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International Space Reference Architecture

Nathaniel Dailey[ab*], MPAP, CEA, Harvey Reed [c]

[a] *The MITRE Corporation, 7525 Colshire Drive McLean, VA 22102 USA Email: ndailey@mitre.org*
[b] *Johns Hopkins University, Paul H. Nitze School of Advanced International Studies (SAIS), 1740 Massachusetts Ave NW, Washington, DC 20036 Email: ndailey2@jhu.edu*
[c] *The MITRE Corporation, 7525 Colshire Drive McLean, VA 22102 USA Email: hreed@mitre.org*
**Corresponding Author*

Abstract

This paper provides a socio-technological [*]transformative architecture as a mechanism to advance international space innovation objectives in support of Long-Term Sustainable (LTS) guidelines in space among nations and organizations, public and private. It enumerates, in the context of an International Space Reference Architecture (ISRA), how the means for LTS guideline implementation spans components of this socio-technological architecture metamodel such that there is traceability and cohesion among technical specifications, behavioral norms, ethics and standards of practice ultimately in support of space policy criterion and Ex-Post evaluation & verification for measuring intended impactful outcomes. Specifically, it focuses, as a basis for exposition, on 1. space flight safety technology mechanisms, utilizing Distributed Ledger Technology (DLT) or Blockchain, and 2. comprehensive interconnected security principles such as: sound satellite cybersecurity mechanisms must be interdependent with and across technology, information, physical, personnel, managerial, trusted supply chain, certification and accreditation processes and procedures. Such an architectural construct can serve to catalyze comprehensive approaches to the advancement of public-private space industry and incentivize good behavioral norms in sustainably meaningful, effective & "sticky" ways that ensure continued & unfettered access to space for all.

Keywords: Space-Diplomacy, Behavioral-Norms, Blockchain, Socio-Technological Architecture, Cyber-Satellite-Security

[*] *Technological, as discernable from technical, in that the former refers to "the use of technology" rather than being, of itself, technical in nature.*

Acronyms/Abbreviations

Near-Earth Objects (NEOs), Space Situational Awareness (SSA), Space Traffic Management (STM), International Space Reference Architecture (ISRA), tactics techniques and procedures (TTPs), Non-Governmental Organizations (NGO), low Earth orbit (LEO), Public Private Partnership (PPP), Telemetry Tracking and Command (TT&C), Information Sharing Center (ISAC).

1. Introduction

The increasing pace of space systems design, development, and deployment in the public and private sectors, both domestic and international, applies significant stress to "the global commons" of the space domain. Venture capital is pouring into the space sector: Over 120 firms invested in space in 2018, topping a peak of 89 in 2015.[14] At the same time, the classic "tragedy of the commons" is unfolding in space with both rapidly increasing debris and Near-Earth Objects (NEOs). While traditional Space Situational Awareness (SSA) and emerging Space Traffic Management (STM) efforts promise to address critical issues in the global space commons, the agreements required for effective cooperation to achieve these goals are substantial and can benefit from a structured architectural approach.

The agreements required for SSA and STM range from launch coordination, to operations in space, to re-entry, and cross both operational domains and sovereign boundaries. All agreements must use technical, operational, and policy language, which is understood and agreed across stakeholders, such that agreements are unambiguous. Multi-lateral cooperation is critical to establish needed language and standards, and a framework to inform and structure such global space activity. This paper proposes an open International Space Reference Architecture (ISRA), as the foundation for shared space related information and agreements which support and enable SSA, STM, and related space activities. Reference Architectures serve as tools for providing common information, guidance, and direction to guide and constrain enterprise and systems architecture and solutions. ISRA is intended to be an internationally governed effort, and sets the foundation for multi-lateral technical, operational, and policy standards and recommendations. ISRA may be used as a mechanism for Space Information Sharing such as those conducted by the Space Information Sharing Center (ISAC). [16]

ISRA is comprised of three fundamental components.

- The first component is comprised of Policy: the keystone for the principles, technical, and vocabulary-based artifacts in the ISRA framework.
    - Identifies the primary producing stakeholder (owner) organizations that contribute.
    - Describes policy criterion to be addressed.
    - Enables end-to-end traceability between organizational context and the eventual implementation(s).
    - Is consistent with the first COPOUS LTS guideline: "Policy and regulatory framework for space activities".
- The second component is a shared vocabulary or lexicon often and frequently informed by a common data dictionary upon which to base a continuous flow of new information to choreograph policy that is readily prepared to incorporate emergent definitions as they become available from civil, commercial, international sectors, ensuring that rapidly advancing concepts are coupled with policy updates.
- The third component is technology innovation and mechanisms to share, existing standards, best practices, and tactics techniques and procedures (TTPs) in space operations that are common to all stakeholders while maintaining safeguards for proprietary and sensitive data. [6] (To include atmospheric flight and space objects databases and supporting situational awareness and operating methods, including satellite owner-operator ephemerides to inform orbital location and planned maneuvers, as well as on-orbit servicing universal physical docking interface design specifications.) [6] One such innovation to consider is the use of a decentralized means of information sharing which enables maximal participation among diverse stakeholders that ensures immutable data integrity accuracy and availability. [5] Such a decentralized and distributed approach will ensure greatest international reach and contribution.

Central to all three of these architectural metamodel components are *desired* principles as seen in forms of space operations behavioral norms, standards of practices as well as theoretical applied ethics concepts leveraged by from academia and international organization missions, such as the European GNSS Agency (GSA), the European Union agency operating EGNOS and Galileo and is responsible to ensure the maximization of socioeconomic benefits from the use of space. [19]

ISRA provides a shared vision for space related international adoption and development, informed by the Multi-National, Multi-NGO and private industry community; each contributing to the ISRA components, in the interest of the long-term sustainability of the global commons of space. This approach is organized around several foundational components can serve to set a framework for the current state and future evolution of a cross-organizational, open international space reference architecture that spans public, private and international domains and serves to build confidence and security for the benefit of a globalized space traffic management and space situational awareness for all stakeholders.

Current regulatory systems are ill prepared to manage a world of privately owned and operated reusable rockets, large-scale constellations of satellites in low Earth orbit (LEO), asteroid mining, and in-space servicing.[1] An internationally minded cross organizational space reference architecture & associated governance structures with openly accepted guidelines, standards, behavioral norms and best practices may pre-empt emergence of misperceiving *intent* among sectors and nations and protect the sustainability of a manageable and safe space environment. "*How can the interests of (civil) industry, free-markets, and national security best be balanced when they come into conflict?* "[1]

The increasing capability among rivals to threaten space assets with harm and to exploit space for military advantage is being used to argue for more rapid government development of more survivable defense space capabilities. However, there is a natural proclivity in the evolution of technology innovation to transition from government owned to government purchased, as space commerce continues to evolve in capability and capacity. This frequently leads to government divestiture of requirements development responsibilities, to private sector driven innovation and developmental activity. [11] There are advantaged to the *dirigiste* economic doctrine in which states play strong directive roles, as opposed to a merely regulatory role, over a capitalist market economy. [20] For example, mission-driven research funding for basic scientific research can be justified through contribution to specific objectives rather than relying solely on the somewhat vaguer promises about science's longer-term benefits. However, a more transformative framework for change aligns *social* and *environmental* challenges, even grand societal challenges such as the global commons in space, closer with innovation objectives. [20] Toward addressing social and environmental objectives such as the LTS guidelines for space as well as the 17 UN Sustainable Development goals, developing new technologies in such a way leads to higher labor productivity, enhanced capacity for collectivized deep learning and subsequent economic growth. The remaining externalities can be managed through light-touch regulation in so far as a state sees fit to apply their unique interest. Subsequently, this frame of innovation policy focuses on stimulating R&D and building national systems of innovation in a collectivized global context for sustainability.

Much of the space sector has changed, from being primarily driven by government and large systems integrators, to being more segmented and subsequently more open to "NewSpace" participants. These changes are exciting for many people and have revitalized hope that the Von Braun paradigm [8] may yet come to be: "But such changes are wrenching for the old guard that created and nurtured the first government led wave of the space enterprise". [11] More governments worldwide can be expected to act on their space aspirations through participating in space activities in different ways. It will become increasingly more important, as it does so, to have a tool for sustainably advancing and a global understanding of shared interests in the space domain, using such a reference architecture.

We must all share the burden of collective defense in space. Public and private industry must partner to ensure that sharable guidelines, standards, behavioral norms, lexicon and best practices are proliferated and accepted. Vocabulary begets mindset and it is a logical place to start building architectures that span organizations and domains. Lexicon is documented in data-dictionaries and permeates throughout a collective system of systems' blueprints. A common and shared vocabulary is not just about having the same words to describe different concepts of different words to describe the same concept. The idea that vocabulary begets mindset is about understanding that common perception and intent among multiple parties can minimize risk of surprise or misunderstanding. Vocabulary can thus have a direct correlation on the establishment and maintenance of behavioral norms in space activities in much the same way that standards influence technology implementation. Establishing norms of behavior for space use will be especially difficult since across nations, alternative social structures, power relations, and leadership dynamics, as well as norms, identities, values, and ideologies, have significant impact on successful formulation and execution of national and international strategies. [13] Such challenges can be surmounted by anthropological understandings of cultural values, social systems, and leadership worldview emerging space fairing societies. Space use is not just for rocket scientists and engineers anymore, it must include multi-disciplinary viewpoints and mindsets. If the answer to "Why conduct ASAT testing" is, "to join the space weapons club", what can we do as a global body to positively affect and change this sort mindset and behavior going forward? Change of international space related mindset begins with just such socio-cultural understanding and vocabulary.

"Engineering is easy… policy is hard" – Deborah Barnhart [10]

Policy is not hard in so much as engineering is not always easy. The challenge that constrains policy formulation around engineering disciplines is the gap among disciplines, or lack of a compressive and multidisciplinary input. Many engineers become executive administrators, fewer professional administrators become engineers and so it follows that there often emerges a sentiment that hard science is hard but soft science is harder. There is a need for a multi-disciplinary approach to couple policy formulation in substantive ways that are meaningful to engineering, and also implement policy intended outcomes through effective administrative mechanisms. In the context of a single organization or agency, we rely on Enterprise Architecture, but among multiple organizations and across domains, a Reference Architecture is an effective enabling tool that in effect serves as a multi-enterprise, cross-organizational or multi-national framework. This however, presents the challenge of working with the concept of social structure, in addition to organizational structure. ISRA is a new way of blending best practices in architecture with the social sciences and is thus is an international relations oriented socio-technological architecture.

Across organizations and nations, shared interests are fundamental. For example, *unimpeded access* to near-Earth outer space. Such access may not actually be assured due to objective reasons of congestion of certain orbits. Thus, this shared interest is evolving and space policy must take this into account when considering intended space policy outcomes. Another example in political and academic lexicon, is what is meant by "principle of freedom of action in outer space", to guide outer space activities and doctrine? What are the legal grounds for, and the modalities of, resorting, in a hypothetical case, to self-defense in accordance with Article 51 of the Charter of the United Nations, as applied to outer space?

Avoiding potentially harmful interference with the space activities of other States is based on international relations theory of common interest and the security dilemma†. Developing a method, like ISRA, that makes it possible to define and measure the harmful nature of interference objectively and absolutely may, in a decisive way, promote relevant agreed understanding. This is why *vocabulary* is given its own dimension in the ISRA meta-model.

"The fundamental principle and supreme rule of all scientific terminology is that terms must be constructed and appropriated so as to be fitted to enunciate simply and clearly true general proposition." – Radcliffe-Brown, A. R.

A balance of leadership for and acceptance of the growing number of space faring organizations, will prove challenging for state and commercial executives alike. [1] So a Public Private Partnership (PPP) may be well suited to carrying out the sharing of space related data with the rest of the world. Organizational lines of demarcation for data and information sharing across multiple organizations must be clear. Technology can and will continue to disrupt the way we think about doing business in space operations and the collective mindset(s) must keep pace to this change.

"Your old patterns constrain you, and your old questions keep you in familiar territory. It is new and different questions that open up new and different possibilities." [2]

The question of centralized control of SSA and STM data is often linked to, "*sovereignty as an insurmountable barrier to the development of a functional space traffic management regime*." [4] "*However, by approaching the policy question of space traffic management as a decentralized safety service rather than a regulatory function, the question of sovereignty becomes less of a barrier*." [4] This is a radically new way of thinking for many long-standing space fairing entities, and such paradigm shifts tend to make people uncomfortable. Certain new technologies may be well suited to couple with this line of thought, such as Distributed Ledger Technologies (DLT), discussed below. Organizational change management principles will be required to overcome some deeply embedded organizational cultural constraints in order to be successful in averting inevitable technology disruption in the future.

ISRA is a vision for an open and international space reference architecture, with which international public, private and non-profit organizations may mitigate the impending risks inherent in growing congestion of space debris in orbital areas of concern for all stakeholders.

2. Material and methods

Candidate quantitative approaches for research may include: multivariate linear regression analysis of the dependent variables of probability of conjunctions / per year, creation of a spaceflight safety index, and quantifying conflict events per year. Candidate independent variables are: mass of debris in LEO per year, launches per year, and quantified ISRA architecture component implementations (e.g. norms, standards and practices). Datasets may be provided from historical sources and extrapolations from discreet event simulations, and behavioral model-based systems engineering results. Inclusion of proxy variables may prove useful where inferential statistical methods explored.

3. Theory & construct of a Space Reference Architecture

Carnegie Mellon University teaches that Enterprise Architect is EA=S+B+T (Strategy plus Business plus Technology). [15] In the greater context of an International Space related reference architecture, ISRA is a mechanism with which to bring together Technology, Vocabulary and space related Policy (ISRA= T+V+P) toward achieving objective outcomes for meaningful long-term sustainable space use and development, such as:

- Encouraging adherence to common norms, ethics and standards, specifications, influenced and encouraged by Space policy
- Provides for implementation consistency of technology to innovate in the spirit of free access to Space for all
- Provides universal language for the all space fairing/related organizations (public, private, international)
- Supports the validation of solutions against an internationally adopted and maintained & open Space reference architecture

† *The security dilemma is "A structural notion in which the self-help attempts of states to look after their security needs tend, regardless of intention, to lead to rising insecurity for others as each interprets its own measures as defensive and measures of others as potentially threatening" – Butterfield, Hertz*

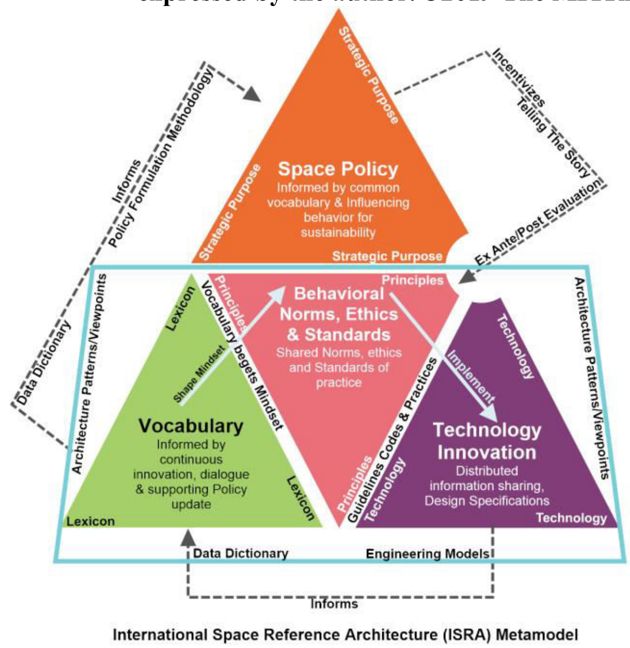


Fig. 1. ISRA Metamodel

3.1 Technology Innovation

ISRA component for technology innovation provides for technical guidance and standards that describe the established and emergent state of the art in space related mission and business. Ever more rapidly evolving technology changes often to keep up with public and private industry. Required services, standards, agreements, security models, communication protocols, web services, etc. are all technical specifications that may be described and addressed such that other components of ISRA are connected and current and that technology innovation, in general, continues to flourish in long-term sustainable ways that ensure *access to space* for all well into the future. Documentation of current and emergent trends in technology innovation may simply take the form of maintainable tables that allow for traceability across the other components of ISRA.

3.1.1 Information Security

It is not enough to simply implement NIST type 2 encryption algorithms for TT&C. Recently, NIST recommended encryption standards that stresses agile software based crypto vice hardwired silicon. While this begins to address disruptive technology innovation, such as quantum computing, more is necessary. Good security practices require a holistic approach; the type of cohesive approach that architectures enable by illustrating traceability across infosec, opsec and personnel security. The challenge with security is in how it is employed. Encouraging the commercial sector to develop such solutions is inherently a good thing. The trust model is outside of US Government circle and the rules will be caveat emptor of who uses such commercial solutions.

A first good step has been taken by the US Department of Commerce in requiring encrypted COMSATCOM systems that are used to support national security missions. [17] This is a minimum risk mitigation step. Requiring TT&C be protected by crypto for flight safety is a good first step. However, if not properly done it will not protect these commercial systems from more sophisticated competitors. Without the associated physical, personnel, trusted supply chain, CYBER, C&A, and operational management security processes/procedures, this minimal step will not be effective against more sophisticated bad actors. [18]

3.1.2 Mission Assurance

One can't be secure from sophisticated threats without trusted supply chains, trusted development and manufacturing, physical security adequate to prevent unauthorized access, personnel security to prevent insider threats, cyber security of the whole enterprise that needs protection, and operational discipline. Without a *holistic* approach, a program, system, business etc. is vulnerable and an easy target for those threats that have expertise and resources. The concept of mission assurance in the space business is inherently architecture centric, and more so, as it spans across organizations and nations.

3.2 Space Vocabulary

Per SPD-3, NASA is leading a working group to update the current Orbital Debris Mitigation Standards of Practice (ODMSP) and will disseminate this for wider government review later this year. This is an important and appropriate step given how technology vocabulary has changed from 2001 to today. This is an example that validates the ISRA metamodel approach as it illustrates how technology influences vocabulary and in turn should further influence new policy formulation and updates. Changes in orbital debris mitigation standards of practice such as placing end of life systems into a certain highly eccentric graveyard orbits, can be streamlined by use of ISRA rather than occurring every 15 years by presidential directive, and in committee or special working groups.

"The linkages between space, information technologies, and the global economy have accelerated and become even more profound" [8]

The "Von Braun paradigm"[8] for space development from the creation of reusable shuttles, space stations, lunar bases, to Mars expeditions has resurged in recent years. Schools of thought in space advocacy vary and change over time and it is important to recognize the value of the *narrative* in policy formulation processes. As we've seen especially in recent years in the U.S., subsets of populations who can take control of the vocabulary creation process, can make people believe that essential key words mean the opposite of what they used to mean with divisive results. Such actors then increase their control over policymaking.[9] Similarly, it is critical in the emergent discipline of Space Diplomacy that sound methods of shaping, documenting, and promulgating agreed vocabulary be established. International agreement is key, as well as denoting agreement in such a manner that is universally accessible and tamper-evident to prevent inadvertent or malicious attempts at shifting definitions with potentially disastrous results. Stable yet evolving vocabularies enable international space policy formulation, continuously derived from current trends in technology innovation, as part of an interconnected framework which simultaneously and directly permeates to influence behavioral norms, ethics and standards of practice such that *mindset* is always current, accurate and relevant with feedback to the times and state of art in technology innovation.

3.3 Space Policy

The Space Policy section of this metamodel provides the context and purpose for the three foundational components and is the keystone for the principles, technical, and vocabulary-based artifacts in ISRA overall. The Space policy component of ISRA must identify the primary producing stakeholder (owner) organizations that will contribute to ISRA and solution architectures that have or will utilize ISRA. It must also describe policy criterion that will be addressed. Understanding and consensus on the space policy criterion of the Reference Architecture will enable end-to-end traceability between organizational context and eventual implementation(s). Commonly accepted and practiced methodologies for policy analysis such as Bardach's 8 steps (Fig. 2) can allow for effectively implemented policy with Ex Ante and Ex Post evaluation mechanisms. Story Telling as the eighth step is critical to effective linkages between policy intent and effect on behavioral norms and standards of practice development. This aspect of ISRA is the most purposefully multi-disciplinary, intended to blend both policy and engineering worlds.

Fig. 2. 8-Step Process for Policy Analysis - Bardach

3.2 Behavioral Norms and Standards

This ISRA central component documents high-level statements that apply to the space domain and tie back to space policy criterion. They incorporate values and organizational culture, and drive technology innovation and engineering models that define how systems function. This component of ISRA supports the way in which space faring and space related organizations go about fulfilling their mission or business and is intended to be enduring and only infrequently amended. They are stand-alone principles sufficient to clearly convey the general intent of the space related activities.

Recognizing that nation states act at their discretion with respect to international guidelines for safety and security in outer space, provisions of article IX of the Outer Space Treaty prescribe a requirement to avoid potentially harmful interference with the space activities of other nation states. The codification of behavioral norms, ethics and standards of practice, together with a universal vocabulary, and policy and technical models, is an approach that enables objective measures of harmful interference by comparing observed behavior (SSA) with prior stated intent (codified shared agreements). This promotes shared understanding of conformant and anomalous behavior. This is the mechanism (for potential means, see section 5.1 below) by which differences of perception may be bridged and amended in the interest of universal clarity of intent, thereby overcoming unintended effects and surprise.

Some outcomes of clearly understood behavioral norms include:

- Conditions of stability in outer space.

- A common characterization for actions of self-defense in outer space to minimize problems of ensuring safety of space operations.
- Objective criterion for what constitutes "harmful interference".
- Criterion for the notion of harm and under what circumstances it should be ascertained
- Clear understanding for the modalities of resorting to self-defense in outer space
- Classification of conflict and near-conflict situations in outer space. ‡

In understanding mutual interest and mindset together for the purposes of codifying shared agreements for space, it is helpful to be cognizant of two basic forms of ethical standards; those that judge based upon the nature of the action being good or bad, and those that judge the goodness of outcomes or consequences of actions. Such theories of moral obligation are generally classified as deontological and teleological respectively in the field of applied ethics and may be *rule* or *act* based. It may become a discourse among the international community over the next few years, to determine the appropriate mix of rules that guide behavior (such as UNCOPUOS 21 LTS guidelines) and *Act-based* theories that are flexible enough to deal with conflict and exceptions. Balanced well, together they avoid the two equal problems of *too-many-exceptions* vs. too much *rigidity*.

For example, the concept of "*Access to Space for All*" is itself a universalistic teleological branch, *act-utilitarian*, and holds that an act is right if it brings about the greatest "*happiness"* [7] for the greatest number of *people*. This is not a mission-driven sentiment but rather on of social impact. The magnitude of social and technical changes required for this sort of deep transition§ is remarkably significant. ISRA provides for socio-technological structure in support of new relationships between the state, the market, and civil society, and, new forms of pro-active and entrepreneurial state action on international and as well as domestic and municipal levels, new networks between the state, business, civil society, and new supranational structures ensuring global coordination. [20]

4. Summary

We have described, in effect, a methodology and a metamodel for bringing together transformative innovation policy that is tightly coupled with a technology information pipeline and linked through continuous vocabulary refresh, in ways that form habits and systems together such that change can be sticky. In other words, ways e.g. culture change and habits, and means e.g. an open international reference architecture for space use, to catalyze comprehensive approaches to the advancement of public-private space industry and incentivize good behavioral norms in sustainably meaningful and effective ways that ensure continued & unfettered access to space for all.

5. Further Discussion on Technology Innovation

5.1 Distributed Ledger Technology a.k.a. Blockchain

One such way for technology to match distributed governance policy is to similarly distribute responsibility for SSA and STM activities in a system that is designed to contrast and compare expected behavior (based on agreed upon norms) and actual activity which in effect allows for automated discovery of anomalous behavior. **

BESTA (Blockchain Enabled Space Traffic Awareness) is proposed as both an extension to the current catalogue, and as an alternative to the single owner / operator model. [5] Blockchain technology is uniquely suited to enable reading and writing among all STM stakeholders, by increasing the confidence in data that is cryptographically attributed to the originator, where that data cannot be counterfeited, changed, or destroyed. Blockchain provides the opportunity to streamline stakeholder relationships, shortening timelines for capturing data, and provides a secure foundation for increased automation. BESTA is an extension of ongoing MITRE permissioned blockchain research and prototypes, including capturing orbital element sets from space sensors. BESTA is based on open source technology, and proposed as an internationally governed effort, usable by all stakeholders.

BESTA provides SSA, based on space object position data input from space sensors owned and operated by contributing nations and commercial interests. SSA data is recorded on the BESTA blockchain which is resilient to attacks and tamper

‡ *All of these outcomes may be supported and analyzed via BESTA, see section 5.1*

§ *Deep Transitions = long-term, connected, radical system shifts in the same direction. -Schot [20]*

** *While ISRA is scoped to focus on Space related treaties, this same DLT system may be used for automated discovery of anomalous behavior for any international treaty or convention, in support of treaty compliance and enforcement efforts.*

evident via native blockchain cryptographic functions. Contributing nations own and operate BESTA blockchain nodes providing a large diversity of operating and political environments, ensuring that BESTA will continue to operate in the event of loss of nodes or malicious nodes. All BESTA nodes operate in a peer-to-peer manner, which prevents any node from imposing their will upon other nodes.

BESTA is informed with SSA position data from contributing countries and commercial interests. In addition, BESTA supports international governance bodies by securely recording critical shared agreements that support STM implemented as processes and blockchain smart contracts (e.g. conjunction alerts). Further, BESTA captures the governing agreements by pairing blockchain technology with decentralized file systems to securely store documents such as policy and regulation, protected against tampering and deletion.

BESTA assumes an architectural context, managed by the governing body to prioritize activities to reach shared agreements. Once agreements are reached, the documents and shared agreements are recorded in the blockchain and decentralized file system. The corpus of recorded agreements informs the larger architecture and completes the cycle of innovation.

5.2 Space Information Sharing Center

ISACs are sector-specific, member-driven organizations stood up by the commercial sector, with international support, to collect, analyze, and disseminate all-hazards, actionable threat and mitigation information to asset owners, operators, and members. [16] Individual, or system level space architectures are increasingly vulnerable to threats of an electronic and cyber nature. Space ISAC members share information about potential security threats. That data is analyzed and the ISAC then shares the resultant information through a secure portal so companies can figure out how to combat those threats as they develop and build new satellites or other space systems. ISRA is ostensibly well suited to serve as an enabling framework to support the Space ISAC efforts.

Acknowledgements

American University School of Public Affairs, Johns Hopkins University, Paul H. Nitze School of Advanced International Studies (SAIS), The MITRE Corporation, U.S. Office of the Assistant Secretary of Defense Networks and Information Integration (OASD/NII), Department of Defense Chief Information Officer “Reference Architecture Description”, in general.

Appendix A Full size ISRA Metamodel

See separate enclosure for Appendix A.

References

List of references

[1] Alver, J.G. Gleason, M.P (2018) SPACE POLICY PRIMER Key Concepts, Issues, and Actors The Aerospace Corporation & The Center for Space Policy and Strategy

[2] Berger, Jennifer Garvey. Simple Habits for Complex Times: Powerful Practices for Leaders (p. 14). Stanford University Press.

[3] Teehan. R, Col. (2019), Enterprise Planning is Key to Space Resiliency, SMC Official Says, Air Force Magazine

[4] Stilwell, R., Dr. (2019) Decentralized Space Traffic Management, Space Policy Institute George Washington University

[5] Reed, H, Dailey, N., Carden, B. (2019) Blockchain Enabled Space Traffic Awareness (BESTA), The MITRE Corporation. Public Release Case Number 19-0631

[6] White House, (2018) Presidential Memoranda: Space Policy Directive-3, National Space Traffic Management Policy

[7] Bardach, E. (2012) A Practical Guide for Policy Analysis: The Eightfold Path to More Effective Problem Solving, 4th Edition pp. 31-33

[8] Pace, S. (2011) Toward a Theory of Spacepower, Chapter 7: Merchant and Guardian Challenges in the Exercise of Spacepower

[9] I am indebted to Dr. Karen Baehler of American University, School of Public Affairs. This discussion is drawn from my discussions with university faculty.

[10] U.S. Departments of State and Commerce Inaugural Space Enterprise Summit June 26-27 2019

[11] Lal, B. (2018) Reshaping Space Policies to Meet Global Trends, Institute for Defense Analysis

[12] R. Azari, (2015) Global Trends in Space Vol 1-2, IDA Paper P-5242

[13] Cusick, B. (2019) JHU SAIS 660.890 Anthropology for Strategists

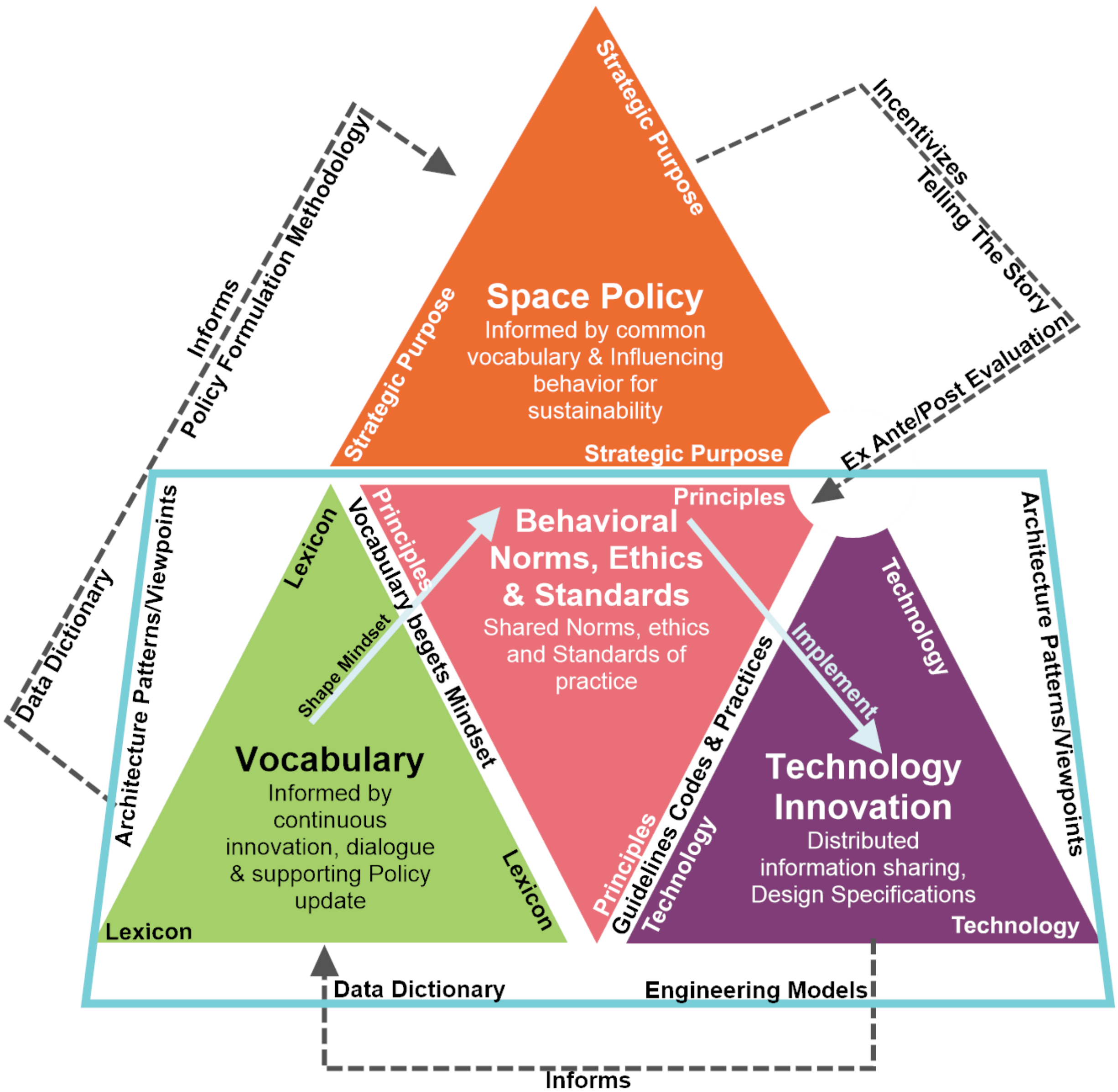
[14] Sheetz, M. (2018) Space companies received $3.9 billion in private investment during ‘the year of commercial launch’: Report CNBC News

[15] I am indebted to Dr. Scott Bernard teachings at Carnegie Mellon University’s Enterprise Architecture certification courses.

[16] (2019) Space ISAC and National Cybersecurity Center Announce MITRE Will Be an ISAC Founding Member, Dark Reading

[17] (2018) Implementation of Cybersecurity for Commercial Space Systems Used to Support National Security Missions, Memorandum for the Commander, Air Force Space Command
[18] I am indebted to MITRE colleagues, and forum discussions for this theme.
[19] UNOOSA (2019) European Global Navigation Satellite System and Copernicus: Supporting the Sustainable Development Goals
[20] Schot, J, Steinmueller, E. (2018) Three frames for innovation policy: R&D, systems of innovation and transformative change, Science Policy Research Unit (SPRU), University of Sussex, UK

Enclosure I Appendix A:



International Space Reference Architecture (ISRA) Metamodel