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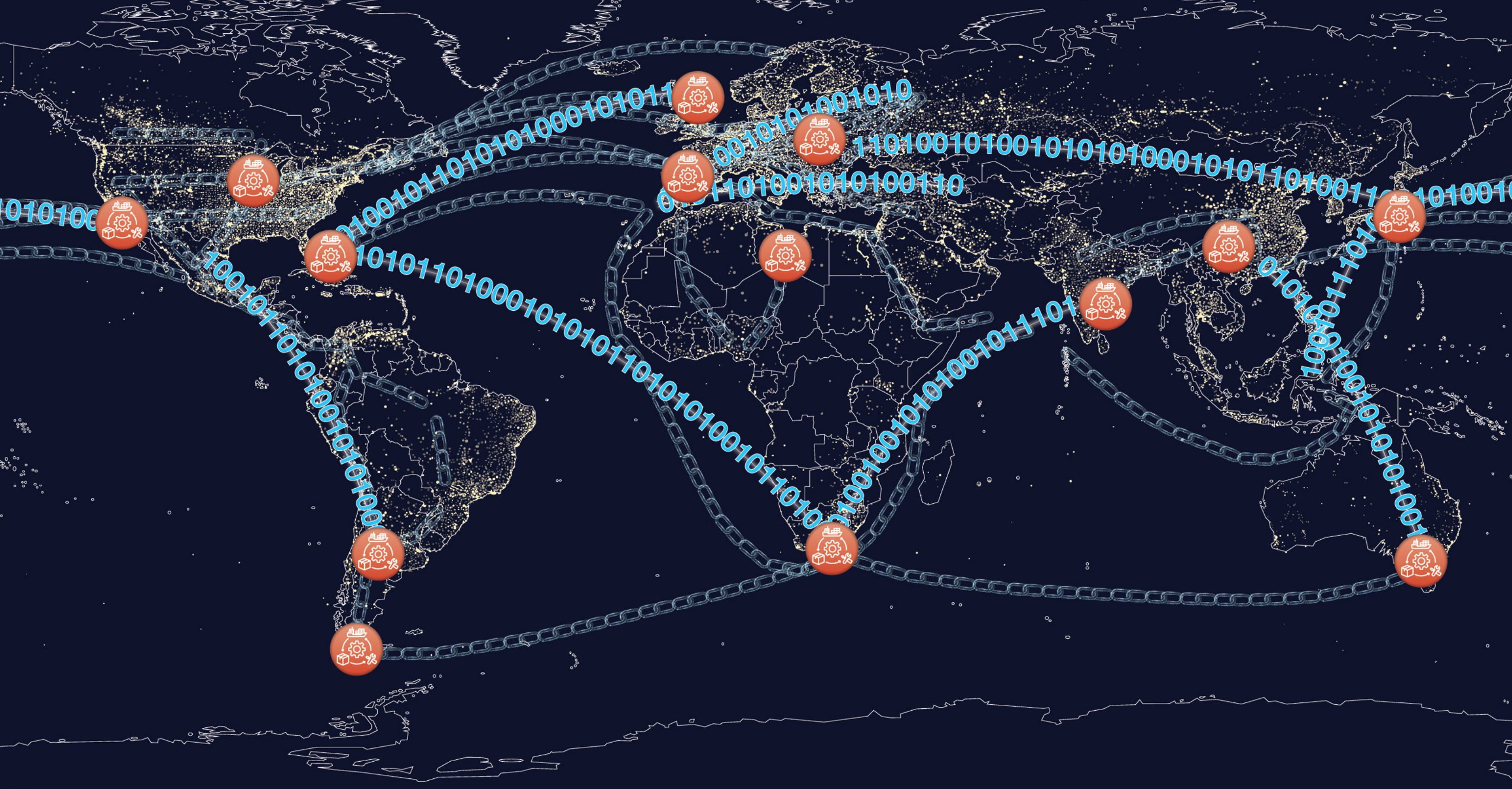

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STAR: SHINING LIGHT ON SPACE SUPPLY CHAIN RISK

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Summary

As the number of space systems increases, so does competition for the raw materials and components needed to produce them. Supply chain information is important to sustain the production of nationally important space-based missions and services. The United States and partner space organizations must maintain dynamically updated information that is current, accurate, and trusted to manage supply chain risks. Recognizing these needs, this paper envisions a topology called STAR, Space supply chain Topology for Assessing Risk, to shine a light on dynamically evolving risks.

Introduction

In the next 10 years, global space spending is expected to double.[1] Higher global demand will drive increased pressure on the supply chain for the U.S. space enterprise. Companies are pivoting to high-rate production for critical national space capabilities, making supply chain efficiency more critical than ever. Other global market sectors (e.g., auto, medical device, gaming, and cloud storage industries) are competing with the U.S. space enterprise for many of the same components, commodities, and rare-earth elements.

More than ever, these factors drive the need for comprehensive, up-to-date, and trusted information to expose problems in U.S. space supply chains. Unfortunately, no trusted system currently exists for pulling together and disseminating information needed to inform decisions. This is particularly challenging considering the expanding diversity of the space supply chain stakeholder community. The community comprises policymakers, procurement specialists, buyers and sellers of products and services, technologists, and security experts.

This paper conceptualizes a topology to aggregate and dynamically update space supply chain information. The envisioned topology could, in the future, provide time-sensitive reporting along the lines of the Waze™ mapping application. For instance, during disaster situations, Waze has informed FEMA where to dispatch fuel trucks to address urgent needs. During other disasters Waze has helped authorities and the public know locations of open shelters and evacuation zones. Our intent is to drive thinking about the benefits of delivering key information at the speed of need, generated from crowd-sourcing distributed information in near realtime. The space enterprise is a long way from having Waze-like solutions for space supply chains. That said, the envisioned topology would connect people, processes, and technologies via information-sharing partnerships, secure cloud-based platforms, and distributed ledger technology (DLT).[2] This paper refers to the topology as the *Space supply chain Topology for Assessing Risk (STAR)*. It is recognized that stakeholders are already making connections, establishing specific information-sharing partnerships, and using DLT. These standalone approaches could be linked within STAR to provide a common nexus for all stakeholders in the space supply chain community.

Establishing STAR will face significant hurdles. To dynamically collect the necessary information, STAR would require buy-in from key stakeholders across the global supply chain. A STAR solution would require cloud and related technologies to compile, process, and turn vast amounts of dynamically collected data into near-realtime decision support. The paper does not presume to suggest the best way to overcome all the hurdles or recommend who should tackle which tasks. The overarching objective is to help establish a community vision for STAR, stimulate discussion, and motivate the community to begin working toward it.

Kinks in the Global Space Supply Chain

The space enterprise is transforming from a legacy of producing a modest number of custom-made space systems commissioned by government organizations to a future where many companies produce a large quantity of space systems using assembly line production. There is an increasing number of systems deployed in low Earth orbit and more being developed to deploy out to cislunar and beyond.

Managing availability and delivery of large quantities of components to build these space systems is a challenge given the *volume* of data that must be tracked and the lack of *visibility* of that data. Incomplete collections of data paint a fragmented picture for supply chain stakeholders. Blind spots manifest as risks for government organizations and companies. Further compounding the risk situation, the availability of space system components is affected by geopolitics, global economics, and competition from sectors outside the space sector.

Global Impacts of COVID-Related Supply Chain Disruption: The Auto Industry

In the height of the global COVID-19 challenge, semiconductor foundry utilization increased. Fearing a slowdown, the auto industry gave electronics suppliers a lower forecast. In response, semiconductor companies shifted to serving other markets including laptops and cameras to meet increasing demands of people working at home. By the time auto makers realized a return in demand, semiconductors suppliers had expended their capacity and auto makers had to wait in line.

The supply of noble gases illustrates broader space supply chain issues. The key noble gases used in space components are neon, xenon, and krypton. For reference, spacecraft ion thrusters use xenon as propellent. Growing demand and geopolitical crises have disrupted the supply of noble gases, making them an excellent example of how global risks affect the space supply chain. For example, Russia's illegal annexation of Crimea in 2014 disrupted Ukraine's steel industry. Ukraine's steel industry was the source of as much as 90 percent of the global neon gas supply.[3] Effects of the COVID-19 pandemic and the 2022 expansion of the Ukraine-Russia war further interrupted production, and the global supply of neon became scarcer. Neon gas scarcity affected Taiwan Semiconductor Manufacturing Company Limited (TSMC) and others involved in semiconductor manufacturing, since neon is a key input in the semiconductor manufacturing process. So, in addition to the space sector, the neon shortage also affected auto industry access to semiconductor chips, illustrating the global scope of the problem[4] (see sidebar).

The neon gases case illustrates how events from the macro to the micro level continue to disrupt supply chains across the space enterprise. On a positive note, the problem of volatility and ambiguity *can* be mitigated through information providing a holistic view of the supply chain.

The Need for an Innovative Supply Chain Tracking Topology

To meet dynamic global supply chain challenges and mitigate risk, the U.S. space enterprise can benefit from a trusted, global, dynamically updated, enterprise view of the space supply chain. As envisioned, STAR could provide that enterprise view. STAR's objective is to connect people, processes, and technologies via information-sharing partnerships, secure cloud-based platforms, DLT, automation, and evolved analytical techniques.[5]

How can this approach work? Once established, STAR would rely on trusted partners to provide data stored in what this paper calls *information wells*. Hosted by vetted stakeholders using cloud-based platforms, information wells would be enabled by technology to ensure data integrity and allow access only to those who are authorized. Data would be collected and processed to inform risk assessments, a primary reason for STAR. STAR is not envisioned as a standalone system. STAR would comprise a network of networks. Figure 1 illustrates five main elements for STAR to dynamically interact so that the whole is greater than the sum of the parts, and each element is described in detail below.

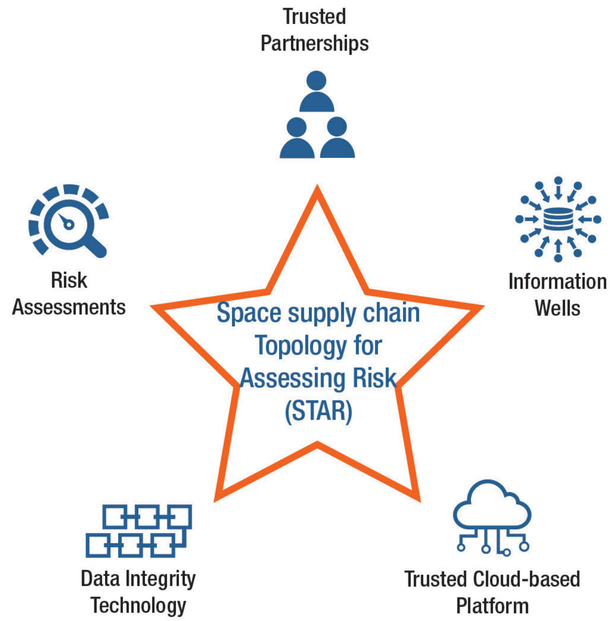

Figure 1. Five Elements of STAR

The scope of the paper is to identify the emerging challenges associated with maintaining supply chains in the face of rapidly developing large numbers of production spacecraft. The paper suggests the STAR approach to overcome these challenges and intends to prompt broader thinking and engineering to implement the STAR approach.

Trusted Partnerships

The first STAR element is a network of trusted partnerships. Trusted partnerships among multiple stakeholder organizations could be formalized with information-sharing agreements. Best practices can be applied in establishing trusted relationships. Best practices can include consistently exchanging agreed-upon types of data and applying common approaches to using the data. Options for sharing can include anonymizing the data to protect the business cases of the contractors involved. Trusted partnerships can be facilitated by nondisclosure agreements and through employee contract stipulations. Since agreements can be time consuming to set up, one approach is to start with the more straightforward task of ingesting data into information wells from publicly available sources and then assimilating the data that members are willing to share and use. This could include business-sensitive data consistent with vetted stakeholder data access and sharing agreements. Once established, partners would be able to provide data and extract information routinely through automated and/or manual processes.

Useful partnership models include the Space Collaboration Council (SCC), the NASA Electronic Parts Assurance Group (NEPAG), and the Space Information Sharing and Analysis Center (Space

ISAC). Potential STAR sponsors and participants include Space ISAC member organizations. Other partner-based models include Microsoft's Supply Chain Platform[6], Amazon Supply Chain[7], and Google's Supply Chain Twin.[8] Microsoft's platform enables organizations to use artificial intelligence, collaboration capability, security protocols, and Software as a Service (SaaS) applications. Amazon's capability is a cloud application that unifies data and provides machine learning (ML) for insights, collaboration, and demand planning. Google's capability allows organizations to build digital representations of their supply chains. Other companies use these services. These solutions include partner ecosystems with Accenture, Ernst & Young, KPMG, and Price-Waterhouse-Cooper. Another capability is Supply chain Levels for Software Artifacts (SLSA), which is led by a cross-organization, vendor-neutral steering group. SLSA comprises Google, Citibank, VMware, and others, maintaining a checklist of standards and controls to prevent tampering and improve integrity.[9] The Internet Engineering Task Force has a working group called Supply Chain Integrity, Transparency, and Trust, which creates industry standards for software bills of materials.[10]

The space enterprise can benefit from commercial know-how to enable STAR to gain maximum insight into the dynamics and risks associated with space supply chains. Once established, STAR enables participants, from supply chain analysts to chief information officers (CIOs), to work together more efficiently up and down the chain to facilitate the flow of information specific to a particular space mission.

There are barriers to building partnerships and information sharing. They include business concerns related to sharing proprietary information and the risk of exposing other potentially damaging information. Per the *National Cybersecurity Strategy*, released in 2023, allies and partners should be included to ensure global supply chains for information and communications technology are secure, reliable, and trustworthy.[11] International partnerships may be constrained by International Traffic in Arms Regulations (ITAR) and other export controls. Therefore, sharing information in a *trusted* environment is critical. Other elements of STAR, discussed in the next few sections, describe implementation approaches to enable trust. Technologies including secure cloud-based platforms and data integrity provided by distributed ledger technology contribute to building and maintaining trust.

Real economic benefits to information-sharing can outweigh costs. For example, information-sharing is a major lever for increased performance and competitiveness. Sharing information helps increase production responsiveness, innovation, co-development, and risk management. Analyzing data from only a single organization limits these advantages. Collaboration promotes coordination and trust between partners who may be geographically, organizationally, and/or informationally distanced. Just like in the Waze example, the sharing of data between connected tiers or partners can help all parties improve processes and make informed decisions in response to a crisis. Manufacturers can ensure that products meet customer availability, cost, quality, and security requirements (discussed in the Risk Assessment section below). Costs are reduced because sharing information increases precision in the management of activities and resources (for example, production levels, stocks, and sales).

It may seem counterintuitive for an organization to willingly share information that may compromise commercial advantage, or intellectual property. Experience shows benefits of "trust through technology," where organizations realize increased performance and competitiveness through sharing information.[12]

Information Wells

The second STAR element is a network of secure databases this paper dubs *information wells*. These are secure collections where organizations contribute and access data. These wells provide secure, traceable, and transparent data management environments, which are important factors for establishing trust. Partners could leverage a broad array of structured and unstructured data through information wells (see the appendix titled "Data Factors in Assessments" for a list of example data sets). Information wells would provide a holistic view of the supply chain spanning the space system lifecycle across design, development, distribution, deployment, and operations. Bills of materials and inventory risk report data would enable end-to-end awareness on component availability. Data would inform the search for alternative components when needed. Aggregated data would inform detection of trends and risk.[13]

Trusted Cloud-Based Platforms

STAR's third element is a network of cloud-based platforms to host information wells and enable secure processing of data shared among partners across the space enterprise. Space supply chain data collected from information wells is dynamically ingested from multiple providers into the information wells residing on STAR's cloud-based platforms. Supply chain data is encrypted into a "hash," and a hash is secured and distributed in the private blockchain. The information is made available for secure sharing to different levels of user stakeholders and partners based on vetted protocols. Representative commercial cloud platforms include AWS Cloud or Microsoft Azure. Decision support on availability for a given need at a given time and location is informed by risk assessments based on calculations using aggregated data on how much of a commodity (i.e., krypton) is needed to meet global demand, coupled with the aggregate quantity of supply.

In the long term, analyzing data from information wells could be performed on cloud-based platforms using analytical tools to automate the analysis. Once the analytical tools are developed, stakeholders could run assessments to pinpoint single points of failure, such as those from sole source suppliers, affecting production of multiple space systems.

Data Integrity

STAR's fourth element is data integrity technology. To implement STAR, the fourth element could use an approach combining trust-based partnerships using trusted cloud platforms that leverage trusted private DLT; e.g., blockchain for exchanging information and providing visibility into demand signals.

Using DLT helps ensure data integrity. DLT enables accountability of data by authenticating the identity of members and by auditing data consent, access, and sharing. A key benefit of DLT is data cannot be altered without detection as a function of data recorded in a distributed network. If one node is hacked, copies can provide verification of data consistency. Any addition of new data violating established consistency would be rejected. Data from primary sources are not altered. Data integrity can be traced to the primary source, where the primary source is verified and authenticated. With the use of robust cybersecurity controls and data encryption with secure sharing protocols, data privacy is protected, and the risk of unauthorized access to the data is reduced.

STAR elements can enable trustworthy, aggregated information. A goal of data integrity technology is tracking data and enabling common use across the stakeholder community. A private blockchain can be appropriate given security concerns.

Risk Assessments

The fifth element and key objective of STAR is robust risk assessments. As envisioned, STAR supply chain risk assessments would be enabled by the other four STAR elements. Risk assessments inform stakeholder decisions based on supply chain concerns. Risk assessments indicate weak areas in space supply chains—business or technical—where malicious actors could disrupt the supply chain via access to hardware, software, and transportation vectors.

Near-realtime data would enable risk assessments of priority items, helping to mitigate uncertainty, applying Sensitivity Analysis test methodology.[14] When disruptive events occur, information well data could be updated and immediately inform rapid analysis so that decisions can be made to mitigate risk and impacts to space operations.[15] The information well data could identify alternative supplies. For example, while xenon provides the best performance of noble gases for ion thrusters, krypton can be an acceptable alternative if the design change is made early enough in the development cycle.

> **A Space Supply Chain Is Only As Strong As Its Weakest Link**
>
> Stakeholders can apply STAR holistically throughout the spacecraft lifecycle to better understand component availability, cost adjustments, quality measures, and security risks. Example milestones where STAR can be applied include:
>
> - **Sourcing** raw materials, such as noble gases; suppliers need to deliver products to manufacturers.
> - **Producing** rocket bodies, solar arrays and other systems and components at the manufacturing facility from raw materials.
> - **Transporting** systems to launch vehicle and spacecraft assembly facilities and then on to launch sites.

Availability, Cost, Quality, Security

The intent of STAR is to enable dynamically updated risk assessments to inform space supply chain decisions. STAR's risk assessment element consists of four correlated assessments to map key risk drivers of availability, cost, quality, and security, as shown in Figure 2 and discussed below. These risk assessment areas, identified through research and interviews with experts, are routinely assessed. As such, a point of the paper is to recognize such assessments need to be conducted dynamically, on a rolling window basis, due to the dynamic nature of changes in both demand and supply. The information needs to be calculated on an on-going basis to provide decision support in time to course correct for specific impact to specific supply chain components and consumables. These four correlated assessments would be implemented through multi-parametric, multi-variant analyses using data provided by partners, stored in information wells, processed in cloud platforms, and secured using data integrity technologies. The following section proposes names and describes each of the four correlated risk assessments.

1. Availability – Global Production and Supply Assessment (GPSA)

The envisioned "Global Production and Supply Assessment" (GPSA) could address risk assessments related to availability. Using trends in data on production levels and distribution channels as key metrics, GPSA analytics would extend beyond traditional availability modeling focused on next tier components. For example, it could establish the probability of component availability according to specified space enterprise mission needs timelines. The results inform decisions on mitigation plans such as anticipating limitations of xenon gas availability to meet propulsion

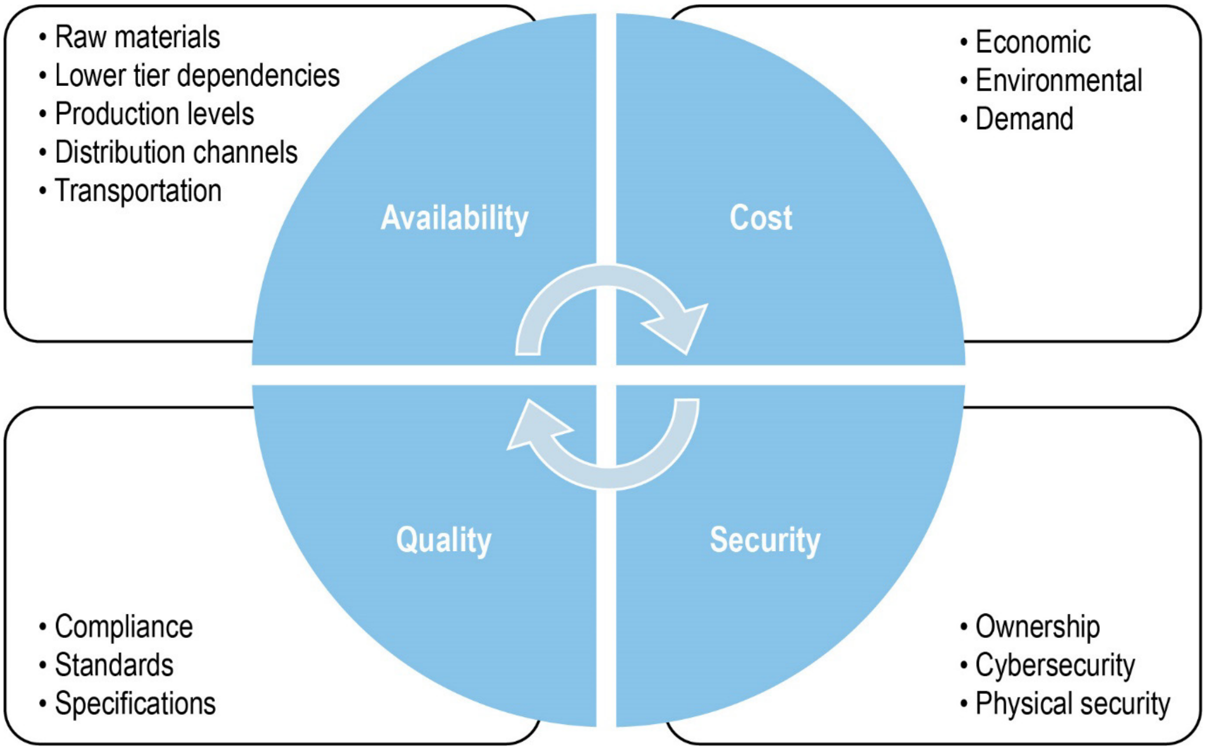

Figure 2: STAR Risk Assessment Element: Four Correlated Assessments

requirements so that a spacecraft provider can shift to use of krypton for ion thrusters.

2. Cost – Global Demand and Space Sector Cost Assessment (G/SCA)

The proposed "Global Demand and Space Sector Cost Assessment" (G/SCA) could address risk assessments related to cost. G/SCA would assess all market segments to provide insight into differentiation, switching costs, speculation, future roadmaps, and projections. For upstream buyers, this assessment considers a variety of factors, including price elasticity due to fluctuations in supply and demand over time and viability of market players given the viability of broad market segment. For the space sector, an additional lower tier is added for systems in the context of global demand. G/SCA assessments of space market segmentation identify the effects on demands associated with tailoring requirements for space systems. Requirements include quality assurance, testing, and related characteristics for a specific component to meet demands for space systems.

G/SCA assessments inform confidence in, and risk of sourcing from, trusted producers and providers in the global marketplace. For example, current global xenon production is 10 million liters[16], of which Ukraine produces 30 percent or 3 million liters[17]. The space market uses approximately 36 percent of this global xenon supply or 3.6 million liters.[18] So, if the supply from Ukraine is disrupted, the remaining 7 million liters of xenon of varying grades (not all of which appropriate for use as propellent) will be in demand by competing market segments. G/SCA will be useful for highlighting price escalation amid geopolitical conflict in part due to speculation.[19]

3. Quality – Space Applications Quality Assessment (SAQA)

The notional "Space Applications Quality Assessment" (SAQA) could address risk assessments related to quality. SAQA would assess the degree to which components meet quality standards and specifications for operational needs. The assessment can be reviewed to prevent issues, such as the effects of using subpar gas detrimental to operations if xenon/neon quality does not meet space system needs. The Russia/Ukraine conflict has affected this risk. Purification processes for neon, krypton, and xenon gases used in semiconductor manufacturing require a certain technical threshold. The conflict has affected Ukraine's ability to deliver that threshold.[20]

4. Security – Supply-side Information for Space Systems Security Assessment (SSecA)

The envisioned "Supply-side Information for Space Systems Security Assessment" (SSecA) could address risk assessments related to security. SSecA would assess multiple dimensions of security for a specific supply-side product or service. Security challenges include situations where the provider's financials infer limited ability to sustainably provide components for the duration needed or that the company has owners or investors from countries that pose national security concerns. For example, noble gas production of xenon and neon were affected by COVID policies in China[21].

See the appendix, "Data Factors in Assessments," for a summary of the four key risk drivers (availability, cost, quality, and security) that STAR tracks.

Existing–capabilities for risk assessment recently developed include Deloitte's CentralSight™ Supply Chain Analytics Tool[22], which seeks to illuminate networks of supplier and business relationships, and MITRE's System of Trust (SoT) Framework[23] to address concerns and risks related to suppliers, supplies, and service providers.

Conclusion

As the number of space systems increases, so does competition for the raw materials and components needed to produce them. Supply chain information is important to sustain the production of nationally important space-based missions and services. The United States and partner space organizations must maintain dynamically updated information that is current, accurate, and trusted to manage supply chain risks. Recognizing these needs, this paper envisions a topology called STAR, Space supply chain Topology for Assessing Risk, to shine a light on dynamically evolving risks.

This paper is intended to serve as a springboard for community dialog to establish, build confidence in, and operationalize a STAR solution for the space enterprise. Other sectors, including the automotive and aircraft industries, have complex global supply chains with similar needs, and their experience in supply chain tracking may serve as exemplars for the space sector.

The intent of the vision for STAR is to provide an approach for trusted, near-realtime risk assessments. These risk assessments can be enabled by harmonizing multiple elements. As the paper describes, STAR can be implemented through a coordinated set of community actions. These activities include building partnerships, pooling data in information wells hosted on cloud platforms, and applying distributed ledger technologies to ensure data integrity.

National-level policymakers and practitioners can promote the STAR vision. Actions can be taken now to identify near-term priorities and incentivize participation in STAR-like solutions. As the space enterprise begins production and deployment of thousands of spacecraft into low Earth orbit, the time is now to overcome policy, legal, technical, and nontechnical barriers. Secure and sustainable space supply chains are a matter of national security and economy, and a chain is only as strong as its weakest link.

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Appendix: Data Factors in Assessments

Risk Driver	Assessment	Data Factors
Availability	GPSA	• Distribution readiness and capacity • Lower tier components' access • Production readiness and capacity • Raw materials access • Transportation readiness and capacity
Cost	G/SCA	• Buyers • Economic environment • Market disruptors • New entrants • Price elasticity • Price sensitivity • Segment size • Suppliers
Quality	SAQA	• Architectural fit • Interoperability • Reliability • Requirements (Operational) • Resiliency • Safety • Scalability • Security • Stability • Supplier capability • Survivability • Sustainability • Workforce availability
Security	SSecA	• Corporate ownership (level of foreign control), governance, management team, business model • Cybersecurity • Due diligence in engaging, selecting, and assessing candidate commercial solution providers • Long-term capital, liquidity, solvency, operating efficiency, profitability, financial ratios, trends, intellectual property rights • Physical security • Transportation security

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availability and slow supply chains. These all rely on microelectronics, for example, with neon as a component.

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