Modular Open Systems Approach (MOSA) for a Robust Commercial Lunar Ecosystem

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Abstract. *Modular Open Systems Approaches (MOSAs) have been adopted worldwide to solve a myriad of challenges. Open systems by their nature maximize accessibility, reduce barriers to entry, and prevent vendor lock. Similarly, modularity speeds innovation, fosters design re-use, and enables incremental development & growth. Architectures developed using a MOSA synergize the benefits of modularity and open systems to produce better products at lower developmental cost and risk, saving the consumer money while allowing greater developer profit margins.*

Specific to the challenge of lunar exploration, a MOSA will ensure interoperability among diverse commercial, government, and international partners. Complex spaceflight systems can be assembled, upgraded, and serviced far more easily and with greater commercial involvement with the use of a MOSA. By allowing partners to self-limit their scope to key strengths, they can focus on producing premier components without carrying the high risk and associated cost of auxiliary tasks they don't specialize in.

We survey commercial and Department of Defense (DoD) lessons learned in past decades, discuss DoD robotics' experience in Iraq and Afghanistan (first without then with MOSAs), and analyze the flourishing commercial ecosystem that has resulted from DoD MOSA adoption. We explore the future of lunar operations to demonstrate the criticality of MOSA adoption in key areas at the right time. Two specific lunar technical fields are studied as examples: Power and In-Situ Resource Utilization (ISRU). Finally, recognizing that the lunar ISRU campaign will be an eminently collaborative operation requiring seamless partnering among diverse commercial, government, and international partners, a comprehensive technology development ecosystem is explored aimed at enabling ISRU in a way that systems and components are affordable for commercial partners to design, build, and sustain.

I. INTRODUCTION

The National Aeronautics and Space Administration (NASA) and other government bodies, when buying niche products such as low-production scale products for military and spaceflight, have tended to rely on a single provider, which bring susceptibility into sole-source vendor lock, minimal redundancy, and supply chain risk. Relatively recently, the concept of MOSA has been explored for Government purchases in an effort to make previously monolithic systems now available as interoperable parts from multiple sources. This has been codified in law; all major military purchases must now follow MOSA to the maximum extent possible.[1]

The Lunar surface is an additional area in which the MOSA concept is being explored. NASA is working closely with commercial industry, academia, and international partners to develop technologies, capabilities, and procedures to enable long-term human presence on the Moon. Key to this endeavor is a robust commercial lunar economy initiated by synergy between commercial industry and worldwide Government agencies aimed at enabling a flourishing commercial economy wherein customers (both commercial and Governmental) purchase commodities and comprehensive spaceflight services from the marketplace. This differs ideologically from the current model where customers are required to self-manage every aspect of spaceflight missions.

In moving towards this shared lunar economy, customers will be able to leverage economies of scale associated with competitive and thriving free-market economies. This bypasses the need for customers to either develop complex partnerships or become well-versed in all aspects of spaceflight, instead allowing them to focus their efforts within their specific areas of expertise. If a lunar MOSA is adopted it would enable a commercial lunar economy with more customers and providers to enter the marketplace, and reduce the cost of space exploration for all involved.

II. OVERVIEW OF MOSA

Modular Open Systems Approaches (MOSAs) are not a new concept. They have been used worldwide for years, especially rising in popularity with the market for personal computers and electronics. The 802.11 "wifi" standards facilitate interoperability across a variety of hardware platforms, while PCI Express (PCIe) and Universal Serial Bus (USB) describe both physical form-factor as well as communication and power interfaces that enable extraordinary and diverse innovation. Similarly, ISO containers have revolutionized commercial shipping and freight, and most people born in the last half century have played with Lego® blocks and know that sets can be combined, even across generations.

Lego is an example of a proprietary implementation of modularity and exemplifies that "modular" does not necessarily imply an "open system". The reverse is also true, in that simply because a system is open does not necessarily mean it will be extremely modular. This is not to say that there isn't value in modularity alone, or open systems alone, just that there are limitations when they are not combined. The "semi-open" SD card standard is an excellent example in that it is proprietary in its management yet licensed to others for use. If SD was not licensed (semi-open), it likely would not have become be the de-facto standard for modular data storage devices it is today. Lego® was able to overcome this limitation and dominate its market by being first to market and executing a sound business strategy.

While Lego® is a success story in modularity despite its proprietary nature, it begs the question, how many other systems remained obscure because lack of a MOSA contributed to stifled innovation, ballooning costs, supply chain risks, and extreme difficulty in upgrades and modifications?

To see examples, we need look no further than historical Government acquisition programs for major systems. Necessarily, many Government purchases are often unique products that cannot be purchased "off the shelf". Historically, Government acquisition relied on a single lead system integrator (LSI) to manage system acquisition from cradle to grave. This often led to entire teams studying the risk vs reward of the Government purchasing the design with its build rights (which would cost more up front) or leaving themselves vulnerable to risk of design changes or cost increases for subsequent production.

III. DOD LESSONS LEARNED

A clear example of the process of adopting a MOSA can be seen in the history of DoD Robotics. In the beginnings of Operation Enduring Freedom in Afghanistan, and Operation Iraqi Freedom in Iraq, Improvised Explosive Devices (IEDs) were killing warfighters throughout both theaters of operation. Robotics were urgently needed to allow warfighters to detect, identify, and dispose of IEDs without putting personnel at risk. There was no time to develop a comprehensive strategy to build up our robotics capabilities in an intelligent, sustainable manner.

As a result, countless robotic systems were rushed to field without viable sustainment plans. The DoD knew this was unsustainable, but the alternative (higher casualties) was unacceptable. The hot, dusty environment coupled with extreme operating conditions led to the need for frequent repair and refurbishment. Technicians had to be trained to perform this work, costly replacement parts needed to be sourced, and replacements needed to be exchanged for damaged systems to ensure the required capabilities remained in warfighters' hands. Within years virtually all of these "legacy" systems would be divested and replaced with more sustainable options.

While providing robotics to warfighters at "emergency" speed, the US Army's Project Manager Force Projection (PM FP) office worked hand in hand with Army Ground Vehicle Systems Center (GVSC) to determine how best to implement a MOSA in the development, acquisition, and sustainment of DoD robotic systems. One of the first products that arose from this groundbreaking approach was Robotics InterOperability Profiles (Robotics IOP).

PM FP and GVSC asked commercial industry to develop Robotics IOP to address known shortcomings in DoD robotics.[2] Robots and their components (sensors, radios, controllers, manipulators, etc.) were not interoperable across platforms; subcomponents were likely to mature at a rapid pace, going through multiple generations over the life of the system; finally, future systems would need to share information across multiple warfighting domains. [2]

Not long after IOP was established, 10 US Code § 2446a (Ref 1) was written which stated major defense acquisition programs "shall be designed and developed, to the maximum extent practicable, with a modular open system approach to enable incremental development and enhance competition, innovation, and interoperability."

Around the same time as IOP was being developed, the technology developers for ground vehicles established the Vehicular Integration for C4ISR/EW Interoperability (VICTORY) architecture.[3]

DoD took a similar approach for system-level robotics software as well as autonomy software. The Robot Operating System – Military (ROS-M) program was established around the internationally-adopted open-source ROS framework.[4] ROS allowed software modules to be independently developed, utilized in different robotics platforms, and incrementally upgraded. ROS-M set out to maximize sharing and re-use of those modules to the maximum extent possible.

Today multiple DoD systems are being developed with a MOSA. The former "monolithic" approach that relied on a single LSI has been replaced with a flexible approach that has allowed multiple industry partners to develop and upgrade components, resulting in greater value and increased pace of innovation. Niche specialists and companies that previously weren't able to contribute to major system are now able to provide their world-class capabilities in support of the warfighter.

IV. APPLICABILITY TO SPACEFLIGHT

In recognition of these successes, there is an opportunity to develop a Lunar MOSA to increase innovation by maximizing accessibility to lunar technology development. To be clear, there are aspects of the lunar campaign that are currently taking place for near term technology demonstrations and science studies that should not be put at risk by changing requirements to adopt a MOSA. However, now is the critical time for the lunar community to adopt a MOSA in key areas. Much like Government relied on industrial partners to develop their MOSA frameworks, NASA and the international community should leverage the strengths of industry to identify the appropriate areas for modularity and standards. There are many possible technology areas to consider for adopting a MOSA, including power, communications, sensors, and ISRU.

ISRU in particular presents a well-bounded framework for ensuring interoperability and accessibility for a wide range of partners, the best value for customers, and the greatest opportunity for rapid incremental technology development. The lunar ISRU campaign directly leverages power, materials handling and processing, excavation, and multiple types of robotics.

It would be beyond the scope of this paper to fully explore every aspect of what a MOSA would look like for the lunar ISRU campaign. However, parallels can be made between requirements for the lunar ISRU campaign and DoD's successes in robotics discussed earlier.

IV.A. Notional MOSA for ISRU Robotics

The lunar ISRU campaign will likely be the most robotics-dependent operation undertaken by humanity to date. It is wholly impractical to send human beings to the Moon for the sole purpose of mining, delivering, and processing lunar regolith. Worldwide technical advancements will allow us to accomplish this ambitious task, but only if our tactical approach is robust from the start.

Going to the Moon to stay requires a complete portfolio of robotic systems capable of performing myriad tasks, working collaboratively with peers, recovering immobile or damaged systems, and seamlessly swapping out components as needed. The architecture that enables these capabilities should also allow for Earth-based incremental upgrades to future iterations, as well as maximizing both design and software re-use.

IV.B. Implementation of a MOSA

There are multiple avenues through which a MOSA can become successful. First, the primary customer (in this case NASA) could define the framework and mandate its suppliers adhere to that framework. Similarly, a MOSA could arise naturally from industry and other partners mutually agreeing on aspects of the framework. However, a third option (and the one undertaken by DoD) offers the greatest promise for a MOSA framework that benefits the lunar ISRU campaign: A collaborative effort between NASA, industry partners, and the international community.

The first step in developing this framework is recognition of the need to utilize a MOSA for the lunar ISRU campaign. Once that is established, a collaborative effort can begin wherein customers (e.g., NASA) ask an industry consortium to investigate the problem space, namely defining which systems, interfaces, and subcomponents could possibly be modularized. Armed with that list, the same consortium can work together to narrow it down to the list of which components should actually be modularized. Then, customers and industry would work collaboratively to develop an iterative plan to work towards the ultimate goal of modularizing those aspects of the campaign. Finally, the industry consortium would define the actual specification of the framework, beginning with the baseline version (v0). Over time v0 would be expanded upon with v1, v2, etc, as necessary to refine the framework and provide further benefit to the campaign while remaining compatible with legacy systems.

IV.C. Additional Possibilities

Recognizing we are able to take advantage of the advancements made in the last decade surrounding MOSAs and crowdsourcing, a truly collaborative effort may be possible that synergizes both concepts. Let us assume a future date where the architecture definition is complete and it modularizes subsystems (batteries, radios, manipulators, end effectors, embedded electronics, computers, autonomy software, mission sensors, autonomy sensors, motors, mobility systems, chassis, etc.)

With this foundation we can leverage principles from agile development, software configuration management (e.g., Github), and smartphone app stores to create an ISRU robotics repository that hosts designs, drawings, and software for each of those modularized subsystems. Fully open system designs (non-proprietary) would be accessible for anyone to work on, while proprietary elements would share metadata on their attributes, allowing customers or developers to identify modules which meet their needs, then contact their owners for private collaboration.

This app store-like repository serves as the foundation for anyone (students through retired professionals) to contribute to a dream project: Developing components of robotic systems for the Moon. Ultimately this may even open the door to crowdfunded spaceflight missions and citizen science on the Moon.

Open-source software projects like Linux, ROS, and others have shown the tremendous desire of the public to take part in projects far greater than themselves. When contributors to Free/Open Source Software (FOSS) projects were asked why they contribute, two of the top reasons given were enjoyment of learning and fulfilling a need for creative, challenging, and/or enjoyable work.[5] Interestingly, some of the most successful open source projects are backed by foundations or consortia.[6]

V. CONCLUSION

MOSAs offer a wide variety of benefits to innovation and all those who want to participate in the lunar technology ecosystem. We are at a critical time in the lunar roadmap and we need to start considering standards, modular systems, and open architectures to enable a robust, competitive, and innovative lunar commercial base. We propose adopting MOSAs and suggest that we need to move quickly in developing MOSAs to ensure lunar interoperability.

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