CubeSats and the Standardization of the Space Industry

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On my honor as a University Student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments

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Introduction.

Many everyday services such as telecommunication, GPS, weather prediction, and data collection rely heavily on satellites to function. As information and data analysis become more crucial in society, satellites continually gain importance. However, satellites are incredibly expensive to develop and deploy. The exorbitant cost is a result of many factors including mass and lack of standardization. However, a new technology that could revolutionize the space industry has recently entered the scene, the CubeSat.

CubeSats are a class of nanosatellites, which refer to any satellite with a mass between 1 kg and 10 kg, that are built to standard dimensions (Units or "U") of 10 cm x 10 cm x 10 cm (Loff, 2015). The most common sizes of CubeSats are 1U, 2U, 3U, or 6U, and they typically weigh less than 1.33 kg per U (Loff, 2015). Originally proposed as a way to allow graduate students to design, test, and operate a satellite, CubeSats are quickly becoming a popular way to perform small space missions. In June 2003, the first six CubeSats were launched from Russia's Plesetsk launch site (Howell, 2018). Originally, only a few CubeSats were launched and most that were deployed originated from universities or research groups. However, in 2013 the commercial sector began to launch CubeSats and the number of launches started to number in the dozens. As of mid-2018, more than 2,100 CubeSats and nanosatellites have been launched (Howell, 2018).

The purpose of this paper is to explore how CubeSats are key in leading to standardization in the space industry. In order to analyze this topic, social construction of technology (SCOT) will be used as a framework. SCOT is a constructivist theory of technological innovation inspired by the sociology of scientific knowledge (SSK), particularly by

SSK’s principle of symmetry (Social construction of technology (SCOT), n.d.). SCOT holds that successful innovations cannot be explained by assuming that they “work” better than failed innovations. Instead, the analyst must undercover the social context that promotes (or fails to promote) a given innovation (Social construction of technology (SCOT), n.d.). There are three basic principles of SCOT, interpretive flexibility, relevant social groups, and stabilization. Interpretive flexibility is the idea that there is no "one best way" to create a new technological artifact; rather, each participating group has its own unique view of how the artifact should be made based on its interpretation of the problem that the artifact is supposed to solve (Social construction of technology (SCOT), n.d.). Relevant social groups are groups of people that consist of "all members of a certain social group [who] share the same set of meanings, attached to a specific artifact” (Social construction of technology (SCOT), n.d.). Finally, stabilization, it can come in two forms: rhetorical closure, which is when social groups see the problem as being solved and they will begin to talk about the problem being solved, or the problem is redefined (Social construction of technology (SCOT), n.d.).

The thesis will start by identifying the relevant social groups in the standardization of the space industry. In this section, the motivations of the relevant social groups will be explored. Before continuing the discussion, the thesis will introduce some additional background information and consider the advantages and disadvantages CubeSats have compared to traditional satellites. Next, the thesis will analyze the arguments for and against standardization in the space industry and the reasons the relevant social groups have for supporting their viewpoints. In particular, the economic factors and technical merits will be evaluated. It will also go in-depth into how CubeSats are instrumental to the standardization of parts in the space industry. The thesis will then attempt to determine the effect standardized parts have made in other industries, for example the defense industry, and draw parallels between them and the space industry. The effects of standardized parts on price, accessibility, and innovation in other industries and how they reflect on the future of the space industry will be the primary focus of this part of the thesis.

Relevant Social Groups.

According to SCOT, relevant social groups dictate the direction a technology will take. There are two main relevant social groups involved in standardization of the space industry, CubeSat manufacturers and traditional satellite manufacturers. CubeSat manufacturers are defined as groups of people who are intending to create a CubeSat mission. Traditional satellite manufacturers are defined as groups of people who are trying to create non-CubeSat space mission. The future of standardization in the space industry is dictated by the interactions of these two groups. CubeSat manufacturers are proponents of standardization while traditional satellite manufacturers are resistant to a change towards standardization.

Recent industry and military interest have led to many plans for CubeSat missions. For example, as of January 6th 2020, SpaceX has launched a total of 182 CubeSats as part of its StarLink constellation (Henry 2020). Additionally, government agencies such as the National Science Foundation, the National Oceanic Atmosphere Administration, and NASA have launched CubeSats as well (Leone 2015). However, CubeSat manufacturers still consist primarily of research groups, particularly universities. Since most CubeSat manufacturers are smaller groups with limited resources, CubeSat manufactures want keep the price of CubeSat missions low. The use of standardized CubeSat systems can help to achieve this goal. By manufacturing cheap satellites, small research groups can stay within a reasonable budget. For larger organizations, cheaper CubeSats can allow for more economically feasible missions or as an inexpensive way to conduct research and test technologies.

Traditional satellite manufactures often need to have systems and technologies that are unique to their specific satellites. To meet the precise requirements that the mission requires, most onboard components and technologies must be designed specifically for the mission. Additionally, most traditional satellites are created by larger, more well-funded organization such as the government or large corporations. Thus, development costs are not necessarily the most influential consideration for these manufacturers and allows them to consider more expensive approaches.

Technology Readiness Levels.

All technologies aboard a satellite must be highly reliable as performing maintenance on a satellite after it has been launched is nearly impossible. In order to define the reliability of a technology in space, technology readiness levels (TRL) are used as a measurement system. There are nine different technology readiness levels, with TRL 1 being the lowest and TRL 9 being the highest. A TLR 1 technology is one where scientific research into the technology is just beginning. When a fully functional prototype or representational model has been created, the technology rises to TRL 6 (Mai, 2017). Finally, when a technology has been "flight proven" during a successful mission, it achieves TRL 9 (Mai, 2017). Most technologies and parts that are used in satellites are rated TRL 6 or higher. Having parts achieve high TRL levels is an extremely long and costly process which plays into the high development costs of a satellite.

Advantages of CubeSats.

The interpretive flexibility tenet of SCOT is the idea that there is no "best way" that a technology should advance. Instead, each relevant social group has its own unique view of how a technology should proceed based on their interpretation of the problem that the technology is supposed to solve. Therefore, CubeSats should be viewed as a vessel for leading the space industry towards standardization. As such, it is important to look at the advantages and disadvantages of CubeSats as a technology in order to determine how successful they will be in changing the space industry.

One of the main advantages that CubeSats hold over traditional satellites is modularity. Mission parameters dictate the body shape and size of satellites. Since missions can vary wildly from satellite to satellite, there is little uniformity in satellite structures. The variation in body dimensions makes it difficult to have modular systems across different satellites. However, CubeSats have fixed body dimensions which easily allow for parts that are compatible with all CubeSat bodies. In fact, entire CubeSat subsystems that have already been flight tested are available as commercial off-the-shelf products from a number of suppliers. Structural components, on-board computers, navigation modules, sensors, power systems, and even propulsion systems are all available for purchase (Small Spacecraft Technology State of the Art, 2018). All of these parts have the benefit of having been extensively tested by a third party and have achieved high TRL statuses. The subsystem modules can be purchased independently from any number of suppliers and be used together as desired to meet the needs of the mission (Technology CubeSats, n.d).

Another major benefit that CubeSats have over traditional satellites is lower cost. CubeSats are cheaper to develop than traditional satellites by several orders of magnitude. A typical CubeSat costs between $5,000 to $50,000 to develop. In contrast, the US Air Force spent $577 million for ten GPS satellites in 2018, which averages to around $58 million per satellite (Elliott, 2018). A large amount of the savings can be attributed to the reduced launch costs for CubeSats. The price to get an object into space is heavily dependent on its mass. It costs between $5,000 to $10,000 per pound to get a satellite into low earth orbit, about 100 km high, and nearly five times as much to get a satellite into geosynchronous orbit, around 36,000 km high (Goyne, 2019). Since CubeSats are much smaller than traditional satellites, and therefore much lighter, sending them into space is much cheaper. Additionally, there are a number of organizations, such as the NASA CubeSat Launch Initiative, that will allow a CubeSat to hitch a ride along with some other larger payload, either for at a low cost or for free. Another factor that reduces CubeSat costs is the use of inexpensive parts. Off-the-shelf components are cheaper than parts that need to be designed and tested completely from scratch. Development and testing expenses are largely bypassed by buying off-the-shelf components. CubeSats, being smaller, also require fewer parts to fully function.

The final benefit that CubeSats possess is a much faster development cycle than traditional satellites. Typically, CubeSats take around 1 – 5 years to fully develop from inception to launch (Goyne, 2019). A traditional satellite, on the other hand, can take upwards to 10 years to be fully developed (Goyne, 2019). CubeSat development is much faster because CubeSats are not as complex as a traditional satellite. Furthermore, the use of off-the-shelf components eliminates a large portion of development time required.

Modularity, low development costs, and fast development cycles allow CubeSats to be successful as a technology. These benefits allow CubeSats to solve problems with price and development time that traditional satellites cannot address. As their popularity grows, CubeSats continue push the space industry closer towards standardization.

Disadvantages of CubeSats.

CubeSats, however, do pose some disadvantages compared to traditional satellites. The chief disadvantage is that CubeSats lack complexity. Space is a major design constraint in the development of CubeSats. The restrictive size of a CubeSat severely limits the kinds of technologies that can be put onboard. For example, propulsion systems are extremely rare in CubeSats although such systems are fairly standard in traditional satellites. As a result, the scope of CubeSat missions can be limited compared to what other traditional satellites might be able to accomplish.

Another disadvantage CubeSats have is low operation time. Most CubeSats only remain operational between 1 month to 5 years (Goyne 2019). In contrast, most traditional satellites are planned to be operational for at least 5 – 15 years and can still remain functional for up to 25 years after the fact (Goyne 2019). The limited lifespan of a CubeSat makes it difficult to perform missions which require a satellite to be operational for long periods of time. Instead, traditional satellites are preferable for these missions since they can be designed with longer operation times in mind.

The final major disadvantage CubeSats have is reliability. CubeSats have large reliability issues, with only 45 percent of missions from academic institutions and 77 percent from commercial companies resulting in success (Venturini 2018). The fast development cycles along with low costs causes the abnormally high failure rates. Traditional satellites, in comparison, are much more reliable because they are expensive. To prevent failure, extensive testing and design is done as to not waste the monetary investment. Manufacturers who are pursuing space missions which require high reliability are disincentivized from using CubeSats because traditional satellites are more reliable.

Merits of Standardization.

Standardization of the space industry is vital because it allows for manufacturing costs of satellites to drop. Currently, building a traditional satellite can cost several tens to hundreds of millions of dollars and a large portion of the cost originates from the design of the parts. Standardized parts allow satellites to avoid the costs involved in the development and TRL certification. Due to the ability to purchase and use prebuilt and pretested systems, all satellite manufacturers can reduce the total development cost of their satellites. Cheaper satellite production is desirable for both CubeSat and traditional satellite manufacturers. As the space industry is quite expensive, any reduction in costs of satellites is appreciated by all in the industry. Additionally, the lower satellite development expenses that result from the use of standardized parts make it feasible for smaller organizations to begin development of their own satellites. Standardization can also lead to new innovation as an influx of new people into the space industry caused by more readily accessible satellites allow for the introduction of new ideas. Both CubeSat and traditional satellite manufacturers benefit from new innovative space technology because it can enable new missions. Another benefit of lower satellite development cost is that an increased number of satellites can be launched. Increased number of satellite missions means that satellites can conduct additional research and provide more satellite services such as telecommunication to benefit society as a whole.

CubeSats play a key role in standardization largely because of their cheap and fast development cycles. Since many mission critical CubeSat parts can be bought off-the-shelf, a basic CubeSat design can be used as a baseline for many different missions. The CubeSat can then be used as an economic platform to quickly test parts in the harsh environment of space. A faster and cheaper verification cycle can lead to technologies becoming flight certified sooner which feeds back into the cycle of innovation. With more certified technology, standardized parts become more useful since it is more likely a part that is necessary for a certain mission has already been created and tested.

Issues with Standardization.

Standardization does, however, pose some problem to the space industry. Most space missions are unique and must meet very specific design requirements. If all parts were standardized, possible satellite designs would be restricted by the constraints applied by using the standardized parts. While this isn’t as much an issue for CubeSat manufacturers, since they tend to work with off-the-shelf components anyways, traditional satellite manufacturers would find this more restrictive. Traditional satellites tend to have missions that require more unique parts and as a result, standardization may be detrimental as it would introduce additional design restrictions. A fully custom satellite has the freedom to design all of its parts to its own precise specifications. However, when a standardized part is used, new unique parts must be designed around the preexisting systems in order to account for compatibility and avoid interference.

Another issue lies in reliability. Standardization leads to parts being produced in mass quantities and a trade-off of mass production is reliability. When a large quantity of parts is produced, it becomes nearly impossible to test each and every one of them. Statistically, this means that some of them are likely to fall below the advertised specifications and be unreliable. Other reliability issues can stem from compatibility issues that may arise from using parts from different suppliers. While parts from a single supplier are likely to be compatible, that is not necessarily the case when using parts from two or more different suppliers. Failure of a traditional satellite would result in the loss of an investment of several tens of millions of dollars and up to a decade of work. For a mission of that magnitude, failure is not an option. Thoroughly and personally designed and tested parts may be more desirable for these manufacturers to ensure reliability. While the loss of reliability is also a detriment to CubeSat manufacturers, CubeSats already have high failure rates and are a comparatively cheap investment so a failure would not be as harmful as the failure of a traditional satellite. A failed satellite that is unable to complete its mission is the equivalent of space junk as it provides no valuable data or services. To ensue mission success, reliability is one of the most important factors to consider. As incompatible or defective components can make the difference between a successful mission and a mission failure, the more rigorously tested custom parts may be more desirable than standardized components.

Parallels from the Defense Industry.

A good example of an industry revolutionized by standardization is the defense industry. Weapons, like satellites, used to be composed completely of unique parts. The lack of standardization among them caused production to be expensive. For example, during the eras of WW1 and WW2, the demand for weapons such as aircraft, tanks, vehicles, and spare parts skyrocketed. The increased demand called for massive increases in production and productivity and was met by streamlined production and standardized parts. The advent of standardization reduced the costs and improved the efficiency of these weapons. Mass produced standardized weapons replaced the individually produced ones and lowered the prices. Likewise, standardization can reduce manufacturing costs in the space industry as standardized systems become more commonly used in satellites.

While some parallels can be drawn from the defense industry, the space industry differs in some ways. A good example of this merely the amount of production. Standardization naturally leads to mass production because standardization allows for more parts to be made faster and for cheaper. The demand for weapons is tremendous, especially during times of war, and requires mass production to be met. However, satellites have fairly limited production runs in comparison to weapons. Another way the two industries differ is the need for reliability. In the defense industry, it is acceptable for some mass-produced weapons to fail. The sheer volume of identical objects produced renders the failure of one particular weapon a nonissue. Additionally, it may be possible to repair a malfunctioning weapon by replacing some of the parts. It is not acceptable for a satellite to fail because of the amount of investment it took to get there. The failure of a satellite would mean tens of millions of dollars and up to ten years of work were wasted. This is compounded by the fact that satellites are nearly impossible to repair after they have been launched.

Conclusion.

In conclusion, standardization of the space industry has the potential to benefit both CubeSat and traditional satellite manufacturers. The primary advantages come from potentially cheaper and faster development cycles and a reduction to the barrier of entry to the space industry. Both of these can increase the amount of innovation within the field. However, the disadvantages of standardization are felt much more heavily by traditional satellite manufacturers. In particular, additional design constraints and reliability are more important factors to traditional satellite manufacturers than to CubeSat manufacturers. Comparisons with the defense industry, show that the widespread use of standardized parts and systems can completely revolutionize the industry through cheaper production and an increase in innovation.

The widespread use of standardized parts has the potential to completely change the status quo of the space industry. CubeSats form the perfect platform to aid the transition, but the future remains unclear. Stabilization of this issue will occur if standardized parts become widely used throughout the space industry or if standardized satellite parts become no longer relevant or used.

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