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UNDERSTANDING THE INFLUENCE OF SPACE SITUATIONAL AWARENESS ON COMMERCIAL SPACE DEVELOPMENT

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ABSTRACT

Understanding the value of space traffic management (STM) and space situational awareness (SSA) in managing investment and planning risk for the space industry is essential to promote envisioned commercial space operations. Efforts to model the health and sustainability of the space economy are complicated by the lack of conceptual models accounting for complex, non-linear feedback and influence relationships across policy, regulatory, technology, and other domains. To further our understanding, MITRE is developing a forecasting model of space industry activity that enables dynamic modeling of factors across mission life-cycles that influence perceptions of space safety and sustainability, business considerations such as risk and insurability, business model factors such as launch costs, regulatory and licensing processes, and other factors that can advance or inhibit space economy growth. This paper presents the initial conceptual model, which is a first step toward a capability to inform and improve decision processes aiming to concurrently grow the U.S. space economy while improving overall space safety and sustainability. In addition, the paper gives special attention to unique needs for shared situational awareness in a contested environment as a factor in successful space commercialization.

PROMOTE THE ENVISIONED COMMERCIAL SPACE OPERATIONS

The U.S. Chamber of Commerce (the Chamber) is working with the Department of Commerce (DOC) Bureau of Economic Analysis (BEA) to improve understanding of direct and indirect contributions and beneficiaries of commercial space operations. The stated objectives of such collaboration are to measure the relative importance of the space sector against overall gross domestic product (GDP) and to understand the factors that will drive or impede the development of the space economy to inform the Chamber's potential policy and promotion efforts.

To further our understanding of the space economy, MITRE is developing a forecasting model of space industry activity that enables dynamic modeling of factors across mission life-cycles that influence perceptions of space safety and sustainability, business considerations such as risk and insurability, business model factors such as launch costs and other operating costs, and factors influencing investment in or impediments to overall space economy growth. Efforts to model the health and sustainability of the space economy are complicated by the lack of conceptual models accounting for complex, non-linear feedback and influence relationships across policy, regulatory, technology, and other domains. Below, we present initial work on a dynamic modeling and forecasting capability to inform and improve decision making involving government provided space situational awareness (SSA) and space traffic management (STM) services to commercial companies and, more broadly, how regulatory constructs may promote or impede space commerce.

Significance of the space economy

Numerous estimates exist to measure the space sector's relative importance upon the U.S. economy including gross output, compensation, and employment. For example, the Space Foundation reported global space economic activity to be $414.8 billion in 2018,[1] with commercial space revenues representing 79 percent of the total. Notably, as a subset of global activity, the Federal Aviation Administration (FAA) measured the U.S. economic role in the space industry at approximately $158 billion in 2016,[2] largely encompassing satellite communications, manufacturing, ground equipment, and launch services. Regarding employment, the DOC Bureau of Industry and Security reported the U.S. space industrial base included over 2.6 million workers in 2012.[3]

Past use of space to enhance terrestrial business operations was available but costly, as in the case of satellite communications from geostationary orbit. However, with decreasing costs of access to space data, and the increasing requirement for robustness and resilient operations, changes across all private and public sector markets are occurring. With safety and security as paramount considerations for agencies and companies alike, space-enabled services are embedded in government and commercial operations. Thus, adaptive costs of access to space data have become secondary relative to operational performance.

Arguably, today's space sector offers a mature set of market products. Low-earth orbit (LEO) and geostationary orbit (GEO) have become a domain in which to acquire and transmit data that people and businesses deem critical, namely positional awareness and high-resolution imagery. As those needs pre-existed the option of orbital access, the space economy as defined merely buttresses prior business operations and consumer demands. In contrast, the future space economy will be qualitatively different in producing outputs distinct from terrestrial use. While the digital economy will continue to encourage investment and reliance upon space-enabled data and imagery, the next phase of growth for the space sector will be off-Earth economic activities to include research and development (R&D) and manufacturing, energy exploration and mining, and agricultural outputs.

Notably, there are several additional economic catalytic impacts that result from the benefits government, consumers, and industries derive from space sector outputs. The use of space-enabled data facilitates the development of a range of products and uses that would not be possible without satellite technology, which increases productivity and more efficient use of economic infrastructure and resources[4]. Other services are enhanced by value added capabilities available because of space-based services.

Defining the space economy

The Chamber, BEA and MITRE are working to improve the understanding of the space economy and evolving future of space operations. To understand the growth in the space economy, it first needs to be defined. The space economy is broad; definitions vary from, "activities related to the manufacture and delivery of components that go into Earth's orbit or beyond," defined by the Congressional Research Service, to, "all public and private actors involved in developing, providing and using space-related products and services," defined by the Organisation for Economic Co-operation and Development (OECD) Space Forum.[5] For this effort, the space economy is separated into four layers as shown in Exhibit 1: direct space activities such as space manufacturing and satellite operations, space-reliant activities such as telecommunications industries and future off-Earth activities, spaced-enabled activities that permit new operations such as ride hailing applications, and space-enhanced activities that are not required but make operations more efficient.

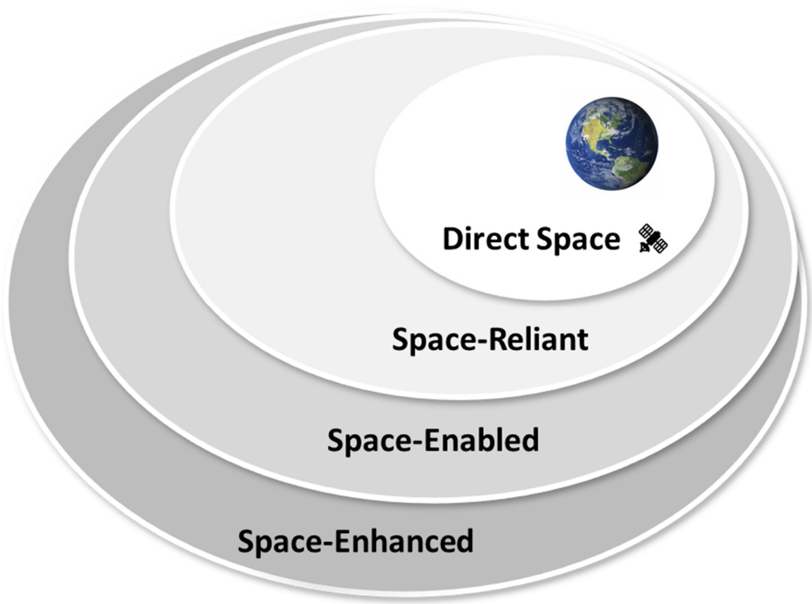

Exhibit 1: Space Economy

Evolving future of space operations

Understanding the evolution, the commercial space economy as an ecosystem will help ensure its safety and sustainability. If the Chamber wishes to promote growth, then understanding the factors important to the enabled industries, and their dependence on the direct space industries, is essential. This is how incentives, policies, and community engagement can be shaped to grow and sustain a robust commercial space industry.

Driving the space economy's expansion as measured by financial investment and revenue are two main factors: decreasing mass costs and increasing satellite data demand. Economic activity in this regard is linked to rising consumer data demand for reliable, high speed, and extreme low latency system requirements, as exemplified by autonomous vehicles, which require connectivity resilience that includes satellite networks. In addition to autonomous applications, evolving markets for 5G and Internet of Things (IoT) deployment require satellite system reliability.

Beyond technology application, many variables will affect growth of the off-Earth space economy. Insurers will face a range of liability and risk considerations, which will require maturity especially regarding human presence, habitation, and private sector employment in LEO and cislunar locations. However, cost structures will normalize as risk pools gain greater participation volume and available insurance product diversity.

As described above, revenue opportunities are motivating the global competition for the commercial uses of space along with the growth of private ownership, investment by new countries, reusable launch systems, and the falling launch costs from vehicles. According to some industry experts, the global space economy is expected to rapidly grow in the next 20 to 30 years from $350 billion to upwards of $2.7 trillion by 2047[6]. However, estimates are inconsistent and have historically underperformed actual operations.[7] Under ideal circumstances, commercial space operations should grow to meet all the demand for the space-based service markets. However, inefficient use of space as a common resource, especially for LEO, could capacity-constrain the industry if spectrum or viable orbits reach a practical limit, or capacity is lost due to collisions and debris. The ultimate potential depends on how efficiently multiple entities choose to use space, and how situational awareness informs those decisions on use, collision avoidance, and debris mitigation to maximize this common resource.

The space industry has already entered a rapid expansion. To provide context of this growth, consider there are about 2,200 satellites currently orbiting Earth. Over 10 percent of those in the North American Aerospace Defense Command (NORAD) and Committee on Space Research (COSPAR) catalogs were deployed in 2019. However, in 2018, the Federal Communications Commission (FCC), under 47 Code of Federal Regulations (CFR) Part 25, approved operating authority for an additional 13,237 satellites.[8] The pace, scope, and unprecedented diversity of innovative space missions and business plans has provoked comprehensive rethinking of every aspect of the traditional approach to planning, regulating, and managing the life-cycle of space activities through discrete planning, launch, early orbit activities, routine mission life, and end-of-life operations. Accordingly, the need is clear for a more robust approach to understanding the potential growth drivers and impediments to commercial space operations.

The increased number of space launches associated with new space missions is another area where fundamental reforms will be necessary. Just in the continental United States, the addition of multiple spaceports, all of which have launch areas that overlap with traffic corridors between major hub airports, will require new policies and procedures to reduce the financial impact on air carriers. As we enter the age of space tourism, U.S. companies will likely press for regulatory and compliance reforms to compete internationally, NASA will be forced to adapt its current human spaceflight SSA and STM processes.

The space ecosystem's sustainability depends on the day-to-day functioning of spacecraft on-orbit. Today that part of the operation remains effectively outside of any governmental authority's regulatory grasp. Therefore, the opportunity to shape a sustainable ecosystem for commercial space growth is in the policy and engagements that precede approvals and deployment of these large constellations.

CENTERING REGULATORY ACTION TO FACILITATE DATA-DRIVEN POLICY DECISION MAKING

Across the space industry, U.S. companies are successfully lobbying for streamlining regulatory and licensing processes to remain competitive in a rapidly expanding global space economy. Proponents of reduced regulatory requirements argue that, because it is in the best interests of a space company to adhere to best practices to reduce risk, obtain insurance, and become a "successful" operator able to attract subsequent investment, new space companies do not need government oversight and should not be burdened or impeded by regulations. Advocates of additional regulatory and compliance measures argue that the incentive to take risk and a "fail early and often" mentality central to most tech start-up cultures does not translate to space operations. Unlike SpaceX, most space companies are not vertically integrated, meaning that the overall safety of the "mission" depends on a company that may have no experience managing the outsourcing of the design, building, launching, and perhaps operations of space objects. Others argue that, regardless of circumstances of any specific company, the government is responsible for all space activities and operations licensed and/or launched from the United States based on international agreements. In this view, the government is obligated to place and enforce compliance measures that reduce risk to space operations.

As more organizations enter the industry and more nations pursue spacefaring ambitions, the direct investment in space technology and infrastructure development needed for launch and ground systems to sustain space services will grow. Further complicating discussions about regulatory and licensing reforms are overall perceptions about space safety and sustainability and how perceptions of "risk" for any specific mission are refracted through the lens of global competition. The global competition between spacefaring states will also increase calls for regulation favorable to commercial space pursuits. More favorable regulation may prompt increased investment and technology developments at the expense of safe and efficient use of the space commons. The growth loop is a consequence of the regulatory environment and direct investment to leverage economies of scale and advances in payload and launch technology and create space capability advances to provide better services which can generate more revenue.

The race to deploy new space-service offerings may lead to less efficient use of space if not managed by the global community. Capacity may ultimately cap space industry growth. Before that cap is reached, the risk of loss of one's assets to collision and uncertainties in the operating environments may deter further investment or yield tighter regulatory restrictions, which would impede industry developments. This could include situations where the insurance industry is unable to determine the risk adequately to help defer normal risks. Collision risk on orbit and perceived safety and security in all operational phases could dampen enthusiasm. These perceived risks could feed a call for greater regulation or control and greater demand for ground infrastructure, such as surveillance to support operations. Either the costs of these controls or the inability to address the uncertainties will limit the pace of growth and the upper end of the potential for the mature market. Understanding of the risks and limiting the harm of a contested environment are key to achieving the greatest potential.

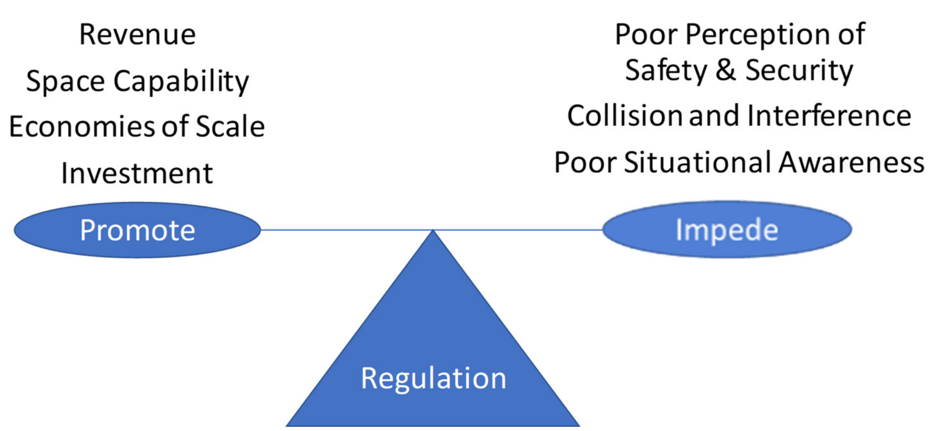

Exhibit 2: Factors promoting or impeding commercial space industry growth

Regulation is therefore in the middle (see Exhibit 2). It will promote investment advances and growth so long as the risks and uncertainties are in check. When the perceived security or safety risks are too great, then regulation must address those causes. Poor situational awareness or lack of organization of the risk mitigations may be the priority. Finding the right mix of policy options and pulling the right set of policy levers, either together or in sequence, requires the ability to dynamically model the factors influencing the space economy.

IMPORTANCE OF SSA IN SPACE COMMERCIALIZATION SUCCESS

SSA is crucial in a contested environment

Space is known in military terms as a contested environment, which means adversaries may focus on blocking access and deny operations by others. In business terms, that translates into uncertainties about the ability to establish or sustain a business enterprise. The contention for the common resource may limit opportunities to generate revenue. Worse yet, after investing to deploy a capability, it may be lost due to direct conflicts, collisions, or unplanned commercial operation events. All those uncertainties drive direct cost or insurance cost. Outside of regulation or control of the environment, the best mitigation of those uncertainties is information and collaboration.

Current SSA and STM reporting, coordination, and data sharing policies and practices are undergoing fundamental change as the space policy, space operations, and broader space commerce communities collectively grapple with long-term implications of what many describe as a new space race. While traditional great power dynamics persist, including renewed lunar mission competition and more aggressive proximity operations involving on-orbit counter-space capabilities, the new space race is overwhelmingly driven by commercial innovation. New space missions include so-called mega constellations, space tourism and mining, on-orbit servicing and manufacturing, life extension vehicles, and commercial inspection missions. Across the range of new missions, systemic weaknesses are being exposed in prevailing policies, practices, and processes that evolved over decades to reduce uncertainty and mitigate the risk of space object collision and interference.

Existing government SSA and STM services cannot adapt and evolve quickly enough to reinforce current optimistic perceptions among new space operators and their investors concerning life-cycle mission risk from collisions and interference. Until recently, these risks have been largely known and mitigatable or manageable through government sponsored and supported coordination, data sharing, collision notification processes, and other practices. These processes and practices are mostly informal and originated during a time when almost space activity was still controlled by handful of governments (and then mostly by the military). Current SSA and STM constructs rely on unenforceable guideline agreements, uneven adherence to “best practices” for space operators, and data sharing agreements and notification processes that rely on government sensors, analytic resources, and notification processes that cannot scale to accommodate and service the breadth and scope of new space missions. More importantly, a paucity of attention has been paid to how the provision and efficacy of SSA and STM services to commercial operators should be factored into long-term modeling and forecasting tools to help decision makers understand their influence on space commerce. We believe there are important, long-term, and sometimes counterintuitive interaction effects between SSA and STM services that influence perceptions of space safety and sustainability, regulatory actions, and other factors that combine to either promote or impede the space economy.

SSA as a counter to ill-defined risk

MITRE developed a surface-to-space architecture that links the on-orbit activity back to pre-launch and transition through congested airspace.[9] The architecture poses many questions about the evolving future of space operations, the interaction with air operations, and reliance on ground infrastructure including launch and landing sites. Specific business risks of the contested environment are highlighted in the architecture: scheduling conflicts for key resources, access issues and ability to deliver service, and surprise actions by others which might disrupt operations, or in the worst case, destroy a deployed capability. MITRE’s surface-to-space architecture has the benefit of industry input to the Chamber request for information on STM and SSA. The architecture and industry input highlighted differing views on how situational awareness would affect these risks. Here are considerations for how better situational awareness would matter to industry success.

The key uncertainty is whether one can complete a planned enterprise to begin generating revenue. This starts with the risk of being blocked by the actions of others. Launches now add substantial new obstacles in LEO, which will create potential conflicts for later deployments. Deployment schedules and object placement will become important to planning how multiple constellations will fit in this shared resource. This is also critical to manned flight services, resupply missions, and other activities that need avenues for egress. SSA must begin in the planning stage with knowledge management of the planned constellations, deployment patterns, and a broad picture of what else may be contending for overlapping space. The architecture recommends a mission broker role to coordinate schedules and create shared situational awareness of how deployments will occur, and what potential adjustments may be, so that each organization can plan accordingly. SSA assures successful missions and minimizes the uncertainty that an enterprise will be unable to complete what is needed to initiate a routine and sustainable service. Such failures would not only strand assets making them space debris but would potentially dampen investor confidence in other endeavors.

The key risk SSA can address is the potential catastrophic loss of one's investment due to the density of debris and increase in planned space objects. There is currently little incentive and no policy requirement for mega-constellation owners to provide advance warning of or insight into maneuvers. Without significant improvements to the current SSA and STM operating environment, some analysts predict at least one catastrophic LEO collision per year within fifteen years (a number that does not include the compounding effect of space debris created by each collision). [10] Even one commercial endeavor being lost to such an incident could deter investment in all operations. A collision between space objects could result in regulations that would reverse launch cost reductions. Even the threat of such events may drive regulations and/or calls for greater ground station and payload capability to mitigate these risks, again reversing the cost reduction trend for space object deployments. Shared awareness of debris risk and collaboration on maneuvers could provide the industry with baseline data on risks associated with collisions and a means to show investors and insurers how the industry will avoid the forecast catastrophe of annual collision events. In the architecture, surface-to-space traffic management is envisioned to arbitrate access and increase mission assurance. In such cases, the term management does not imply control, but a collaborative function to inform operator decisions, and backed by cross-agency coordination and public-private data sharing to limit disruptions or collisions that would degrade or destroy capability.

Third is more routine radio interference that may affect service quality or viability. The current operating environment does not manage the spectrum in LEO nor account for the dynamic nature of new space vehicles which can maneuver out of the orbit originally used in assessing interference. Awareness of the potential of interference will be key to reliable service. Shared awareness in terms of public-private data sharing could protect space objects against being inadvertently blinded or jammed in routine passing events.

REFINING WITH INDUSTRY INPUT: A SPACE INDUSTRY ACTIVITY FORECASTING MODEL

Through dynamic modeling, we can validate, test, and understand how changes in regulations, support systems and infrastructure, and technology innovations would contribute to the evolution of each layer in the space economy. To support this effort, MITRE and the Chamber are developing a dynamic forecasting model of space operations and the space economy with industry and government input. The model will be a function of the policies, operational procedures, and feedback structure in the larger business ecosystem including considerations such as risk and insurability, operating costs, levels of situational awareness and safety, and other drivers of adoption or inhibited growth. The model will allow decision-makers to test the impact of space architecture decisions and enablers on the growth of surface-to-space operations and the impact on the space economy and safety assurance.

The model's development is a four-step process of data gathering and research, identifying causal structure of key variables, programming the forecasting model, and validation. The team is working iteratively to refine the objectives and outcomes and to identify the stakeholders, key factors and causal relationships for a high-level conceptual model. Our plan is to validate this structure with government and industry experts to ensure realistic relationships and feedbacks in the model. After programming the model, the team will compare the model results to historical data, where it's possible, and work with subject matter experts to confirm the key impacts are as expected and that the model intuitively responds to changes.

Initial model

The model considers space operations in the context of situational awareness and safety, regulatory architecture, investment, and costs providing a holistic framework of the space economy. Exhibit 3 illustrates our high-level conceptual model of the space economy. The following sections describe the anticipated causal relationships. These relationships need to be validated with industry and government expertise and data.

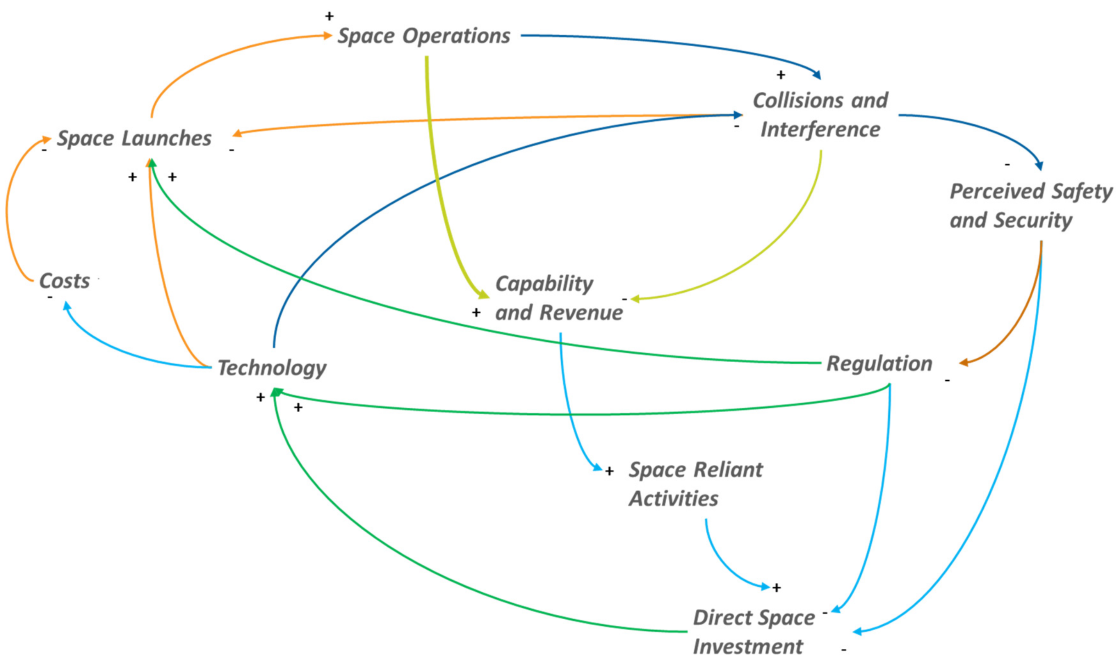

Exhibit 3: Conceptual Model of the Space Economy Model

Space Launches and Operations

Space operations represent the number of active U.S. and global satellites and other spacecraft in low, mid, and high Earth and geo-synchronous orbit. Remote sensing can improve satellite monitoring to help identify capability issues and extend the life of satellites. Availability of spaceports and ability to launch, costs, and regulation constrain space launches, which control the number of spacecrafts in operation. Debris and congestion limit the conditions for launch, which can be alleviated by debris recapture.

Collision and Interference

Technology improvements in space domain awareness and safety engineering can reduce the risk of collision that spacecraft have at launch, in orbit, and on de-orbit. Some collisions are catastrophic causing an orbital breakup generating debris, which further increases collision probability until the debris is too small. Technology improvements in cyber security would also be expected to reduce interference with spacecraft. Collision and interference would be expected to reduce the level of safety and security, and the perceived safety and security of space operations.

Regulation

Real and perceived safety and security reductions could be addressed through insurance and regulation, increasing required safety and security standards, and other development requirements. Streamlining the approval process with proxy approvals or other regulatory improvements would reduce the approval burden and provide timely mission approval for launch increasing satellites in operation. Reducing uncertainty through regulation and situational awareness will encourage direct investment in space activities.

Capability, Revenue, and Investment

Space operations provide services generating revenue based on their capability and functionality level. Collisions and interference risk will result in a loss of capability negatively impacting the reliability and functionality of operations. Economic growth and increases in capability and revenue will likely increase space-reliant activities, which increase direct space investment. Highly regulated environments provide stability for investors increasing the speed of investment. That, along with improved approval timeliness, set conditions to support direct space investment while decreases in perceived safety and security introduce uncertainty that causes investors to be more cautious.

Technology and Costs

Regulatory and insurance requirements for safety and security increase the need to impose commonly applied industry standards. New industry standards along with other requirements for new capabilities and replacement of existing satellites increase the need for space investment. Imposition of such practices and space investment would improve capabilities in space domain awareness, safety engineering, and cyber security as well as increase the satellites/payload per launch. In the short-term, new operating norms or regulatory standards may increase launch costs. If the value of these norms is not understood, then operators may migrate to space faring nations with lower standards. However, in the long term, improvements to launch vehicle technology could lower costs for deploying capabilities into space. Advances in payload technologies will also expand the possible space operations and space-based service offerings.

Model Exploration

Once developed, the model will provide the capability to test the impact of space architecture decisions and enablers on the number of satellite and other space operations and the annual space economy over the next 20-to-30 years. We hope to explore the impact of options for space domain awareness, remote sensing, orbit and debris generation, on-orbit servicing and maintenance, and proxy approvals.

NEXT STEPS

With the direct space industry already moving out, the Chamber sees it as imperative to understand the drivers for the evolution of space operations. MITRE is currently working on a dynamic simulation model to provide a prototype decision support tool to evaluate the impact of space architecture decisions and to understand factors driving the space economy and safety of operations. To complete this work, we need to refine and validate the model structure with government and industry experts as well as identify data sources for the validated model.

Having the capability to understand industry influencers and their impacts will help the Chamber assure safety while promoting space operations and industry sustainability.

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[1] "Measuring the Value of the U.S. Space Economy," The Journal of the U.S. Bureau of Economic Analysis, December 2019.

[2] https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2018_ast_compendium.pdf

[3] Bureau of Industry and Security. 2014. U.S. Space Industry "Deep Dive" Assessment: Employment in the U.S. Space Industrial Base. September 2014.

[4] https://www.ukspace.org/wp-content/uploads/2019/05/The-Case-for-Space-Final-Report-July-2009.pdf

[5] For definitions of the space economy see: "Measuring the Value of the U.S. Space Economy," The Journal of the U.S. Bureau of Economic Analysis, December 2019.

[6] In a press release from October 12, 2017, Morgan Stanley estimated the space industry will grow from $350 billion to more than $1.1 trillion by 2040. From an October 31, 2017 released estimate, Bank of America predicts the space industry will grow from $350 billion to $2.7 trillion in 30 years.

[7] FAA (2018), Annual Compendium of Commercial Space Transportation: 2018, US Federal Aviation Administration, Washington, DC, p. 83.
https://www.faa.gov/about/office_org/headquarters_offices/ast/media/2018_AST_Compendium.pdf

[8] https://spacenews.com/op-ed-small-satellites-are-big-business/

[9] Surface to Space "To Be" System Functional Description, MITRE 2019.

[10] Orbital Traffic Management Study, SAIC, 2016. p. 5.

