

While commercial space is moving at a rapid pace in technological advancements, the development of industry standards has not necessarily kept pace. This is in part due to the importance placed on technology advancements required to achieve certain space faring goals like NASA's Moon Base and eventual missions to Mars, and those leading the charge in technology development are the same subject matter experts whose experience is needed to contribute to the development of commercial space industry standards. There is also the position that additional standards and requirements may impede technological developments. However, consensus standards can reduce the burden of determining use between government standards, individual commercial company standards, and differing international standards allowing for enhanced coordination and more efficient technology advancements. Which is why standards planning in the commercial space enterprise has become just as important as technology planning.

However, there are not as many approaches outlined for conducting standards planning and integration. Technology roadmaps are a tool that are widely used across the industry and enable its priorities and advancements. Approaches and examples of standards planning are fewer in comparison, but standards roadmaps will be an important tool to continue to develop consensus standards for commercial space and to plan for the integration of those standards into government agencies, commercial companies, and international organizations. Certain technology roadmapping approaches can be applied to standards planning and roadmaps to assist in furthering consensus standards development, adoption, and integration.

2. ROADMAPPING APPROACHES AND APPLICATIONS

2.1. Technology Roadmapping Frameworks

The Fundamentals of Technology Roadmapping (2) is an approach developed by Sandia National Laboratories to formalize and guide technology roadmap development in the research and development sector. This approach consists of three phases: 1. Preliminary Activity, 2. Development of the Technology Roadmap, and 3. Follow-up Activity. The first phase focuses on the initial landscape components to understand the essential conditions of the roadmap including key stakeholders, participants, and needs. This phase also calls for sponsorship or directive from leadership and determining the scope of the roadmap.

The second phase outlines the process for creating the roadmap, and its elements include identifying the product, specifying system requirements and major technology areas, determining technology drivers and

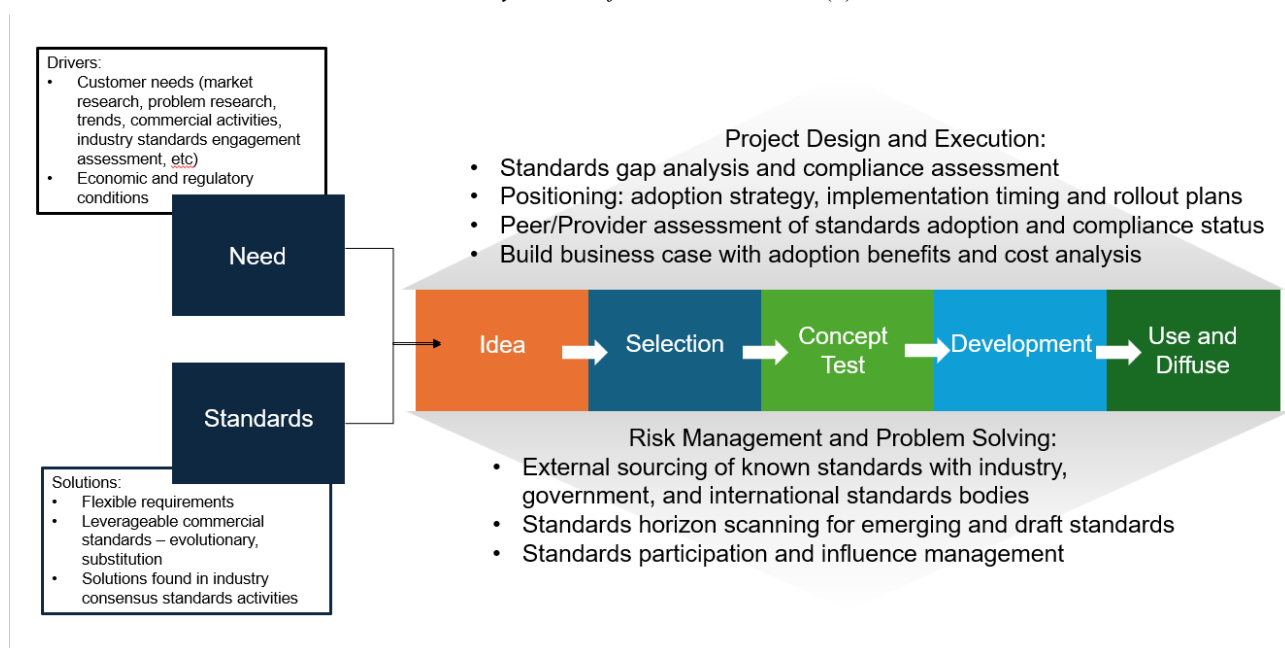
alternatives, recommending which technology alternatives should be pursued, and drafting the roadmap report. The third phase focuses on validation, implementation, and periodic reviews and updates.

This framework establishes a clear process to analyze the needs and technology alternatives to approach technology planning. The core elements of the process could be adapted to address standards planning efforts. The steps in the preliminary activity would remain largely the same, focusing on a needs-driven approach to determine the reasons for developing a standards roadmap. The second phase would focus on major standards domains and program requirements, as well as standards drivers and their adoption targets. The third phase would again follow the same steps as outlined in the original framework. With minimal deviations, this framework could support standards development planning activities for organizational objectives.

Looking at another technology roadmap process, outlined in the Technology Roadmapping Seminar developed by Jay Paap (3), it leverages key themes of the Sandia Technology Roadmapping Fundamentals framework and follows a structure adapted from the Myers and Marquis Dynamics of Innovation Model. (4) This process starts with the identification of needs and technologies. The needs include drivers like economic and regulatory conditions and landscape analysis of market research, problem research, trends, technology forecasting, and competitor assessments. The technology element identifies solutions such as leverageable technologies and alternative technologies found in other industries. The analysis of needs and technologies are inputs into the following project design and execution process for developing the roadmap: 1. Idea, 2. Selection, 3. Concept Test, 4. Development, and 5. Use and Diffuse. The project design and execution should also include hypothesis testing and substantiation, product specifications and timelines, competitor assessment of capabilities and plans, and a business case with stories and numbers. This process is also guided by elements of risk management and problem solving including external sourcing of known technologies with industry, government, and academia; scouting for novel technologies; and IP management.

Although these approaches and frameworks were created specifically for technology planning, many of the key elements can be adapted for standards planning and roadmap development given the similar considerations at the enterprise level. Figure 2 demonstrates the adaptation of the Jay Paap process for the development of a standards planning roadmap activity. While the general

Figure 2: A Standards Roadmap Approach. Adapted from Technology Roadmapping Seminar process (3), based on the Dynamics of Innovation Model (4)



framework remains the same, key inputs related to drivers and solutions diverge. The landscape analysis involves assessing industry standards engagement, and other considerations within the project design and execution and risk management elements focus on standards gap analysis, adoption strategy, horizon scanning, and influence management.

2.2. Standards Roadmaps in Alternate Industries

The commercial space enterprise can look to other established industries to model the development, adoption, and implementation of consensus standards. The Institute of Electrical and Electronics Engineers (IEEE) published a standards roadmap on Neurotechnologies for Brain-Machine Interfacing. (5) The roadmap is a result of gathering key stakeholders, evaluating existing standards and standards gaps, and reviewing current standardization efforts. It provides recommendations to the industry to consider the promotion of positive effects of standardization, awareness on how standards are developed, and the importance of flexible governance and regulatory mechanisms. The appendices delve deeper into specific domains exploring within each existing standards, current standardization efforts, and priority topics and recommendations. The IEEE roadmap is a succinct document that examines the current state of the industry's landscape as it relates to consensus standards and provides considerations for a unified path forward.

The International Financial Reporting Standards (IFRS) Foundation released a Jurisdictional Roadmap Development Tool to support regulators and other

authorities in designing strategies for adopting and using standards developed by the International Sustainability Standards Board (ISSB) to ensure standardization of sustainability-related financial disclosures. (6) The tool encourages the adoption of the ISSB standards while acknowledging that the adoption and use of the standards are optional. The document is designed as a toolkit developed to include a standards adoption roadmap development guide and reference roadmap templates. The framework outlined in the development tool consists of four key aspects: 1. Regulatory Process (how), 2. Reporting Entities (who), 3. Requirements (what), and 4. Readiness (when). Within each of those areas, a decisions and outcomes table is created to highlight matters of consideration, decision points, and potential outcomes. The themes from the decisions and outcomes table form the core of the jurisdictional standards adoption roadmap, but there is additional supporting information that is also key to consider including assurance, supervision and enforcement, resources and capacity building, and digital reporting. This tool demonstrates the importance of generating processes and examples to lead the industry in strategically adopting consensus standards.

3. ROADMAPPING APPROACHES APPLIED TO STANDARDS PLANNING FOR COMMERCIAL SPACEFLIGHT

In examining roadmapping approaches and applications, it is clear the commercial space enterprise could largely benefit from intentional, integrated standards planning activities. Currently, the enterprise is operating in a fragmented model. Space agencies and other government organizations develop and maintain their own

requirements, and commercial companies are working to develop tailored, in-house standards. While international organizations and standards development organizations are trying to keep pace and create more cohesive standardization efforts.

The entities within each of those domains are strategically leading the development and pursuit of standards planning, but not necessarily at the enterprise level. Current efforts are siloed and serve individual organizational objectives, which can ultimately slow technological progress. It will be critical for unified standards planning and adoption efforts to take place in order to meet the significant technical challenges of spaceflight. No agency, company, or country will achieve those missions alone, and intentional standardization will enable those partnerships.

Roadmap development for the purpose of guiding enterprise activities, whether for technology or standards planning, utilizes similar frameworks and techniques. The adaptation of existing approaches will enable more intentional standards planning and adoption. The commercial space enterprise should leverage those frameworks to pursue integrated understanding of existing standards and standardization efforts, planning for future standards and needs, and adoption of standards. Consensus standards in any industry are only as valuable as they are utilized.

4. CASE STUDY: OSMA COMMERCIAL ROADMAP FOR INDUSTRY STANDARDS AND PARTNERSHIPS

4.1. Foundations and Purpose

As the commercial space industry continues to expand, so does the need for voluntary consensus standards. There are several Standards Development Organizations focused on developing standards for commercial spaceflight, and NASA is actively engaged in supporting those activities. While NASA maintains and publishes its own standards, those standards are only leviable on NASA-led missions. However, as the agency works to further engage in a public-private partnership model to achieve mission speed and success, there are more commercial standards, owned by commercial providers, that are adjudicated and substituted for NASA standards on NASA-led missions. The increased use of NASA adjudicated commercial standards and the development of consensus standards for commercial spaceflight have led NASA's Office of Safety and Mission Assurance (OSMA) to define the agency's path forward in supporting the development of safety and mission assurance (SMA) related industry consensus standards and strategic use of commercial standards for spaceflight missions. NASA OSMA has established a standards integration roadmap to support mission assurance

evolution objectives to further align NASA with commercial and industry standards and to ensure the agency's adherence to the Federal Participation in the Development and Use of Voluntary Consensus Standards and in Conformity Assessment Activities, Circular No. A-119. (7)

4.2. Roadmap Development

The roadmap is a scalable framework that originally focused on SMA standards specific to human spaceflight missions but has been expanded to include standards for science and space technology missions. Leveraging a combination of the roadmapping approaches outlined in previous sections, the roadmap was built, piloted, and scaled to its current scope. The initial concept of the roadmap was outlined in a white paper titled "Navigating the Complexities of Safety and Mission Assurance Across NASA's Partnership Landscape." (8) The paper addressed prioritizing deeper integration of SMA principles, tools, and methods at the enterprise level as the agency increasingly pursues public-private partnerships. The roadmap was identified as another tool to support those objectives.

The white paper established the essential conditions that would drive the development of a standards integration roadmap for NASA OSMA aligned with leadership directives. The next step included defining the scope and boundaries for the roadmap. A landscape analysis was conducted examining organizations, activities, existing standards, and regulatory conditions related to commercial and industry standards for human spaceflight. This led to the development of four strategic focus areas within the roadmap: 1. NASA Internal, 2. Industry Standards Development Organizations, 3. US Interagency Entities, and 4. International Organizations. Further fidelity was added to the focus areas aligning the NASA Internal and Interagency Entities domains to commercial standards and the Industry Standards Organizations and International Organizations domains to industry consensus standards. NASA and other federal agencies have more interactions with commercial standards developed and maintained by commercial providers and partners through acquisitions activities. Industry consensus standards are developed and maintained through Standards Development Organizations and International Organizations. This is a simplification of where each of the types of standards for commercial spaceflight interact within the focus area domains of the roadmap.

The roadmap has four goals aligning to the four focus areas, each with supporting objectives in the near-term, mid-term, and long-term timeframes over the course of five years. The goals are as follows:

1. **NASA Internal:** Lead evolution of Mission Assurance and support appropriate use of commercial standards
2. **Interagency Entities:** Ensure alignment of standards and policies with regulatory authorities and other federal agencies
3. **Industry Standards Development Organizations:** Engage in industry consensus standards development activities
4. **International Organization:** Support international collaboration and standards development

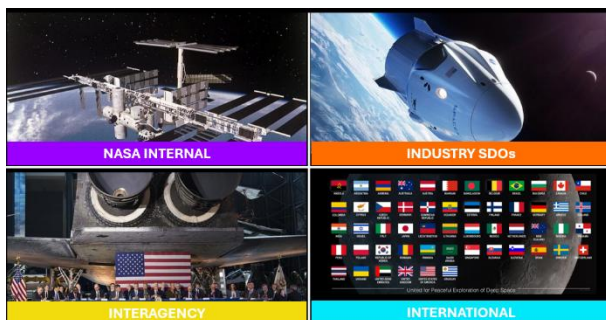


Figure 3: OSMA Commercial Roadmap for Industry Standards and Partnerships Focus Areas

The roadmap's long-term objectives define adoption strategies within each of the focus areas. For commercial standards, this includes working to adopt unified requirements across federal agencies to ensure seamless integration and operational consistency in government-commercial missions and utilizing a mix of NASA and commercial requirements while preparing for a consensus standards forward posture. For industry consensus standards, this includes a strategic commitment to a reciprocal model where the agency both contributes to and adopts/utilizes industry standards.

4.3. Current Initiatives

There are several ongoing initiatives within the stated goals, including the development of an agency-wide working group established to facilitate communication and collaboration between cross-functional teams throughout NASA, including the agency's three technical authorities, on topics related to human spaceflight commercial and industry standards. This working group also provides a horizon scanning function to feedback into the roadmap design and execution process. The group has facilitated greater awareness and understanding of NASA's engagement with the ASTM Committee F47 on Commercial Spaceflight, leading to the pursuit of another initiative under the roadmap.

NASA OSMA has established a process to streamline internal reviews and balloting decisions of draft SMA consensus standards from external Standards Development Organizations in which NASA participates. Leveraging an existing process used to review NASA-owned SMA standards, this new systematic approach will allow the agency to more effectively and efficiently engage in externally led efforts to establish consensus standards. As organizations, like Committee F47, continue to advance the development of industry standards for commercial spaceflight, it is critical for NASA to expand its direct support and lend expertise to those efforts in a coordinated manner.

Another initiative under the roadmap is the development of a trend analysis report to examine NASA's involvement and influence in activities related to commercial spaceflight consensus standards. Looking across Standards Development Organizations, US Interagency, and International activities, The Aerospace Corporation examined the current landscape for commercial spaceflight consensus standards and conducted an evaluation of the agency's direct support of those efforts. It is critical for NASA to engage, and even take a leadership role, in those activities to share its vast and unique knowledge and to ensure the agency's eventual adoption and use of consensus standards. This initiative also functions to provide feedback into the roadmap through analysis of standards participation and managing influence (from Figure 2). The recommendations from this report will prompt future efforts under the roadmap.

4.4. Next Steps

The roadmap will continue to incorporate initiatives over the next few years, as well as pursue the objectives outlined within each of the four focus areas. NASA OSMA will also concentrate on creating greater awareness of the roadmap objectives and initiatives throughout the agency's SMA community in order to generate support and ownership of future activities related to commercial and industry standards utilization. OSMA would also like to leverage the roadmap to inform other related efforts in partner organizations. The Trilateral SMA activity that includes the European Space Agency, the Japan Aerospace Exploration Agency, and NASA has established a communication circle to pursue certain topics, including standards. The OSMA standards integration roadmap will be shared with these international partners to generate discussion and provide insights into NASA's standards planning for the integration and eventual adoption of industry standards. OSMA would also like to leverage the Space Collaboration Council as another venue to share the roadmap process, objectives, and initiatives with both industry and government partners.

With enhanced visibility among interagency, industry, and international partners, the roadmap has the potential to become a framework to encourage other organizations to conduct enterprise level standards planning and standards roadmap development to support the near-term integration of commercial standards and eventual widespread adoption of commercial space industry consensus standards.

5. DISCUSSION: EVOLUTION OF STANDARDS PLANNING FOR COMMERCIAL SPACEFLIGHT

The technology roadmapping approaches described in Section 2 are useful frameworks for individual organizations to lead standards planning efforts to adopt and integrate consensus standards into their requirements. However, there is an opportunity for the commercial space enterprise to pursue the development of a standards roadmap that encompasses existing standards, current standardization efforts, future standards needs, adoption frameworks, and example roadmap templates.

Currently, the most comprehensive resource of space industry technical standards is the compendium published and maintained by the US Office of Space Commerce. (9) This collection of standards would be a prime starting point for an independent organization within the enterprise, similar to the efforts by IEEE and IFRS, to establish a Commercial Spaceflight Industry Standards Roadmap Toolkit. The roadmap would consist of a landscape analysis of current standards and standards development efforts, as well as recommendations for future standards. It could include analysis on general perception of standards and document current priorities related to standards among different agencies, companies, and international organizations. It would also demonstrate the process for individual organizations to develop their own standards adoption roadmaps with detailed processes, templates and examples.

A comprehensive roadmap and roadmap toolkit to guide the enterprise in developing and adopting standards would eliminate the current fragmentation of standards efforts and support integrated requirements for technology development to increase the momentum of the industry and meet the demands of current and future spaceflight mission objectives.

6. CONCLUSION

Technology development does not happen in a vacuum; there are mission goals, competitive drivers, and a desire to go beyond what has been done before. However, without use of strategic tools to guide the intentional planning, analysis, and prioritization of technology needs, the developments would remain conceptual. The

same use of tools to guide the development and adoption of standards will enable an equivalent caliber of results. With the increasing number of consensus standards being developed and published for commercial spaceflight, it is becoming important to establish a strategic direction for continued development as well as integration and adoption of these standards into government agencies, commercial companies, and international organizations.

Using Enterprise Systems Engineering concepts related to standards planning will allow for a smoother and more successful transition to the widespread use of industry standards. Adapting frameworks from technology roadmaps will provide a foundation for organizations across the enterprise to straightforwardly engage in standards roadmapping and develop tailored approaches for standards integration and adoption to achieve shared mission objectives.

With more standards planning efforts underway, it will become necessary for an over-arching, enterprise-level standards roadmap to be developed. This roadmap should include a compilation of existing standards, current standards development efforts, and priorities and recommendations for future standards. This roadmap should also include tools and frameworks to guide the development of organizational level standards adoption roadmaps to encourage the widespread adoption of industry standards for commercial spaceflight.

In Enterprise Systems Engineering, technology and standards planning are viewed as a mutual step in the process, and it is time for the commercial space enterprise to engage in standards planning with equal dedication.

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