every data transaction is recorded on the distributed ledger, providing an immutable and transparent record. Encryption techniques supported by Blockchain further safeguard the confidentiality of sensitive information.

- **Automated Procurement and Supply Chain**

Smart contracts streamline the procurement process, automatically executing orders based on predefined conditions. The transparent and traceable nature of Blockchain ensures authenticity and accountability in the supply chain, reducing the risk of counterfeit components.

- **Real-Time Monitoring and Compliance**

Blockchain-enabled sensors and monitoring devices on spacecraft provide real-time data, recorded on the distributed ledger. Smart contracts continuously verify compliance with mission parameters, triggering alerts or corrective actions in case of deviations.

- **Post-Mission Tokenized Benefits**

Upon mission success, token holders receive benefits in the form of tokens representing a share of the mission's achievements. This may include access to exclusive data, future mission opportunities, or dividends from commercial ventures arising from the mission's success.

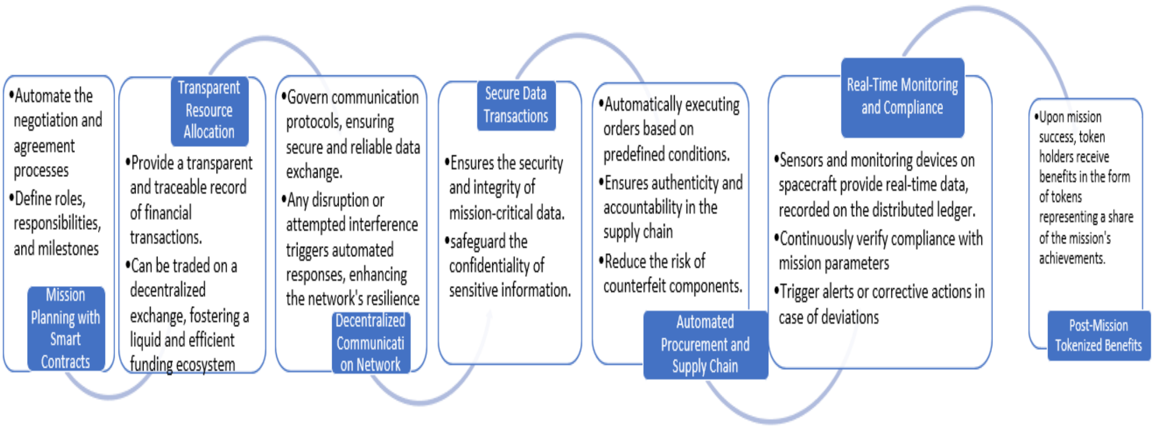


Figure 14: Operational Scenario making use of Blockchain.

Natural Language Processing

The latest developments in Artificial Intelligence have generated a lot of attention, in both academic and industry areas, towards LLMs (Large Language Models), with special focus on the Natural Language Processing (NLP tasks) [192]. NLP underwent an important development, going from rule-based systems, built on top of domain expert-framed rules, till proper machine models, which learn the rules directly from training data, avoiding the manual rule framing (which was laborious, expensive and high maintenance) [193]. Figure 15 shows the evolution of Artificial Intelligence from Machine Learning to LLMs, including NLP.

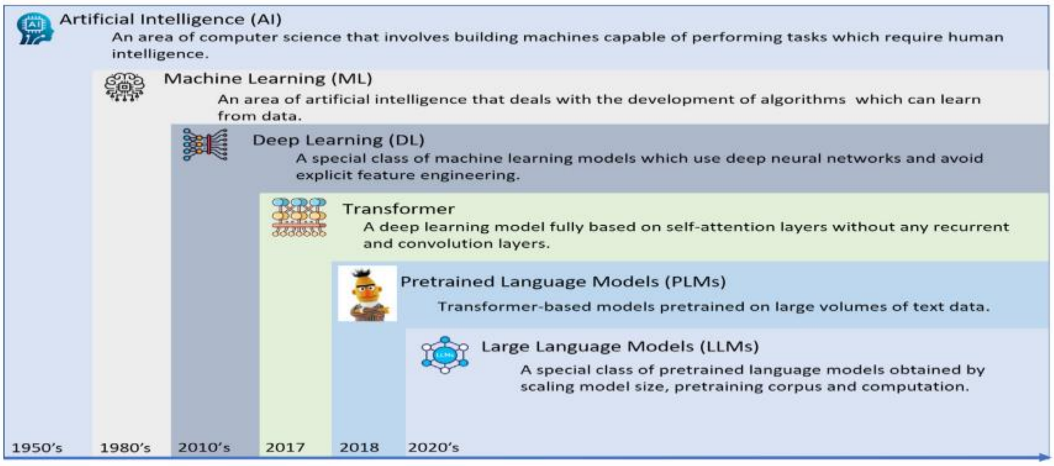


Figure 15: Evolution of Artificial Intelligence from ML to LLMs (NLP) [189]

NLP is starting to be used more and more also for project management purposes. According to the Standish Group, every year, about $48 trillion are invested in projects, although only 35% of those are considered successful [194]. The growing engagement in using NLP for Project Management solutions shows the potential that this application can have for the future. Especially related to Project Management, it is predicted that by 2030, about the 80% of project management tasks will be run by Artificial Intelligence, Machine Learning and Natural Language Processing, making use of Big Data [195]. Project Management in current organizations is still far from achieving the expected success rate. When the correct data is available, Machine Learning can support PM exceeding human accuracy by making predictions. Output could be improved under multiple aspects, from the faster identification of launch-ready projects that have the right fundamentals in place, to the accurate selection of projects that have an higher chance of success, risk assessment and removal of human biases from decision-making. When dealing with Project Management, certainly the benefits of NLP usage shall be looked into the support to PMOs. Multiple data analytics and automation startups are providing important inputs to this field. These new tools will radically transform and improve the performances of PMOs under multiple aspects.

Examples include a better monitoring of project progress, the capability to anticipate potential issues and address them automatically, generation of project reports and assessment of the best PM methodology for each individual project. PMOs shall make use of NLP also to monitor compliance for processes and policies, and support development of new organizational strategies.

Also in the space agencies, that are indeed project-based organization, the introduction of PMOs shall be done together with the introduction of AI-based technologies to support a more efficient application. In the space industry, NLP holds the potential to streamline project management processes, enhance communication, and improve overall efficiency. Hereafters a few applications and a Case Study are showcased to highlight the potential of NLP in Project Management for the Space Industry.

- **Automated Documentation and Reporting**

One of the primary challenges in space project management is the vast amount of documentation and reporting required. NLP technologies can automate the extraction of key information from project documents, facilitating the creation of comprehensive reports. This reduces the burden on project managers and allows them to focus on critical decision-making tasks.

- **Requirements Analysis and Planning**

NLP tools can assist in the analysis of project requirements by extracting key information from natural language specifications. This streamlines the planning phase, helping project managers to define project scopes, allocate resources, and set realistic timelines. The ability to convert textual information into structured data enhances the accuracy of project planning.

- **Risk Assessment and Mitigation**

Identifying and mitigating risks is a critical aspect of space project management. NLP algorithms can analyze project-related documents, identify potential risks mentioned in natural language, and provide insights to project managers. This proactive approach allows for more effective risk management strategies, reducing the likelihood of project setbacks.

Certainly, there are new risks and challenges that arise within Project Management when making use of NLP. First of all Data Privacy and Security: in the space industry, where sensitive information is commonplace, ensuring the privacy and security of project data is paramount. Project managers must carefully consider the implementation of NLP technologies to comply with industry regulations and safeguard classified information. Moreover, Space agencies have been operating for decades and they strongly rely on project management working practices that are difficult to be changed. Certainly, a gradual integration with existing systems shall be performed, although even a gradual introduction leads to multiple challenges. Compatibility issues, training requirements, and potential disruptions to ongoing projects need to be carefully addressed.

One more point to be addressed is the accuracy of the algorithms, that heavily depends on the quality and diversity of training data. In the space industry, where terminology and language can be highly specialized, ensuring that NLP models are trained on relevant and comprehensive datasets is crucial to avoid misinterpretation and errors.

The main challenge then refers to the application of a Project Management Office within the Space Industry, which is strictly linked to the harmonization necessary for the execution of multiple and complex projects in parallel. Especially the European organizations are a bit behind when talking about the introduction of disruptive technologies, and even more when applying to PM guidelines. Hereafters is an example of a Case Study from the Orion mission, showing the application of NLP to the requirements management for the Orion mission. In 2022, also the European Space Agency started a first attempt to use NLP for similar purpose, but this is the only agency in Europe where a first attempt is done. Still much more has to be done to make it a standard application in all the organizations within the Space sector and the industry at large. One thing to be noticed is that when looking at the future, space agencies like ESA tend to use even more the Outsourcing business model. Also in the case of NLP for the application with project management and requirements management, this is done through an external contractor, namely Thales Alenia Space, that brings the expertise to the agency [196] . In line with what mentioned in previous chapters, the public sector is much behind with respect to the private industry, where more risks and challenges are assumed also to move forward towards new technologies. The two sectors, moving at a different speed, push the public organization to improve their work by externalizing more and relying on other industries in order to remain competitive.

Case Study – Orion: Enhancing Requirements Management in Space Project with Natural Language Processing [197].

This case study delves into the application of Natural Language Processing (NLP) for requirements management in a high-stakes space project of the Orion project that involved the development of a next-generation satellite system for advanced Earth observation. The integration of NLP in requirements management aimed to streamline the process, enhance accuracy, and improve collaboration among multidisciplinary teams.

The Orion project faced challenges typical of large-scale space endeavors, including intricate technical specifications, diverse stakeholder inputs, and the need for meticulous requirements documentation. Traditional methods of requirements management proved time-consuming, and the risk of misinterpretation was a concern. To address these challenges, the project management team decided to integrate Natural Language Processing into the requirements management process. The NLP system was trained on a comprehensive dataset comprising technical documents, stakeholder communications, and historical project records.

The NLP system was designed to automatically extract key requirements from natural language specifications. Team members could input unstructured text, and the system would identify and categorize requirements based on predefined criteria. This streamlined the initial phase of requirements gathering, saving time and reducing the likelihood of overlooking critical details. The NLP system incorporated semantic analysis to enhance the clarity of requirements. It identified ambiguous terms or conflicting statements within the requirements documents, providing project managers with valuable insights to resolve potential issues early in the development process. This semantic analysis significantly improved the precision and unambiguity of the requirements. NLP-powered tools facilitated better communication among multidisciplinary teams. Project stakeholders, including engineers, scientists, and administrators, could interact with the system using natural language queries. The system's ability to understand and respond to queries reduced communication barriers and improved collaboration, ensuring that everyone had a clear understanding of project requirements.

The NLP system provided real-time updates on changes to requirements. This feature was instrumental in managing evolving project needs, allowing the team to adapt quickly to shifting priorities. Version control mechanisms ensured that all team members worked with the latest requirements, minimizing the risk of errors resulting from outdated information.

The integration of NLP in requirements management for the Orion project yielded significant benefits. The process became more efficient, with a notable reduction in the time spent on gathering and refining requirements. The enhanced clarity and precision of requirements contributed to fewer misunderstandings and errors during the development phases, ultimately accelerating project timelines.

Certainly, challenges and lessons learned have been derived from this application. For example, despite the success of integrating NLP in requirements management, the project team faced challenges related to the specificity of space-related terminology. The NLP system required fine-tuning to comprehend highly technical language accurately.

Additionally, team members needed training to maximize the system's capabilities effectively.

The Orion project was a pioneer for the usage of NLP in requirements management, and its success opened the door to further exploration of NLP applications in other project management aspects. The project team publicly expressed interest in leveraging NLP for risk analysis, project documentation, and stakeholder engagement in future space initiatives. Figure 16 shows a summary of the above points.

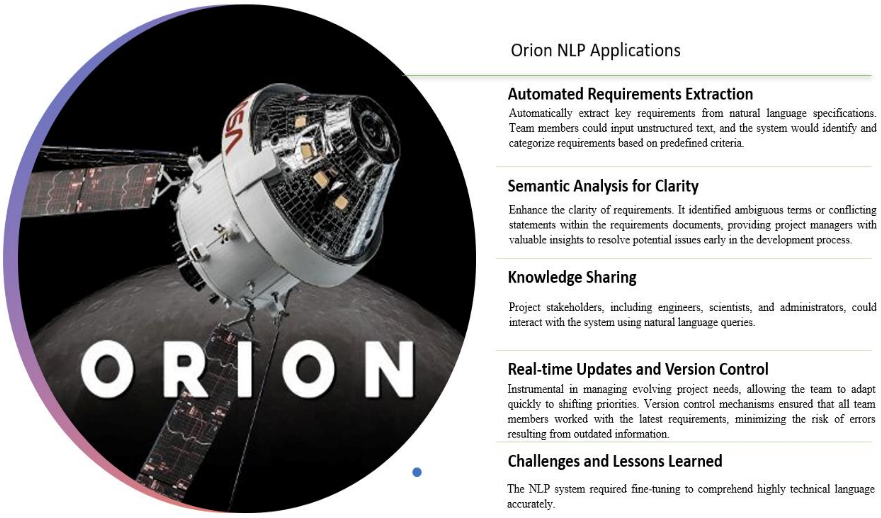


Figure 16: Orion NLP application and challenges

Computing Paradigms

Computing paradigms, also known as programming paradigms, represent overarching styles and approaches to designing and implementing software systems. Each paradigm is characterized by a set of principles, methods, and concepts that guide how programmers write and structure their code. The evolution of computing paradigms has been driven by the need to solve increasingly complex problems and leverage advancements in hardware and software technologies. Among the several types of computing paradigms the main ones that certainly need to be mentioned are cloud computing, fog computing and edge computing. Each of them represents a branch with specific features and applications.

Cloud computing are probably the most known and have proven themselves to be beneficial in almost all areas of applications, providing remote processing and storage of the end-user data and software in the bigger data centers [198]. The limitations of cloud computing are linked to the smaller requests and the access to remote data center, where the latency and bandwidth problems represent a real issue. In this respect, fog computing becomes a powerful tool, where the fog nodes are capable of filtering the data that are sent to the cloud, and meanwhile they process the rest of the data [199]. An improvement from the fog computing is edge computing, where the computation is performed by edge devices that provides more efficient and faster results [200].

The space industry, characterized by its complexity and reliance on data-intensive processes, is undergoing a paradigm shift in project management, that shall certainly get more efficient with the integration of cloud computing, fog computing, and edge computing.

In addition, the space industry, mainly driven by the large amount of Big Data, are moving towards larger usage of computing paradigms.

Space projects often experience dynamic workloads, requiring scalable computing resources. Cloud computing allows project managers to scale infrastructure based on project demands, ensuring that computational resources align with the evolving needs of the mission. This adaptability contributes to efficient project execution and cost-effective resource utilization. Cloud computing is often an externalized service that space agencies outsource. An example is the partnership between the European Space Agency and Amazon Web Services and Swedish Space Corporation [201].

Fog computing certainly is among the most used in the Space Sector, especially for Enhancing Onboard Decision-Making and Real-time Data Processing Onboard. Fog computing introduces real-time data processing capabilities onboard spacecraft and rovers. Project managers can leverage fog nodes to perform initial data analysis, reducing the need for continuous communication with Earth for decision-making. This capability is crucial for missions with latency-sensitive tasks and enhances the autonomy of space systems. In fog computing, critical project management decisions can be made closer to the data source, minimizing communication latency. Project managers can ensure that time-sensitive commands are executed promptly, contributing to the success of mission-critical tasks. Fog computing thus plays a pivotal role in projects where rapid response times are imperative.

Moving to the edge computing, this becomes a powerful tool for Onboard Decision-Making and Autonomy. Edge computing empowers space project managers with onboard decision-making capabilities, enhancing the autonomy of spacecraft and robotic systems. Project managers can pre-program edge devices to analyze data locally, enabling autonomous responses to dynamic mission conditions. This reduces dependence on continuous communication with mission control and enhances mission resilience. Edge computing also contributes to project management by enhancing system redundancy and fault tolerance. Onboard processing capabilities ensure that critical functions can continue even in the absence of continuous communication with Earth. Project managers can design missions with a higher degree of redundancy, mitigating the impact of potential failures and improving overall mission reliability. Figure 17: Edge and Cloud computing in the Space sector shows the application of Edge and Cloud computing in the Space Industry as of today.

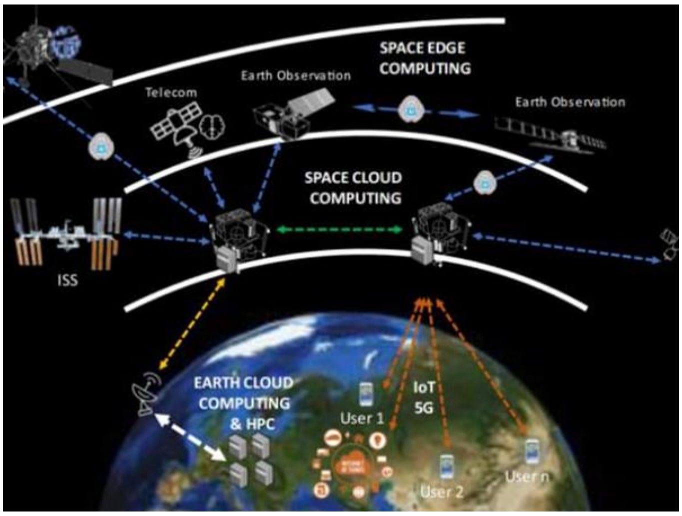


Figure 17: Edge and Cloud computing in the Space sector [202]

Certainly, the introduction of these new technologies also bring new challenges, for example linked to Data Security and Privacy. Project managers in the space industry must address data security and privacy concerns associated with cloud, fog, and edge computing. Ensuring the confidentiality and integrity of project-related data is paramount, requiring robust encryption, access controls, and compliance with industry standards and regulations. The integration of cloud, fog, and edge computing technologies poses challenges also related to interoperability. Project managers need to ensure that these systems work cohesively, allowing for smooth data flow and communication across the entire project lifecycle. Establishing standardized protocols and interfaces is essential to address integration challenges.

What is certain is that mainly from a sharing of technologies aspect, the computing paradigms would certainly be an incredible tool in support to the PMO. With respect to the proposed PMO strategy, a positive application of the computing paradigms could be applied to all the three areas identified (Strategy, Resources and Knowledge), with computing being a shared solution that shall be managed and applied to multiple parallel projects.

Discussion and challenges when introducing a PMO in the Space Industry in today's Space Economy

According to Fernandes [203], organizations should implement a tailored PM, with associated tools and processes as a key for successful PM within the organization. The three-dimensional PMO and the three solutions identified, if applied to missions, such as Mission A and Mission B of the case study, is expected to be a powerful tool that would improve the quality and efficiency of the two missions, reduce risks, time, and uncertainties linked to technologies, strategies and resources. As an example, the sharing of human resources would certainly bring a homogeneous approach for the management of the missions. It would also lead to a more efficient delivery of the outputs of Phase D. Lack of resources would not be strictly linked to a project, but instead, with a shared project team allocated to multiple projects, resources could better cover for each other and support different projects if needed. Sharing of resources could also lead to a better and more efficient sharing of technologies, although sharing of human resources could be tricky and could cause some friction between different management solutions/processes, when developing a PMO, this should be properly described and detailed, in order to provide general guidelines, more standardized, that would reduce the risk of frictions between people. The development of a tracking tool that needs to ensure efficient tracking of operational items would be a simplified and homogeneous choice applicable to all the missions. A well-established tool would be used by all the missions, without the need of investing resources in the analysis and development of new tools and strategies each time. Last, projects could easily talk to each other if the same naming convention is used, avoiding confusion, and improving efficiency. In the case of project reviews, for example, the review board would not need to understand every time what acronyms mean, but there would be a homogeneous understanding of systems, activities, etc., across all the projects within the organization.

While developing this research study and conducting an analysis within one dedicated Space Agency, a number of challenges have been identified when trying to introduce a PMO within the organization. The case study gave the opportunity to discuss the PMO implementation with two different teams with two missions and study their response to a change of the project management approach.

Before analyzing the specific case of this space industry, it is worthy noticing that when talking about bringing a change to the organization, the possibility of introducing a change, especially in the field of project management, is very much linked to the organizational culture and the open-mindedness of the management, which often is made of aged people, that having worked with similar guidelines and standards for the past fifteen to twenty years of their professional career, especially in the Space Industry, they often seem to be reluctant to embrace an organizational change in this respect.

Resilience to change in the space industry is intricately linked to the effectiveness of project management methodologies and the prevailing organizational culture. This chapter delves into the interplay between project management practices and the cultural fabric of space organizations, examining how they collectively contribute to resilience in the face of dynamic shifts within the industry.

First, management of projects is a very complex task within a space organization, where projects (i.e. Space Missions) are already a complex subject, with many inputs coming from external stakeholders. In order to implement a new organizational structure, that may have an impact on multiple projects, it is necessary to consider the fact that different projects often involve different stakeholders (e.g. different Member States), and in some cases, it happens that some Member States contribute more to some missions rather than others and having a shared approach (less from a strategic perspective, but more from resources and knowledge) could be a challenge that a space agency may need to face. For this reason, a transformational change on the organization policy needs to be addressed before the PMOs could be implemented. Despite this may be a big element that may actually stop the implementation of the proposed strategy, in reality this is a necessary change that shall be adopted within the Space Agency, not only because of the introduction of the PMO, but also due to the changing dynamics and the needs coming from the external players that push the organizations for a change in order to remain competitive. Consequently, the PMOs shall be seen not just as an organizational change, but more as a necessary tool for improving the efficiency and remaining competitive in the space ecosystem and the evolution of the Space Economy and its related dynamics.

Focusing a bit more on specific aspects, the first point important to be addressed is the Project Management needs and flexibility.

As previously described, the current approach includes a mix between waterfall and agile approach, supported by the implementation of the ECSS standards. A limitation to the current approach is that still the waterfall component is too strong with respect to the agile component, while it shall be the opposite. As of today, single projects are addressed individually, while a more open approach and possibility to implement changes at any time shall be the key for more successful projects. If a PMO is definitely of help (e.g. with sharing of knowledge and lessons learned), the PMO shall not be implemented as a rigid approach and shall allow for continuous improvement and transformation even within the application of the PMO itself. If space agencies introduce a new PM approach, they shall do this by having learned that rigid schemas do not work anymore in today's space economy, but rather there shall be more a change in the organizational culture. Organizational culture plays a pivotal role in building resilience. A culture that aligns with project goals fosters an environment where employees embrace change as an inherent part of their roles. Leaders must cultivate a culture that values innovation, flexibility, and continuous improvement within the project management framework. Resilient space organizations embody the principles of a learning organization. This involves encouraging a mindset where project teams continuously learn from experiences, adapt processes based on lessons learned, and foster a culture of innovation to stay at the forefront of advancements in project management methodologies. In the dynamic space industry, adaptability is a core competency. Resilience is built when project managers and team members are equipped with the skills to swiftly adapt to changes in technology, regulations, or mission objectives.

When introducing a PMO, certainly this shall be done as a full change, but at the same time shall not cause disruption in the current projects, nor delays or issues with both internal and external stakeholders. Resilience requires an integrated change management approach within space projects. Project managers must facilitate a smooth transition when adapting to new technologies, regulatory updates, or mission objectives. A structured change management process ensures that teams embrace change with minimal disruption. The leadership plays an important role: it holds the key to shaping the organizational culture. Resilience to change is deeply influenced by the ability of leaders to communicate a shared vision, empower teams to adapt to new circumstances, and exemplify a proactive approach towards challenges within the project management landscape. Resilience requires a delicate balance between fostering innovation and maintaining stability. Project managers must encourage innovative approaches to problem solving while also ensuring that the organization retains a stable foundation for consistent project delivery.

Especially when introducing a PMO, one big challenge is linked to the cross-functional collaboration. The proposed approach includes three main areas: Strategy, Resources and Knowledge, and it is therefore necessary that project managers facilitate collaboration among diverse teams, including engineers, scientists, regulatory experts, and administrators. Despite it is difficult to characterize in objective terms, effective communication is fundamental to resilience in project management and a transition into the adoption of PMOs. Space organizations must establish transparent communication channels, ensuring that project updates, changes, and challenges are disseminated promptly.

One last thing strictly related to PMOs is the need for continuous improvement. As mentioned already above, even the adoption of a PMO does not mean to stop the innovation within PM approaches. In addition, PMOs need to be continuously revised in order to maintain their functionality within the organization, depending also on the evolution of the variables, such as new missions, new policies, new resources and needs coming both internally and from external inputs. Figure 18 summarizes the main challenges associated with the introduction of PMOs in the space agency.

Figure 18: Main challenges for PMOs introduction in the Organizational structure

5. Discussion of the results

The comprehensive analysis of the literature on the Space Economy has revealed substantial gaps, particularly in academic research on its characterization and on Project Management (PM) and Knowledge Management (KM) within space agencies. By addressing these gaps, this research has made significant strides in both areas.

Characterization of the Space Economy

Utilizing the "What," "Who," and "How" building blocks of theory has proven effective in structuring the characterization of the Space Economy. The "What" component clarified the broad spectrum of products, services, and economic activities that comprise the Space Economy. This includes traditional areas such as satellite communications and navigation, as well as burgeoning sectors like space tourism, asteroid mining, and in-orbit manufacturing. This comprehensive scope addresses the fragmented understanding seen in previous studies and offers a holistic view that integrates various elements of the Space Economy.

The "Who" component identified the diverse actors in the Space Economy, ranging from established space agencies like NASA and ESA to private companies such as SpaceX and Blue Origin, and new spacefaring nations and international organizations. This broad identification of stakeholders highlights the complexity and dynamism of the Space Economy, providing a clearer picture of the ecosystem's multifaceted nature.

The "How" component examined the processes, technologies, and business models driving the industry. By elucidating these mechanisms, the research offers insights into how different parts of the Space Economy interact and function together, filling a critical gap in understanding the operational dynamics of this rapidly evolving field.

Project Management and Knowledge Management in Space Agencies

The second research question focused on the lack of scientific literature regarding PM and KM within space agencies. The study highlighted the need for modernized approaches to manage the increasing complexity and scale of space projects, especially given the new public-private collaborations and numerous new missions. Traditional PM methodologies, tailored for long-term, government-funded projects, are no longer sufficient.

The research proposed the adoption of the Project Management Office (PMO) as an enhanced solution for PM and KM in space agencies. The PMO framework, supported by a case study, demonstrated its potential to improve efficiency, collaboration, and knowledge retention. The case study provided practical insights, highlighting how PMO can facilitate better coordination between diverse entities with varying objectives, timelines, and resources.

Bridging the Literature Gap and Future Directions

This research has effectively bridged the significant literature gaps in both the characterization of the Space Economy and the development of PM and KM practices within space agencies. By providing a structured and comprehensive framework, the study offers valuable insights from a scientific and academic perspective, fostering a more integrated and coherent understanding of the Space Economy.

Additionally, the research highlighted the pivotal role of emerging technologies, such as Artificial Intelligence (AI) and advanced computing paradigms, in the future characterization of the Space Economy. These technologies are anticipated to become key components, offering significant support for both PM and KM processes. AI and other technological advancements can enhance data analysis, decision-making, and collaborative efforts, improving the overall efficiency and effectiveness of space-related projects. However, the integration of these new technologies also opens up new research areas. This study introduces the need for continued academic exploration into how these technologies can be seamlessly integrated into existing frameworks and their impact on the broader space industry. This emerging field presents a clear literature gap that must be addressed to fully harness the potential of technological innovations in the Space Economy.

6. Conclusions

The Space Economy is a continuously evolving phenomenon. A characterization of the Space Economy is a very complex subject which evolves over time with new players, products, services and applications that are developed on a regular basis with new businesses arising all over the world.

This research focused first in the identification of the overall classification of the “What”, “Who” and “How”.

The “Who” aspect, from a qualitative perspective, showed how the Space Economy as of today includes all types of institution (from Agencies, to Industries, to Universities), as well as multiple types of Investors (Venture Capital, Business Angels, Public Organizations...). In the next decades it is not expected a qualitative change in the Who aspect, but rather a quantitative change, with new players, belonging to the above categories, entering the Space Investments world.

The “How” aspect is probably the one where the major changes are expected in the upcoming years. The arrival of numerous new players, especially from the private sector, but not only, is pushing the space agencies towards the need for transformation. The dynamics of the space sector are changing enormously, and in order to remain competitive, space agencies need to change their management approach both internally as well as with external stakeholders. Business approach like Outsourcing and PPPs are becoming a necessity and the need to transform the Project Management guidelines is a mandatory direction to move forward to. Moreover, still within the "how" aspect, the need of regulation is more visible every day. The International Space Policy is addressed at worldwide level, while now local regulations mainly apply and regulate the market on a geographical basis. The more satellites are launched in space, for both manned and unmanned missions, the more is the need to develop international regulation. Space is becoming a busy environment, and issues like Space Debris are not anymore to be under looked. Many players around the world have similar priorities and constraints: this may facilitate international agreements.

Finally yet importantly, the focus of this research was on the "What" aspect. This is probably the most dynamic of all the above drivers. The 21st Century shows a world driven by research and above all business. Major evolutions are expected in all the three branches of Manufacturing, Services and Commercialization. This is also driven by the development of new technologies, which make use of Artificial Intelligence (AI) machines.

The Space Economy is a dynamic phenomenon, moving at a fast pace. The three drivers show not to be independent from each other, and the growth of one, influences directly or indirectly the others. While, traditionally, the Space Sector was characterized by a slow pace, where investments, development and operations took a very long time, nowadays the new players, mainly from the Private Sector are showing a different approach, characterized by a higher risk appetite. The transformation of the Space Sector is pushing the Space Economy to become a leading sector at large scale, from technological, to social to economic perspectives.

Moving to the second part of this research, it started with the analysis of how public space agencies need to deal with the introduction of new space missions that continuously enrich their portfolio, with recommendations that are certainly applicable to all the European space agencies, but that focused especially on one of the three big ones, making use of a case study to address the needs for improvement of the Project Management. The activities of the organization in question, are minutely regulated by the application of the ECSS standards that are applied to each mission and each phase of the mission. Each space mission is considered as a stand-alone project, making space agencies project-based firms [205], with the need to introduce multi-project management. Moreover, space missions are large-scale, complex projects, each one requiring a big investment of resources, time, money, and people. The management of such complex projects shows important limitations in current PM processes in space agencies, starting with the natural project complexity, to challenges in knowledge management and sharing as well as communication processes.

The current approach of Space Agencies to PM is to implement a typical agile or waterfalls approach, often in a hybrid form. Nevertheless, these approaches are limited, especially when dealing with large organizations such as the space agencies, where projects are numerous, complex, and are integrated organizational structures. Under this scenario exhibiting many new and complex missions joining the current operational set of satellites, and the need to introduce new resources, we relied on an in-depth case study analysis to suggest a new PMO approach aimed at improving the efficiency of PM and KM in the agencies. Given the complexity and the number of projects, we suggest a three-dimensional framework of PMO governance, addressing the need for a centralized and coordinated management of the projects under three areas: Strategy, Resource, and Knowledge. The Strategy PMO is responsible for the overall governance of the organization and the projects with a focus on improving efficiency in tasks such as inter-organizational risk mitigation, replicated structures and responsibilities, and control mechanisms. The Resource PMO improves the resource planning and allocation to multiple projects. Lastly, the KM PMO aims at providing continuity across phases and proper transfer of knowledge among projects. The main outcomes from the application of the three PMOs are associated to the sharing of human resources, technologies, and the application of a common naming convention. We argue that all together these elements would improve the quality and efficiency of projects within an agency, save time, and reduce risks associated to individual projects.

The three PMOs together aim at addressing commonalities among the missions and avoiding "re-inventing the wheel" every time a new project is brought into the organization. While the three PMOs have the objective to harmonize the projects across the organization, we acknowledge that, given that different space missions have different requirements and objectives, not all parts of the projects could be harmonized, and some level of tailoring should always be put in place. Indeed, this complexity cannot be decoupled from a space project due to its own nature.

Finally, it is important to acknowledge the limitations associated to this study. First, due to the diverse nature of space agencies around the world, and the restricted access to internal practices, while still relevant, the case study findings may not be fully representative of all space agencies, thus providing useful indications only for the European context. Second, the rapidly evolving nature of PM and KM practices necessitates continuous monitoring and updating of the conclusions and recommendations provided in this study. Moreover, the sharing of technologies and other resources may be difficult from the procurement point of view, allocation of funds and participation of Member States contributing to different missions. This shall be addressed as a separate study, addressing the economic / political distribution and decision power within the organization. More limitations are associated with the proper nature of the Space Agencies and missions, which pose natural limitations to modernization. Before exploring those, it is worthy to mention that this is a limitation in itself. While the private sector presents with a higher appetite for risk, the public space agencies are much more conservative. For this reason, improvements are more easily accepted by the private entities, which experiments more easily, while the public sector prefers well-established practices. This is certainly a limitation when performing research, because applications may undergo long delays before being applied in the public space agencies.

Limitations of this study are also linked to the diversity of missions. While the agency used especially to address the second research question, mainly focuses on Earth Observation projects, it is well known that space agencies around the world include many other types of missions. From a general perspective, I could say that this research could be applied to other missions with different scope, but still under the classification of "unmanned missions", while for "manned missions" (meaning with astronauts on board the spacecraft), further considerations shall be addressed and deeper analysis shall be carried out. An horizontal approach could be very challenging, especially when considering the different nature of human beings, and the different needs that each one of them pose when preparing for a travel to space.

One more limitation is linked to the relationship between multiple agencies, both at national and international level, that regularly work with each other. If the ECSS Standards are a big part of the harmonization between agencies, the adoption of new working practices, for example linked to PM and KM in one agency shall be used to form new standards to be applied by other agencies. When working together, it is useful that they would be able to share similar approaches with different missions. To give an example, when talking about the Sentinel missions, under the Copernicus program, several parties are involved in this project [71]. The adoption of new practices by one agency certainly may (and shall) have an effect on the working approach with the other organizations.

Future areas of research are then suggested for the following points: 1) analyze and compare working practices in different geographical areas (e.g. space agencies in Europe vs. those in India, or Space Agencies in the US vs. those in Japan, etc); 2) monitor PM and PMO practices evolution in public agencies (within or outside the space sector), to address new advantages / limitations of new practices, or how to adopt practices from other public agencies into the

Space Sector; 3) analyze the structure of the policy within the space agencies, such as how Member States / Cooperating States, etc, influence the funding allocation and sharing between projects, and how to improve this.

More areas of research shall focus on other limitations listed above: 1) How to increase the appetite for risk for public space agencies (this includes not only a mindset approach, but clearly also new regulations, budget allocations, resources); 2) Human Spaceflight standardization areas: to identify common areas for multiple manned missions. Probably this is becoming more and more relevant with both public and private organizations working together and the need to find common grounds between them. Probably this would lead to the development of new standards, similar to ECSS, but specific for manned missions; 3) Inter-agencies standardization other than the ECSS Standards, focusing more on PM and KM.

One last topic that the authors suggest for future studies, certainly relate to the introduction of new technologies and in particular the growing importance of AI and ML that are slowly being introduced also within the agency in question. The authors suggest further studies in terms of AI and ML application from a project management point of view, to be used also in combination with other technologies such as NLP that for example is already being experimented in other agencies for the management of requirements.

13. List of Acronyms

AI	Artificial Intelligence
BOT	Build-operate-transfer
BPO	Business Project Office
CMA	China Meteorological Agency
CNSA	China National Space Administration
ECSS	European Cooperation of Space Standardization
ESA	European Space Agency
EUMETSAT	European Organization for the Exploitation of Meteorological Satellites
ISO	International Standards Organization
ISRO	Indian Space Research Organization
JMA	Japan Meteorological Agency
KM	Knowledge Management
NASA	Indian Space Research Organization
NOAA	National Oceanic and Atmospheric Administration
OECD	Organization for Economic Co-operation and Development
PBO	Project Based Organizations
PDAP	Payload Data Acquisition and Processing
PDGS	Payload Data Ground Segment
PM	Project Management
PMBOK	Project Management Body of Knowledge
PMO	Project Management Office
PMSI	Project Management and Strategic Integration Office
PPP	Public-Private-Partnership
R&D	Research & Development
RFW	Request For Waiver
SIAS's	Satellite Industry Association's
SPO	Strategic Project Office
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space

Appendix A: Satellite Communications and Telecommand/Telemetry Exchange

The appendix is based on the knowledge available from the ECSS Standards [216].

Satellite communications play a crucial role in space science, as well as in our today's life, enabling the exchange of data and commands between ground stations and orbiting satellites. Satellite communications involve the use of artificial satellites orbiting the Earth to relay signals for various purposes, including television broadcasting, internet services, navigation, and scientific research. Satellites act as intermediaries between ground-based communication systems, enabling global coverage and efficient data transmission. The two main components are Telecommand (TC) and Telemetry (TM).

Telecommand, which is the uplink component of satellite communications, refers to the process of sending commands or instructions from a ground station to a satellite. These commands control the satellite's operations, such as adjusting its orbit, activating onboard systems, or configuring payload instruments. The telecommand uplink typically follows these key steps:

- Ground Station Preparation: The ground station operator prepares the telecommand instructions based on the satellite's operational requirements or mission objectives.
- Encoding and Modulation: The telecommand signals are encoded into a format suitable for transmission and modulated onto a carrier signal. This encoding ensures that the commands are correctly interpreted by the satellite's onboard systems.
- Uplink Transmission: The encoded telecommand signals are transmitted from the ground station using specialized antennas and radio frequency equipment. The signals travel through the Earth's atmosphere and propagate into space towards the satellite's orbit.
- Satellite Reception: Upon reaching the satellite, the telecommand signals are received by the satellite's onboard communication system. This system includes antennas and receivers designed to capture and demodulate the incoming signals.
- Decoding and Execution: The satellite's onboard computer processes the received telecommand signals, decoding them to extract the intended instructions. The satellite then executes the commands accordingly, initiating specific operations or adjustments as directed.

The second component of satellite communications, specifically for the downlink part, is the telemetry. This involves the transmission of data and measurements from a satellite back to a ground station. This data is critical for monitoring the satellite's health, performance, and environmental conditions. The telemetry downlink process typically unfolds as follows:

- Sensor Data Collection: Various sensors and instruments onboard the satellite continuously collect data related to its position, orientation, power status, temperature, and other operational parameters.
- Data Encoding and Transmission: The collected telemetry data is processed, encoded, and modulated onto a carrier signal for transmission. The encoding ensures that the data is efficiently transmitted and can be accurately decoded at the ground station.
- Downlink Transmission: The modulated telemetry signals are transmitted from the satellite back to Earth using its communication system. The signals propagate through space and enter the Earth's atmosphere towards the designated ground station.
- Ground Station Reception: At the ground station, specialized antennas receive the telemetry signals transmitted by the satellite. The signals are then demodulated to extract the encoded data.
- Data Processing and Analysis: The received telemetry data is processed and analyzed by ground station operators or satellite engineers. This data provides insights into the satellite's operational status, performance metrics, and environmental conditions.

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