GAME CHANGER | MARCH 2020

BLOCKCHAIN IN THE SPACE SECTOR

Karen L. Jones

Blockchain, the technology that underpins cryptocurrency, offers businesses and governments the means to decentralize intermediaries and conduct peer-to-peer transactions using a distributed ledger and secure immutable records. The general press continues to spotlight blockchain and how it will revolutionize the business enterprise. Blockchain for space systems may offer compelling advantages by reducing complexity across a range of business, operational, and security applications. This paper offers a framework to assess the utility of blockchain for the needs of space business. The more transformative the change, the longer the time to integrate into the space business ecosystem and regulatory structures.

As blockchain, or the more general term, *distributed ledger technology* (DLT), gains traction in various applications in the space sector, many centralized third-party trust organizations focused on financial, legal, security, and logistical oversight functions will likely consider adapting their operating models to gain some of the advantages and value that DLT offers. This paper examines blockchain and distributed ledger technologies and their relevance in the space sector and describes the potential for a gradual adoption trend over the next few decades.

Blockchain Applications in the Space Sector
Blockchain can touch almost any aspect of the space sector. Other industries, such as finance, manufacturing, and communications, are leading blockchain innovation and adoption. The space sector will follow and adopt after these leading industries demonstrate progress and benefits.

Strengths	Weaknesses
• Now moving beyond the hype bubble, demonstrating practical applications • Decentralized—no single person or entity controls the digital ledger • Single source of truth, ensuring transparency, tracks provenance • Efficient—can eliminate the need for intermediaries • Immutability ensures trusted source • High potential to automate, decentralize, and democratize operations	• Obtaining consensus on how to implement blockchain to work together will be challenging • Difficult to replace entrenched and institutional centralized incumbents • Limitations are around performance and scalability • Lack of privacy • Still susceptible to security vulnerabilities

Introduction

> ***"Blockchain technologies have the power to disrupt many industries. To avoid missed opportunities and undesirable surprises, organizations should start investigating whether or not a blockchain can help them."[1]***
>
> *— National Institute of Standards and Technology*

Blockchain, or the more general term, *distributed ledger technology* (DLT), is gaining traction across various industries outside the space sector. Space stakeholders now have an opportunity to import lessons learned from other industries. A healthy dose of skepticism is needed when considering adoption of a technology that has received significant media attention, and sometimes hype, over the past decade. However, asking the right questions early can go a long way toward deciding whether DLT is appropriate. Key questions should include:

- How can we make this technology work for us?
- What applications appear most promising?
- Is DLT appropriate to use? If so, when?

Some space stakeholders are already testing the blockchain waters. This paper will examine these DLT demonstrations and implementations across the space value chain, including fundraising, smart contracts, supply chain management, networking and communications, identification management, traffic management and regulation, and intellectual property and licensing.

Blockchain Background

Blockchain technology was introduced during 2008 when an anonymous person going by the name Satoshi Nakamoto released the paper "Bitcoin: A Peer-to-Peer Electronic Cash System." Although the identity of Nakamoto has never been revealed, the public debut of the Bitcoin paper spawned a revolution in digital trust applications. Today, Bitcoin and other cryptocurrencies represent just one of many practical applications for digital trust solutions involving consensus-based protocols. This is a *foundational* capability and holds transformative power across many industrial sectors, including space.

Unlike disruptive technologies, foundational technologies (classic examples are electricity or TCP/IP protocol) exert influence gradually. Foundational technologies must first overcome technological, organizational, regulatory, and political barriers.

Most of today's space sector blockchain implementations are conceptual or nascent. A Boston Consulting Group survey conducted jointly with the Aerospace Industries Association confirms that blockchain is in the early stages in the aerospace and defense industry. According to the survey, only 20 percent of respondents indicated that their firms are assessing blockchain in a meaningful way, half were unsure what their companies were doing about blockchain, and the remaining 30 percent said that their companies were not pursuing the technology.[2]

What Is Blockchain?

> ***Blockchain-related lexicon has grown and continues to change rapidly. Many terms are overlapping, which can increase general confusion.***

Blockchain is a subset or type of DLT that includes cryptographically linked "blocks" (e.g., a list of transactions) and a "chain" where each block is time-stamped and placed in chronological order. Figure 1 provides a general diagram for how DLT and a more specific implementation or "blockchain" work.

This paper focuses on DLT as it is less specific and more applicable to the space sector. DLT is a distributed digital database in which transactions and their details are recorded in multiple places at the same time, without a central database or administrator. Underlying DLT are the following key elements:

- ***Distributed database.*** Every node on the network maintains its own copy of the transaction data and other data on the "block," and each node updates when someone submits a new transaction.
- ***Peer-to-peer transmission.*** There is no central point of storage, such as a server. Instead, information is recorded and interchanged between participants (or nodes) on the network.

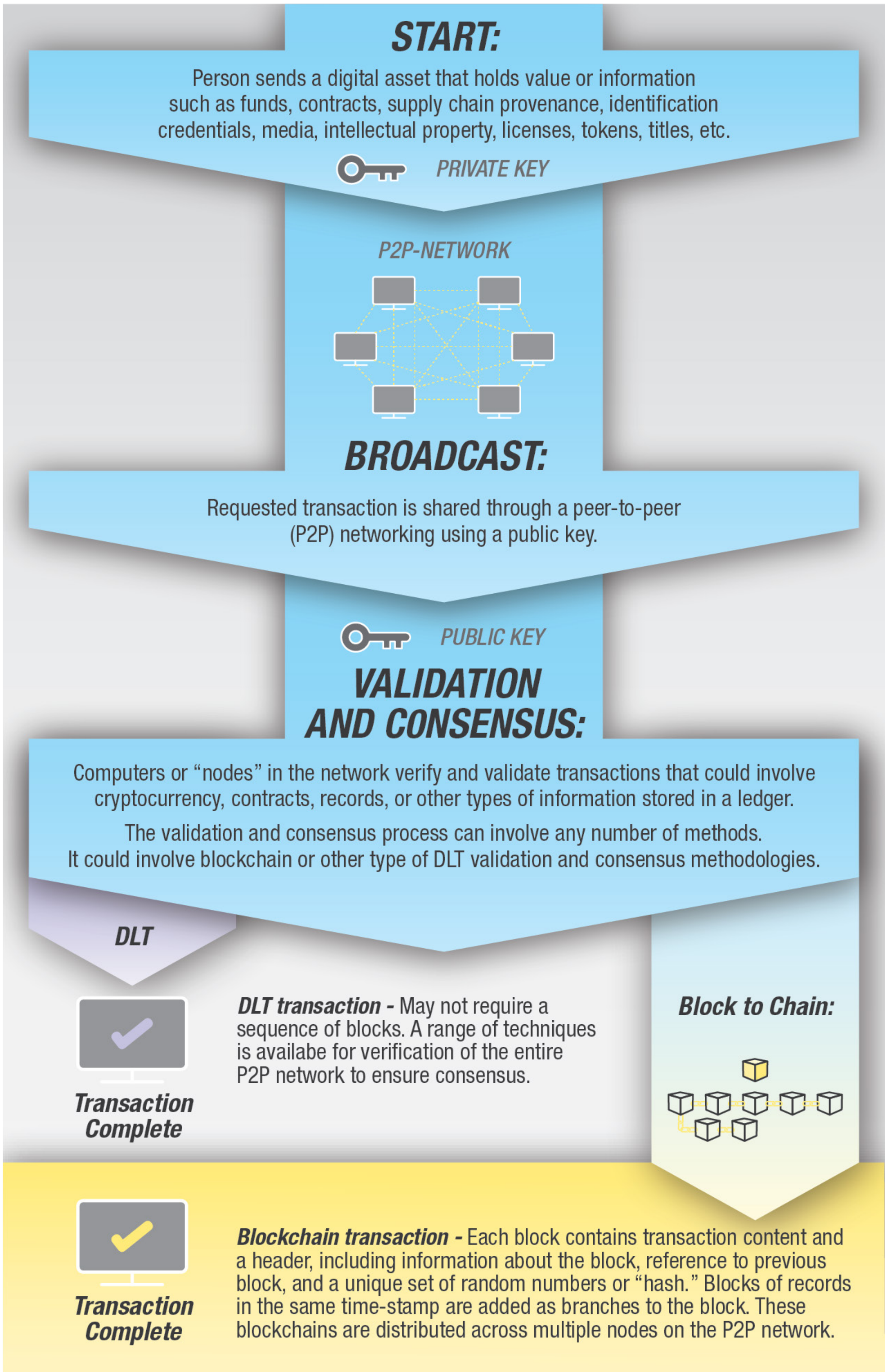

Figure 1: Blockchain and DLT – How do they work and how are they different? *A typical DLT transaction may not involve blockchain. However, there are some types of DLT implementations that store transaction content on "blocks." This type of transaction (lower half of Figure 1) is referred to as* blockchain transactions.

- ***Trust.*** A new record's authenticity can be verified by the entire community.
- ***Transparency.*** Transaction history is available to those with ledger permissions.
- ***Immutable records.*** Any one person is prevented from altering the legitimacy of the information; changes are verified through a peer-to-peer (P2P) network to achieve consensus.
- ***Embedded logic.*** Enables process automation; algorithms and rules automatically trigger transactions between nodes.

Both DLT and blockchain are distributed databases that seek to achieve consensus efficiently and without the use of a centralized authority.

DLTs—Different Types of Permissions and Access

As space sector participants consider whether DLT is suitable for a business or a regulatory application, various strategic questions can provide a framework for determining whether DLT is a suitable option to pursue. Answers to these questions will determine whether a space sector participant should consider DLT and whether the DLT application should be closed or open (see Figure 2). There are three types of DLTs:

1. ***Open Participation/Open Ledger.*** This is the most open DLT and any user can manage the ledger. Bitcoin and Ethereum are two prominent examples. Nodes on the blockchain network apply some type of consensus model,* which allows mutually distrusting users to work together.

2. ***Open Participation/Permissioned Ledger.*** For permissioned ledgers, nodes need permission from a central entity to access the network and make changes to the ledger. Ripple, created for banks and payment networks, is an example of an open permissioned or "trusted" ledger that acts as a transaction validator. The main idea of Ripple was to create a system of direct asset transfers in realtime that would be cheaper and more transparent.[3] Another example of permissioned DLT is Sovrin, managed by the Sovrin Foundation (Salt Lake City, Utah), which claims to be a new open source standard for digital identity and a decentralized global public network. The Sovrin Network is operated by independent stewards (rather than open permissions) and "uses the power of a distributed ledger to give every person, organization, and thing the ability to own and control their own permanent digital identity."[4]

3. ***Closed Participation/Permissioned Ledger.*** A closed DLT controls both who participates and who maintains the ledger. A closed ecosystem requires that participants have permission to access that DLT. The owner group maintains a private ledger. This type of system might include a consortium or private enterprise that restricts access to an authorized set of participants. A closed or permissioned ledger is accessible only to members (e.g., of the consortium) or different divisions or subsidiaries (e.g., of the enterprise).

Private or permissioned digital ledgers are already the dominant DLT-based solution within the automotive, aerospace, and aviation market, where the primary beneficiaries operate within highly connected ecosystems seeking increased security and efficiency advantages. Beyond fundraising applications, the space industrial base will most likely adopt permissioned DLT due to unique space sector concerns such as security, export control, and the need to protect proprietary information.

Drivers and Benefits

Need for Consensus and Security: Replacing Centralized Trusted Authorities. A DLT implementation is designed to disintermediate or replace existing trusted and centralized authorities with a new model for decentralized authentication with speed, cost, and security benefits. Over the next several years, it is reasonable to expect that DLT will cut out the intermediary in many industries. In fact, cryptocurrencies

* While new consensus models continue to emerge, two common consensus models are (1) "proof of work," which involves solving an advanced math problem and getting credit for adding a verified block to the blockchain, and (2) "proof of stake," where a miner puts up a stake or locks up an amount of coins to verify a block of transactions. For more information, visit https://blockgeeks.com/guides/proof-of-work-vs-proof-of-stake/.

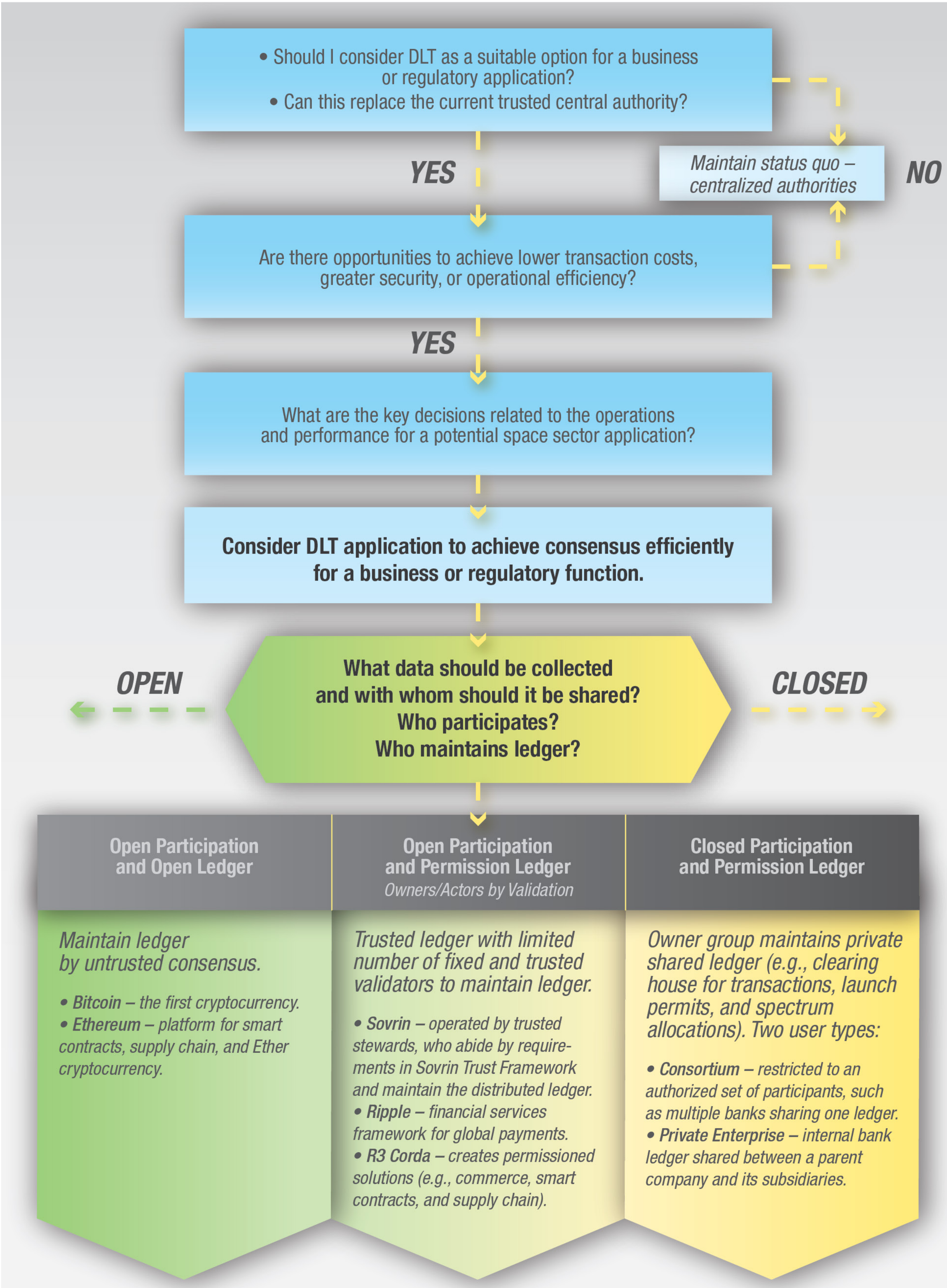

Figure 2: DLT can be initially categorized by who can participate and how the ledger is maintained.

are already thriving and propagating without any central bank authority. Any entity who is currently playing a role as a third-party ledger manager, guarantor, or trusted authority should view DLT as a potential disruptor of its own position.

DLT Benefits for the Space Sector. All space sector DLT applications discussed in the following section seek one or more of the following benefits:

- ***Transparency.*** DLTs can be set up openly or privately. Open ledgers (Figure 2, left side) allow anyone to review transaction history without special permission. By contrast, closed or permissioned ledgers still allow for a degree of transparency and accountability within a group or enterprise.
- ***Efficiency.*** DLT technology can automate and improve business processes and organizational efficiencies (e.g., self-executing contracts).
- ***Privacy and Access.*** Privacy and permissioned access are facilitated by combining cryptography and data decentralization.
- ***Resilience.*** DLTs can increase the resilience of communities and ecosystems. Embedded peer-to-peer smart contracts, for instance, do not need to go through a centralized authorization or distribution center. Instead, there are multiple nodes and no single point of failure.
- ***New Products and Services.*** Decentralizing traditional models can create new cooperative business models. It remains to be seen what might emerge in the space sector since most efforts are in concept or demonstration phase. Etherisk (Switzerland) has established a blockchain-based insurance protocol to build new decentralized insurance products. Perhaps satellite underwriters could adopt this new model. As discussed below, new business models could include transitioning single operator satellites into "multi-tenant satellites" or leveraging open source networking standards and DLT to share resources such as ground station networks.

Space Sector Applications

This section explores the various application areas where digital trust solutions offer the potential for advancement throughout various parts of the space value chain, including concept and design, acquisition, manufacturing, assembly, operations, and related user applications. Similar to other industries, space sector DLT can be applied across the entire value chain (see Figure 3).

While this paper focuses primarily on business applications, there are plenty of possibilities where DLT could support regulatory functions. The federal government has taken notice of DLT's potential and has introduced pilot projects for employee digital records, asset management, supply chain, procurement applications, and monitoring the provenance of medical products. For example, the U.S. Office of Personnel Management is using a prototype DLT for retired employee digital records.[5] As another example, the Food and Drug Administration noted in its document, "Sentinel System Five-Year Strategy 2019-2023," that DLT may allow patients "to permit access to their personal health data while maintaining their privacy." The FDA noted that it will carefully assess DLT's potential benefits, including efficiency gains and new capabilities.[6]

The seven value chain functions shown in Figure 3 are profiled below.

1 – Financing New Ventures. The introduction of Indiegogo (2008), Kickstarter (2009), Crowdfunder (2010), and other "crowdfunding" internet-based ventures have threatened to eliminate the intermediary or traditional fundraisers and venture capitalists. Internet-based crowdfunding startups have demonstrated impressive yields. According to Fundly, a site that tracks crowdfunding statistics, over $34 billion was raised by crowdfunding during 2017.[7] However, Internet-based crowdsourcing ventures can still also introduce new costs. Crowdfunding application providers typically charge a 5 percent platform fee and a 3 percent credit card transaction fee. Unlike a DLT, crowdfunding sites are centralized as an application hosted online, and, typically, a central party manages and operates the site.

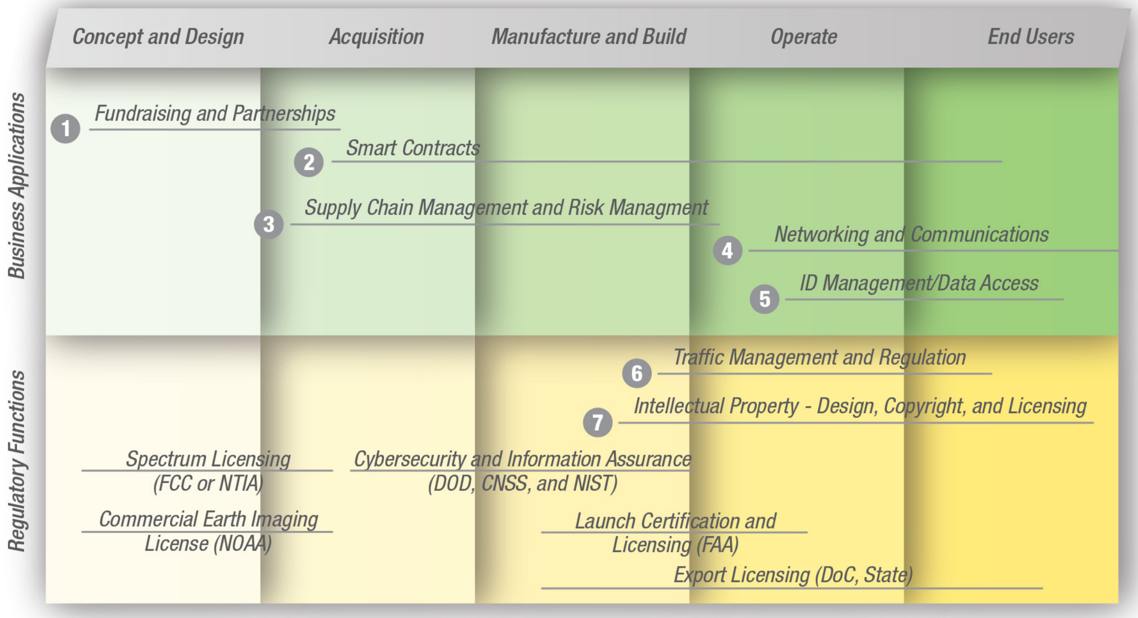

Figure 3: Potential DLT applications across the space value chain. *This chart outlines business applications across five value chain phases and key players.*

Fundraising in the form of cryptocurrency "tokens" now competes with Internet crowdsourcing, even though crowdsourcing is relatively new and still considered disruptive. DLT can introduce greater efficiencies. The Ethereum blockchain platform, for instance, has introduced a platform called "Acorn," which seeks to create an open global community and marketplace for crowdfunding. The platform incorporates a peer-to-peer "smart contract" based upon a governance structure and service, like cryptocurrencies, that can overcome geographic, political, and economic barriers.

With the advent of blockchain, the crowdfunding landscape changes. Both initial coin offerings (ICOs) and security token offerings (STOs) are proven methods for blockchain-enabled fundraising whereby a crypto coin represents an investment. Are venture capitalists concerned? Hardly. Instead they are embracing the new technology and introducing decentralized DLT-based "crypto-funds." That said, financing new ventures through ICOs or STOs[†] may not always be the best application for DLT. The Harvard Business Review notes that ICOs can introduce some negative unintended consequences. During the early stages, benefits to the venture founders are mixed because an ICO gives decision control to the community for "speed, focus, and collaborative effort."[8] This reduces flexibility and decisionmaking. If a space startup venture considers using an ICO for early fundraising, it should also consider the merits of starting with a "centralized" governance structure to encourage agile decisionmaking and to protect confidentiality (e.g., business plans and proprietary information). Later, after the project gains traction and demonstrates success, exposure to a larger investment community makes sense, when the business proposal is mature and ready to be reviewed and governed in a more decentralized manner.

Space Decentral. Space Decentral is one example of fundraising using DLT. This self-described "decentralized autonomous organization" uses blockchain to "reinvigorate the push for space exploration with the public in control."[9] Space Decentral intends to design space missions collaboratively, share research for peer review, crowdsource citizen science efforts, and crowdfund projects that lack national budgets. Space Decentral plans to use blockchain technology to coordinate workflows and business logic and use self-executing smart contracts and tokens. While Space

[†] STOs come with an underlying security or investment such as a stock, bond, or fund. While ICOs can often circumvent the Securities and Exchange Commission (SEC) regulatory process, STOs are launched with an expectation for regulatory governance.

Decentral's progress at this point has not stretched beyond building a community of interest and a draft white paper, its strategy is worthy of mention as it seeks to broaden the participation and investment in the space industry to include private citizens, entrepreneurs, space enthusiasts, and the public at large.

2 – Smart Contracts. Smart contracts, or self-executing contracts, digitally facilitate, verify, or enforce the negotiation or performance of a contract. They rely on a set of if-then statements that automatically trigger events when certain conditions are met. During the past few years, smart contracts have received quite a bit of hype and, more recently, increased skepticism. Ideally, smart contracts enforce contract terms automatically, without bias and without a centralized trusted authority. Embedded computer code evaluates and executes smart contracts. This "trustless execution" removes the middleman (e.g., lawyers or brokers). There are limitations to the use of smart contracts. A rule-based contract cannot interpret legal intent or spirit of the law. Instead, it is constrained by if-then logic. A smart contract is further constrained by the boundaries of the database in which the smart contract resides. Smart contracts rely on external information or "oracles." External data from oracles feeds the smart contract, which can trigger predefined actions of the smart contract. The main challenge with oracles is that people need to trust these outside sources of information, whether they come from a website or a sensor. Shermin Voshmgir, author of the Token Economy, notes that since "oracles are third-party services that are not part of the blockchain consensus mechanism, they are not subject to the underlying security mechanisms that this public infrastructure provides. One could replicate 'man-in-the-middle attacks' standing between contracts and oracles."[10] Or perhaps the oracle data feed is unintentionally inaccurate. Intentional or not, an understanding of these risks is important before deciding that a smart contract is the best solution.

Given the complexity of participants involved in space, from launch to orbit, and the number of stakeholders who must monitor their vested equities, it is reasonable to expect that the space sector presents many opportunities to use smart contracts. Prototypes, pilot projects, and testing could help to identify and mitigate various risks associated with smart contract applications. Below are two examples:

a. ***European Space Agency – Space 4.0.*** The European Space Agency (ESA) is looking at how space will evolve with a diverse and complex set of actors, including commercial space companies, academia, the private sector, citizens, and various countries. The World Economic Forum's "Fourth Industrial Revolution" model describes the planet's future in terms of "fusing the physical, digital and biological worlds, impacting all disciplines, economies and industries, and even challenging ideas about what it means to be human."[11] ESA has established an analogous framework for space called *Space 4.0*, which represents the complex and automated interactions between governments, private sector, society, and politics. ESA focuses on "administrative" DLT applications for accurate payments, procurement, supplier agreements, and automated smart contracts.[12] ESA envisions a sustainable space sector closely connected with the fabric of society and global economy, and DLT could become an enabling technology to support this vision.[13]

b. ***NASA "SensorWeb" and the Internet of Things (IOT) in Space.*** NASA is looking to use smart contracts on the Ethereum blockchain in the agency's SensorWeb program. The main objective of the program is to create an interoperable environment for a diverse set of satellite sensors via the use of software and the Internet (see Figure 4).[14] NASA's SensorWeb application is really a demonstration of how blockchain based smart contracts can be used to enable applications to interact with hardware devices. Smart contracts can describe the capabilities of a thing—in this case, NASA's distributed sensors.

3 – Supply Chain Applications. A DLT integrated supply chain network for space systems offers compelling advantages, including a forensic audit trail and a single source of truth. There is rising global concern about the provenance of goods, particularly for food and medicine.

According to George Mason's Mercatus Center, "Provenance tracking works by using digital tokens issued by blockchain participants to authenticate the movement of the good. Every time the item changes hands, the digital

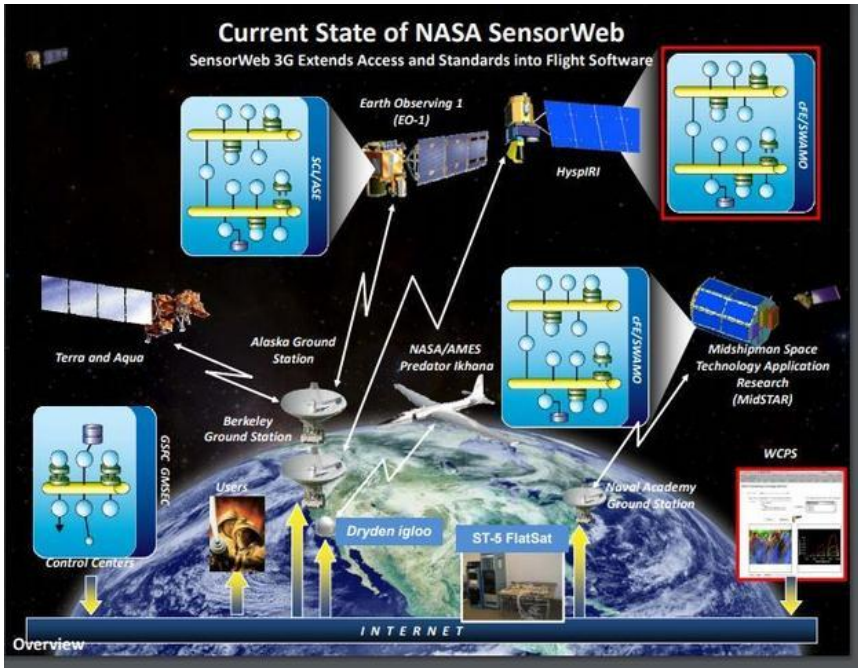

Figure 4: NASA SensorWeb—an interoperable environment for a diverse set of satellite sensors.
(Source: NASA website – Goddard Space Flight Center)

token is moved in lockstep. In other words, the real-world chain of custody is mirrored by a chain of transactions recorded in the blockchain."[15] Moreover, the supply chain data is encrypted and sealed, which makes it very difficult to alter. In addition, digital transactions on the blockchain can be easily audited and various risks can be monitored, such as the hazards posed by used or counterfeit parts.

Using blockchain to track the origins of raw materials and to follow domestic and international supply chains can meet this increasing demand for information with levels of transparency and accuracy not previously attainable. Tracking the origins of raw materials can also help companies improve their own internal processes.

Supply Chain Management. IBM's global vice president of Blockchain Solutions, Eric Piscini, noted that DLT applications for the supply chain are "pretty mature in the food and drug industries and the opportunity to reuse the assets from them to build the supply chain for space instead of starting from scratch would certainly be an advantage." For instance, Food Trust establishes visibility and accountability in the food supply chain—from growers to processors and distributors and, finally, to retailers. Piscini cited another example: TradeLens, a supply chain platform underpinned by DLT that was jointly developed by IBM and Maersk GTD is an integrated transport and logistics company and leading ocean transportation carrier,[16] which interconnects an ecosystem of supply chain partners, such as cargo owners, ocean and inland carriers, freight forwarders and logistics providers, ports and terminals, and customs authorities.

As the space industry becomes increasingly global and interconnected, a DLT-enabled digital platform can help to foster collaboration, trust, and cross-organizational automation, stretching beyond one company's tracking or enterprise system to include all supply chain participants, from cradle to grave, including raw materials, parts, components, and systems. For example, if a counterfeit part is discovered on a satellite bus, perhaps years after deployment in space, the satellite prime contractor could use the DLT record system to trace back the part to the source. Other DLT supply chain participants could also receive alerts and determine whether they, too, have used this part.

A cradle-to-grave approach can solve several supply chain concerns for the space industry as various participants can share technical information about parts and materials, including:

- Detection of cyber threats.
- Managing accurate inventory levels.
- Responding to product recalls in a timely manner.
- Detection of parts and components fraud (e.g., counterfeit parts).

It is still unclear who the DLT pioneers will be for space systems. However, some companies that are involved in both aviation and space, such as Boeing and Airbus, are already making progress. Boeing, for instance, has embarked upon an ambitious plan to digitize its aviation supply chain, which extends to more than 50 states and 140 countries. Boeing spends more than $43 billion buying more than 1 billion parts per year. Three million parts arrive at Boeing facilities every day from 5,400 suppliers.[17] Also technology venture startups have emerged that aim to focus on the aerospace parts industry, including, for example:

- VeriTX (Toronto, Canada), partnering with Northern Block, a blockchain consulting firm, to develop a DLT platform to manage aerospace parts networks for both commercial and military customers.
- Parts Pedigree Ltd. (UK), partnering with Pattonair (UK) and parts machining specialist Advanced Manufacturing Ltd. (UK), is working to create a digital cloud-based service using DLT to notarize, track, and view aviation parts and paperwork throughout the supply chain.[18]

Off-the-Shelf (OTS) Quality Control. The space sector is currently moving toward missions of shorter durations (five years or less) and production of greater numbers of satellites quickly in support of large low Earth orbit (LEO) constellations and small satellite swarms. Builders of smaller, lower cost, and short duration satellites are looking at off-the-shelf (OTS) parts as a means to gain competitive advantages to produce greater numbers of satellites quickly.[19] As the space sector expands its use of OTS, it is conceivable that DLT applications for supply chain management and supply chain risk management will become increasingly critical and perhaps a competitive discriminator within the commercial space sector.

Supply Chain Risk Management. Supply chain risk is the vulnerability that an adversary may sabotage, maliciously introduce an unwanted function, or otherwise compromise the design, integrity, manufacturing, production, distribution, installation, operation, or maintenance of a system. From a supply chain risk management (SCRM) perspective, the Department of Defense inspector general (DoD-IG) identifies the need to "improve the accuracy of the requests for supplier threat assessments and require the prioritization of the critical components on the requests and the inclusion of all key information needed…to conduct the assessments."[20]

Recognizing the DOD posture toward SCRM, a recent Aerospace report noted that blockchain mediation represents a superior technological and process solution toward mitigation and recommends that the Air Force and DoD continue to build expertise in blockchain technology and other SCRM mitigation approaches.[21]

4 – Networking and Communications. DLT presents many opportunities for the space sector to coordinate space-based data across sensors and missions. NASA and the commercial sector are exploring how to combine artificial intelligence, DLT, spacecraft, and sensors to efficiently manage space-based infrastructure and missions. A few examples are discussed below.

Deep Space Networking and Computing: Basic Research. NASA recently provided $300,000 grant funding for a research project named the "Resilient Networking and Computing Paradigm," led by Dr. Jin Wei-Kocsis of University of Akron's Department of Electrical and Computer Engineering. Dr. Wei-Kocsis indicated that the long-term goal is to "achieve scalable decentralized cognitive networks in deep space."

Thomas Kacpura, Advanced Communications program manager at NASA Glenn Research Center,[22] noted that "blockchain is one possible engine that can drive cognitive outcomes for autonomous operations. We are currently examining enabling technologies for trusted autonomous operations in space and looking to develop a simple representative distributed system which will emulate how far apart nodes in deep space can work as a distributed blockchain to ensure trusted autonomous operations." The idea is to decentralize NASA's future network of nodes in deep space to allow for a more resilient and responsive network. This research project could lead to decentralized processing among NASA's space network nodes.

Network of Blockchain Nodes in Space: SpaceChain. SpaceChain UK has created smart hardware that can be installed onto satellites with the SpaceChain operating system (OS). The first satellite blockchain node was launched into space on February 2, 2018. In March 2018, SpaceChain completed and integrated Qtum, an open sourced blockchain application platform on the SpaceChain OS. By September 2018, SpaceChain completed partnerships with more than 10 space and blockchain companies.[23] The universal space OS "converts single-operator satellites into multi-tenant ones, while the blockchain provides a highly secure sandbox between multiple space applications. That way, users will be able to develop different types of space-based applications on a single satellite, maximizing the efficiency from this expensive resource."[24] SpaceChain aims to establish a community incentive model using tokens that act like tickets to upload and execute space-based applications and store data onto the SpaceChain network. Recently SpaceChain created and launched a Bitcoin multisignature payload or "wallet" to the International Space Station. This payload intends to demonstrate new levels of cybersecurity for transactions in low Earth orbit.

Open Source Networking Standard for Ground-to-Space Communications: EtherSat. EtherSat, Inc. (San Jose, California) is developing an open source networking standard for ground-to-space communications to make communication with spacecraft more efficient. The proposed blockchain-enabled satellite communications network aims to improve utilization of existing ground station networks to save new space companies considerable capital investment and deployment time.

5 – Identification Management (IdM). During the first half of 2019, 4.1 billion records were compromised from security incidents. Compared to midyear 2018, exposed records were up 52 percent across various industries.[25] These damaging and costly security breaches are, in part, a consequence of the Internet being developed without a true identity layer. To address this infrastructure flaw, a consortium called the Decentralized Identity Foundation (DIF), a 503c standards organization, seeks to define the "foundational elements necessary to establish an open ecosystem for centralized identity and to ensure interoperability between participants" using DLT.[26] Two types of IdM have emerged in two categories[27]:

a. ***Self-Sovereign Identity.*** Here, the identity is controlled by the owner. Examples include Sovrin, uPort, and OneName. The Sovrin Network, for instance, is an open-source decentralized identity network built on permissioned DLT. The validators or nodes could be banks, academic institutions, or another trusted institution. Sovrin adds the missing identity layer to the Internet and provides a complete approach to identity from the distributed ledger to the device, making secure and private self-sovereign digital identity possible for the first time in history.

b. ***Decentralized Trusted Identity.*** Decentralized trusted identity provides a proprietary service that performs identity proofing of users based on existing trusted credentials (such as a driver's license or passport) and records identity validation by DLT. ShoCard, for instance, is a mobile-identity platform using biometrics for authentication. ShoCard integrates biometric recognition technology and DLT-based data.

How will the space sector adopt IdM enabled by DLT? It might not be that different from other institutions. For example, NASA may want to adopt this type of technology for better identification and authentication of its employees. The commercial satellite industry may apply this technology to ensure that its networks of users are legitimate customers. The space sector is currently experiencing increased integration across infrastructure, networks, and cloud analytics. The ecosystem of cooperative partnerships and players is expanding horizontally. As more companies emerge from their vertical silos, increased identification management will be necessary.

6 – Intellectual Property Rights Management for Design, Copyrights, and Data Licensing. Transfers of intellectual property do not necessarily require government registration to be effective. Yet, if enforcement action is necessary, it is difficult to prove the transfer (e.g., assignor, assignee, and transfer date). DLT could address this challenge by creating an immutable record involving the intellectual property, including records from the original owner and the complete chain of ownership. The U.S. legal system, the United States Patent and Trademark Office (USPTO), and other intellectual property rights organizations could consider DLT a form of indisputable evidence for property rights. In fact, it appears that the country of Iran might be the first to adopt DLT for copyright protection.[28]

In addition to government registration of intellectual property, blockchain technology could be used to "tokenize" digital rights. Digital tokens could be bought and stored in a digital wallet with a software license encoded, referred to as Token-as-a-License (TaaL).[29] A TaaL could be used to simplify the distribution of satellite generated data, analytics, or imagery, essentially removing data brokers or middlemen from the transaction. These tokens, representing licenses for the use of satellite data, products, and services could be customized to fit the needs of the business and would work like a smart contract.

7 – Traffic Management and Regulation. Recognizing the practical benefits of blockchain for the civil transportation sector, trucking companies are joining the Blockchain in Transport Alliance (BiTA), "the largest commercial blockchain alliance in the world, with nearly 500 members in over 25 countries."[30] BiTA develops industry standards to use distributed ledgers to improve operations, including logistics and supply chain tracking. Beyond supply chain and logistics solutions, the transportation industry is also looking to address the future needs of the autonomous vehicle market.

In May 2018, the Mobility Open Blockchain Initiative (MOBI) launched a venture with more than 30 companies (e.g., BMW, General Motors [GM], Ford, and Renault) to establish a MOBI vehicle standard that creates a distributed ledger for vehicle identification numbers (VINs). This project stretches beyond VIN registry and acts as an electronic wallet and identifier for communicating with various networks and paying tolls. VIN information would include vehicle identity, ownership, warranties, and current mileage. Both GM and IBM are filing a significant number of patents to address blockchain-powered solutions for transportation management and the future autonomous vehicle market.[31]

Space Sustainability and Traffic Management: ConsenSys Space TruSat. While the civilian trucking industry is making progress to address traffic management and regulation through blockchain-based solutions, the space sector is not sitting idle. In October 2019, ConsenSys Space, an Ethereum Venture Lab, introduced TruSat as an experimental open-source and open-sensor system for creating a trusted distributed ledger of satellite orbital positions. [32] With an eye toward improving space sustainability, the application is designed to track space debris. TruSat's app-based system, which uses Ethereum blockchain solutions, is designed for "citizen space" observers. The idea is to address a gap in the emerging space sustainability ecosystem by providing a widely trusted source of data for assessing orbital operations. ConsenSys Space's October 2019 press release notes that "data controlled by a single government is not well-suited for independent assessment of space sustainability practices, whose legitimacy rests on trust by a multinational set of stakeholders." A distributed ledger controlled by multiple stakeholders essentially removes any bias that could potentially be created by centralizing any single source. To this end, TruSat strategically places its data beyond the control or bias of any one company or country.

Whether the quality and accuracy of crowdsourced celestial observations is adequate remains to be seen. However, the general model provides an additional source of satellite location data since satellite operators do not have appropriate incentive to self-report nonconforming orbital behavior.[33] Consensys Space's business model also embraces the involvement of citizen scientists. According to Bianca Vasquez, founder of Society of Women in Space Exploration, observing satellites requires rural locations where light pollution is lower. This in turns creates opportunities for new "citizen scientists" to participate in the space industry.

Space Sector Application Summary

Figure 5 summarizes the various DLT applications in the space sector and general industry. Non-space DLT applications are maturing faster than space applications. Within the space sector, DLT maturity ranges from the early R&D phase (e.g., supply chain management and Internet protocol [IP] management) to a more mature growth phase such as financing new space ventures.

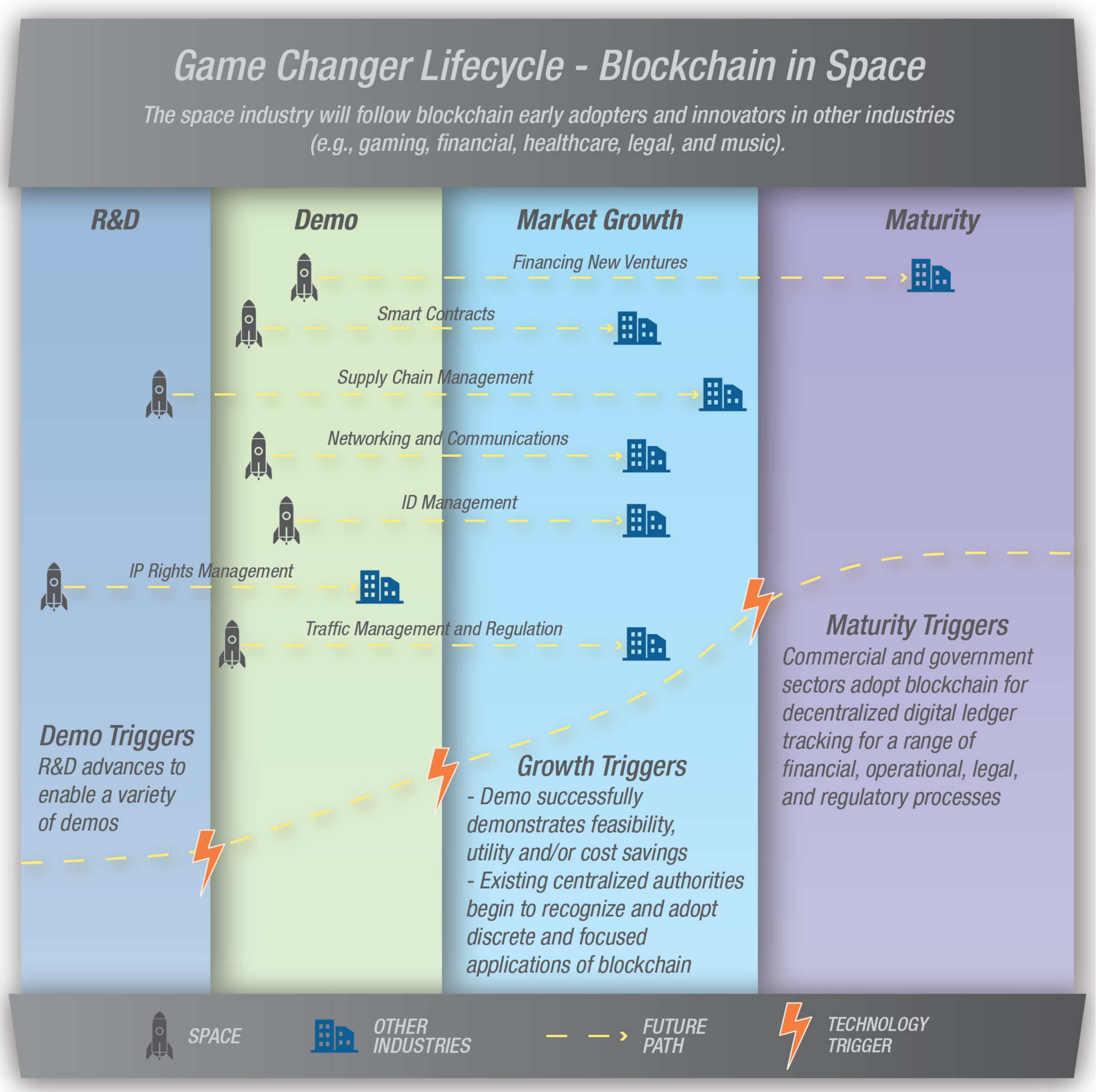

Figure 5: Lifecycle maturity curve—blockchain in space and other industries.

Conclusion: Space Industry Gradually Adopts DLT

Foundational technologies, such as DLT, require time to build and take hold.

As space stakeholders continue to consider the advantages of DLT, they should keep asking themselves fundamental questions about the potential value proposition, including:

- Under what scenarios and conditions should I rely on a trusted central authority?
- How can I leverage a consensus-based decentralized authority to achieve lower transaction costs, greater security, and efficiency for my business and regulatory operations?
- What are the key decisions related to the operations and performance for a potential space sector application (e.g., smart contracts, traffic management, IP rights)?
- Who should be making those decisions?
- What data is or should be collected to support those decisions?
- Once aggregated, with whom should the data be shared?

DLT has been described as a *foundational* technology rather than a disruptive technology.[34] Like TCP/IP, on which the internet was built, DLT will require broad coordination and "the level of complexity—technical, regulatory and social—will be unprecedented," according to the *Harvard Business Review*.[35] Unlike disruptive technology, foundational technologies establish new models, often requiring years or even decades to take hold. For example, TCP/IP gained traction slowly and it took over 30 years to replace circuit switched[‡] technology. DLT could require as much time to evolve and gain broad industry adoption.

Such a long adoption time might seem surprising given that cryptocurrencies, such as Bitcoin and Ethereum, based upon blockchain technologies, were introduced and proliferated rapidly after 2008. However, the evolution of cryptocurrencies did not require complex interactions across industry sector players. Instead, the cryptocurrency model allows anyone to participate and offers immediate utility to those who choose to trade. By contrast, the establishment of a space sector-wide DLT will require the cooperation of many commercial and government space players, and they will likely opt for additional security measures and controls. Most DLT examples discussed in this paper (smart contracts, supply chain management, IP management, networking, and ID management) are probably best suited as closed DLT systems[§] because the general public is not typically involved in these types of applications in the space sector.

DLT establishes trust through collaboration (peer-to-peer sharing) and encryption—this is a new paradigm. There is no trusted central authority. It will require time for various industries to determine whether this new type of trusted network works for them or if simpler centralized solutions might suffice. The gaming and financial industries are recognized early adopters of blockchain. Other industries ripe for blockchain transformation include healthcare, legal, music, and real estate. In addition to studying DLT market adoption in other industries, space sector participants should be aware that various organizations such as the International Telecommunication Union (ITU), the Institute of Electrical and Electronics Engineers (IEEE), and the International Organization of Standards (ISO) are beginning to create focus groups and working groups to ensure that future DLT applications are safe, secure, and reliable.[36]

It is reasonable to expect that the space sector will slowly adopt DLT—first starting with localized demonstrations and later expanding to enterprise models. Eventually, for some applications, industry-wide consensus models could emerge with DLT as the enabling technology. While there are some drivers that will push the space industry in the

‡ Circuit switching involves establishing a connection between two points using a specific path on a network for the duration of a message exchange.
§ Closed participation and/or permissioned ledger where an owner group maintains the ledger.

direction of decentralized authorities, an industry-wide collaboration requires time, initially for vetting and asking critical questions such as:

- How can we make this technology work for us?
- What applications appear most promising?
- Is DLT appropriate to use? If so, when?

If DLT still seems appropriate, DLT adopters must allocate adequate time for coordination, stakeholder involvement, legal and regulatory acceptance, and standards setting.

This paper introduces a framework to evaluate the suitability and utility of DLT for specific space business applications. To overcome any appearance of a "hammer in search of a nail," stakeholders should understand the fundamental nature of blockchain and how best to apply it. Watching other industries grapple with why and when to apply blockchain is a good starting point. Space stakeholders should also monitor DLT technology evolution and market adoption into the space value chain. If these early DLT adopters successfully demonstrate strategic advantages (such as increased efficiency, security, or resilience), fast followers will soon seek to gain the same or greater advantage. To this end, industry leaders should continue to educate themselves on the fundamental nature of DLT and collaborate and work together to identify the most suitable and valuable applications for the space sector.

References

[1] National Institute of Standards and Technology; U.S. Department of Commerce; "Blockchain Technology Overview"; January 2018.

[2] M. Aaronson , H. Caffrey , S. Won , and J. Ahlquist; Boston Consulting Group; "Getting Real About Blockchain in Aerospace and Defense"; October 2018.

[3] Ripple website; https://ripple.com/company

[4] Sovrin Foundation; https://sovrin.org/

[5] Jessie Bur; "OPM Wants New Technology for Employee Management"; Federal Times; June 5, 2018.

[6] Food and Drug Administration; "Sentinel System: Five-Year Strategy 2019-2023"; January 2019; p. A-12.

[7] Fundly; provides annual crowdfunding statistics; https://blog.fundly.com/crowdfunding-statistics/.

[8] Jeffrey Bussgang, Ramana Nanda; "The Hidden Costs of Initial Coin Offerings"; Harvard Business Review; November 2018.

[9] "Space Decentral: A Decentralized Autonomous Space Agency" Draft Version 0.9.2; https://spacedecentral.net/White_Paper.pdf.

[10] Shermin Voshmgir; "Blockchain Oracles"; www.blockchainhub.net.

[11] Klaus Schwab; World Economic Forum; "Fourth Industrial Revolution"; https://www.weforum.org/about/the-fourth-industrial-revolution-by-klaus-schwab.

[12] David Torben; ESA HQ – Strategy Department; "Distributed Ledger Technology Leveraging Blockchain for ESA's Success"; November 2017.

[13] Ministerial Council 2016; "What is Space; http://www.esa.int/About_Us/Ministerial_Council_2016/What_is_space_4.0.

[14] Karen Graham; "Nasa to Use Blockchain Tech in Distributed Spacecraft Missions"; *Digital Journal*; February 1, 2018.

[15] Christine McDaniel and Hanna C. Norberg; Mercatus Center, George Mason University; "Can Blockchain Technology Facilitate International Trade?"; April 2019.

[16] TradeLens; www.tradelens.com

[17] Supply Chain Dive; "Inside Boeing's Digital Supply Chain Turnaround"; October 2, 2018.

[18] "Pattonair wins EU Backing for Cloud-based Passport"; *Aerospace Manufacturing*; December 18, 2019.

[19] Allyson D. Yarbrough, Shawn P. Ashley, Lawrence I. Harzstark, and Maribeth Mason; "Got Reliability? Off the Shelf (OTS) Electronic Parts for Resilient Space Missions"; March 2019.

[20] U.S. Department of Defense – Inspector General; "Air Force Space Command Supply Chain Risk Management of Strategic Capabilities"; August 14, 2018.

[21] The Aerospace Corporation; TOR-2018-02827 "DODIG SCRM Mitigation Options"; September 28, 2018.

[22] Interview with Thomas Kacpura; Advanced Communications Program Manager at NASA Glenn Research Center; March 19, 2019.

[23] https://spacechain.com/.

[24] SpaceChain Foundation; "Space Chain: Community-based Space Platform."

[25] Risk Based Security; "Cyber Risk Analytics: 2019 MidYear QuickView3Data Breach Report"; August 2019.

[26] www.identity.foundation

[27] Paul Dunphy, Fabien A. P. Petitcolas; "A First Look at Identity Management Schemes on the Blockchain"; IEEE Security and Privacy Magazine; 2018.

[28] Financial Tribune; "Blockchain to Enhance Online Copyright Protection in Iran"; February 27, 2019.

[29] Vivien Fuhrer, "Token as a License, Blockchain's Next Evolution"; June 11, 2018.

[30] https://www.bita.studio/.

[31] Gareth Jenkinson; "Can Blockchain Become an Integral Part of Autonomous Vehicles?"; August 24, 2019.

[32] Press release from ConsenSys website; "ConsenSys Space Launches TruSat System"; October 21, 2019. https://consensys.net/blog/press-release/consensys-space-trusat-_-10-22-2019/

[33] ConsenSys Space; "TruSat Whitepaper"; Version 3.0

[34] Marco Iansiti and Karim R. Lakhani; "The Truth About Blockchain"; *Harvard Business Review*; January–February 2017.

[35] Jeffrey Bussgang, Ramana Nanda; "The Hidden Costs of Initial Coin Offerings"; *Harvard Business Review*; November 2018.

[36] Catherine Williams; Access Partnership; "Blockchain: A Regulatory Overview"; July 2019.

Acknowledgments

The author would like to thank Eric Piscini of IBM Blockchain Solutions, and Lori W. Gordon, David S. Eccles, Colleen Stover, Josef S. Koller, Thomas A. Kashangaki, and Luc H. Reisbeck of The Aerospace Corporation for their helpful review and comments.

About the Author

Karen L. Jones is a senior policy analyst and technology and market strategist at The Aerospace Corporation's Center for Space Policy and Strategy. Jones has more than 30 years of experience across diverse industries, including federal government, information technology, telecommunications, remote sensing, satellite industry, environmental technology and services, oil and gas, mining, and renewable energy. Prior to joining Aerospace, Jones was a management consultant with Arthur D. Little and IBM Global Services. She has an M.B.A. from the Yale School of Management.

About the Center for Space Policy and Strategy

The Center for Space Policy and Strategy is dedicated to shaping the future by providing nonpartisan research and strategic analysis to decisionmakers. The Center is part of The Aerospace Corporation, a nonprofit organization that advises the government on complex space enterprise and systems engineering problems.

For more information, go to www.aerospace.org/policy or email policy@aero.org.