# Economics and Financing of Communications Satellites

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**Abstract**

The economics and financing of satellite communications is a very large and complex topic. It ranges from normal business planning, analysis, and investment financing, to issues of government policy, dual-use technologies, and national security and defense. Commercial satellite systems represent a special case of economic analysis since such systems are heavily dependent on a government market that is focused on political considerations of budgeting and regulation. Today, satellite telecommunications systems are critical to almost all nations of the world, and they are especially important in approximately 60 nations that have domestic launch and/or satellite operations capabilities. This chapter will specifically focus on four topics: (1) a summary of the economic characteristics of the industry and a review of major trends in the industry, (2) a summary of the elements of a business plan for satellite telecommunications, (3) an analysis of

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issues in the manufacturing productivity for satellites and an analysis of commercial satellite manufacturing compared to government satellites, and (4) a brief discussion of future cost considerations including the increasing risk of space sustainability, insurance, and rules concerning disposal of satellites after their useful lifetime.

**Keywords**

Auction of spectrum • Commercial satellite systems • “Dual use” of satellite networks • Economics • Insurance • Investment financing • Launch costs • Manufacturing • Market sectors • Operating and capital costs of satellite networks • Satellite services • Satellites • Size of markets • Telecommunications • Video services

## Introduction

In 1876, Alexander Graham Bell invented the telephone. The invention spread rapidly and became the standard mode of remote voice communications during the first half of the twentieth century. Copper wires were strung and these became the major mode for the transmission of voice communications.

In the 1940s, Arthur C. Clarke suggested the possibility of using geostationary satellites to beam telecommunications signals from a point on Earth back to multiple points. However, during the mid-twentieth century, telephone signals were being relayed on land with copper cables and microwave towers and across the oceans with similar cables of limited capability compared to those that are in use today. During the 1960s, the first telecommunications satellites were launched successfully to low Earth orbit (LEO).

Although communications satellites had greater capacities than ground systems for overseas transmissions when first deployed in the 1960s and 1970s, this was no longer true when faster terrestrial communications using fiber-optic cables were developed in the 1980s. Cable transmissions of any type, it should be noted, are best designed for point-to-point communications, while satellites are best for point-to-multipoint uses.

Local commercial television broadcasts over the air were inaugurated in the late 1940s and grew rapidly. The larger selection of stations enabled by subscription cable delivery of television to households gradually became a standard form of TV delivery in most countries of the OECD. By the 1990s, national and international cable TV distribution was widespread and direct broadcast satellite TV to consumers was also beginning to grow, enabled by smaller terrestrial receiving antennas and more powerful satellites (Satellite Industries Association, http://www.sia.org/satellites.html). Satellite delivery is particularly advantageous in remote areas not served by cable but is also a strong competitor to cable in urban areas. As mentioned above, it is also the only system that can effectively deliver point-to-multipoint signals in nations that are not well wired, such as in developing countries.

There has been a very rapid and dramatic change in developed economies over the past two decades in terms of telecommunications delivery media. This has been a shift from wireless TV and wired telephone to wired (cable) TV and wireless cell phone systems – although direct broadcast satellite services now represent a significant delivery mode in many economically advanced countries as well. This shift is also beginning to occur in developing countries as well, but some of these patterns are less pronounced and some satellite networks (such as O3b) are seeking to provide broadband Internet services and video services directly to consumers in Africa and other parts of the world and thus seeking to bypass terrestrial cable networks.

These shifts are particularly significant for the satellite and space industry. Space capabilities are actually central to all systems today by being a part of the overall telecommunications services delivery chain. Cable TV, although wire-based to connect to homes, is dependent on network uploads via satellites. Cell phones and systems are also linked and coordinated by backhaul precision timing through GPS satellites. And, of course, satellite TV and radio are now ordinary consumer services in a very competitive market sold and distributed by many companies in many advanced economies such as the United States, Canada, Japan, Korea, Australia, and Europe to name only some of the countries where competitive satellite services are sold.

## Satellite Telecommunications Services

Satellite communications networks are separated into several types as noted in earlier chapters and particularly chapter "▶ Space Telecommunications Services and Applications." Fixed satellite services (FSS) typically transmit between a GEO satellite and one or more fixed locations terrestrially. The various types of telecommunications services that FSS networks provide include television distribution, broadband data, and voice communications. Some higher-powered FSS networks provide direct to home video and audio services.

So-called broadcast satellite services (BSS), as defined by the International Telecommunication Union (ITU), provide direct transmission to the home via very small dishes. There are also what are called direct audio broadcast services (DABS) or satellite radio services. Although different frequencies are allocated by the ITU for FSS, BSS, and DABS services, the distinctions between these services are not always very clear to consumers. This is because higher-powered FSS satellites can provide services that look and act like direct broadcast satellites services for either television or radio services. Overall revenues from these various types of satellite networks are heavily weighted toward video services. Television distribution and direct television satellite services generate over 75 % of the revenues, with data transmission representing about 20 % and voice services representing only some 5 % – at least for satellites serving the most economically developed countries.

Mobile satellite services (MSS) transmissions are conducted from satellites to receivers that are not fixed in any one point terrestrially. They include maritime, aeronautical, land mobile services, and other transportation-related uses, including emergency and police communications. Many of these networks are private.

In addition, there are many support services included in the satellite industry. As also described below, they include the manufacturing of satellites, launching services to get the satellites into proper orbits, ground receiving equipment, and many financial, insurance, and other business services.

All components of the industry have been growing, even during the recent economic recession beginning in 2008. Worldwide, the overall telecommunications satellite industry now generates the largest amount of revenues – by far – of any commercial space industry. The largest component of the communications satellite industry, in terms of revenues, is for provision of telecommunications services; this represented 58 % of total industry revenues in 2010. This was followed by revenues from the sales of ground equipment (31 %), manufacturing (8 %), and launches (3 %). (Satellite Industries Association, http://www.sia.org/satellites.html).

There are many satellite applications that provide opportunities for very useful and profitable businesses. Figure 1 in chapter "▶ Satellite Applications Handbook: The Complete Guide to Satellite Communications, Remote Sensing, Navigation, and Meteorology" of this handbook provides a good overview of the many types of satellite applications that affect our daily lives. Over time, it is clear that many of these applications have become a critical part of the economic infrastructure. Of the various market sectors of the commercial satellite world, communications satellites predominate in terms of total revenues, number of users around the world, and direct impact on people's lives. Despite this predominance of satellite communications, the other services, such as remote sensing and space navigation, are still greatly important. Satellite meteorology is typically not a commercial service, but it is nevertheless vital to public safety.

## The Business of Satellite Communications

Satellite telecommunication, in light of its huge revenue stream and the billions of consumers that use this service, is clearly the most mature of space applications. In fact, some economists would say that the 50-year-old communications satellite industry virtually represents the only example of a mature commercial use of space.

Planning, financing, building, launching, and operating a communications satellite or satellite system has become routine business. It is a long-term investment, and fits a standard business model. Satellite systems require a high up-front capital expenditure, a reasonably long manufacturing and start-up period (over 2 years), and face a number of high investment risk factors. In spite of the obstacles, satellite telecommunications has proven to be a space application that can generate a long-term multibillion dollar (US) revenue stream and profitable returns.

These systems are in some ways very different from most industries and in other ways identical. The differences are centered on the large government presence in the technological developments as well as the role of governments as a purchaser of these services. The similarities are like those with any other regulated infrastructure or utility that requires complex and expensive investments in equipment and/or distribution systems and that provide essential services to a large number of people. Because of these similarities to any private investment, this chapter will focus on specific topics unique to satellites and space businesses and will not attempt to describe normal business and economic issues that can easily be found in any basic management or economics textbook.

Early space telecommunication systems were not standard business ventures. They were built from a combination of public and private research and development (R&D) investments and required access to space. This vital launch service, in the first decades of communications satellite service, could only be provided through a government launch vehicle. Until the late 1970s, the only vehicles capable of performing the launch services were either in the United States or the USSR. And, the USSR was not in the commercial launch business and did not launch private satellite payloads. The US government's involvement in technological development and regulation, government purchase and use of the services (both military and civilian), and government policy were integral to any corporate telecommunications business plan.

The US government's role has dramatically changed over time. But it is still very important today. Although the US Department of Defense (DoD) has its own satellite telecommunications system, it also purchases a large amount of commercial capacity to fulfill its total communications needs.

In addition, in recent years the DoD has dedicated transponders and instruments on commercial satellite platforms. The use of these "hosted payloads" (both in the case of the United States and Europe) is currently growing and is projected to grow even more. This combination, which creates a new and profitable business opportunity for private satellite operators, also potentially enables defense agencies to save money by requiring fewer dedicated expensive satellites within its own fleet. But it adds an interesting dimension to the relationship between government and industry both in the United States and Europe and raises numerous questions about the role of private business with security-related space assets. This subject of dual use of communications satellites was addressed in chapter "▶ An Examination of the Governmental Use of Military and Commercial Satellite Communications."

The government is also a regulator. In the United States, the Federal Communications Commission allocates the available spectrum and is the US interface with the International Telecommunications Union. Most other countries have a governmental agency or ministry that oversees the use of radio frequencies including those for satellite communications. Often, this is the entity that participates in the International Telecommunication Union (ITU) processes and international conferences (As noted in chapter "▶ Space Telecommunications Services and Applications" the ITU oversees international spectrum issues and defines different types of satellite services and the associated frequencies for that service. The ITU also oversees the assignment of valuable locations in the geostationary orbit, which is where the largest telecommunications satellites are placed. Constellations that operate in low Earth orbit and medium Earth orbit are also under the purview of the ITU in terms of international regulatory processes.).

Governments fund and perform R&D that supports the technological development of the industry. It is also the province of governments to issue licenses for launching payloads into space (In the United States, the Department of Transportation, Federal Aviation Administration, is responsible for licensing launches. In most other countries this is a ministry that addresses space, but in Europe, the European Aviation Safety Agency (EASA) is assuming authority for some suborbital flights for the emerging industry known as "space tourism" or "space adventures."). These licenses require companies to demonstrate a set level of financial responsibility for their space activities and mandate that they follow detailed safety procedures and take a number of steps to avoid the creation of space debris (All FAA regulations can be accessed at: http://www.faa.gov/about/office_org/headquarters_offices/ast/regulations/).

What has changed over time is that any company can now purchase a launch and obtain access to space for a legitimate business purpose. There is competition for these services and they are not limited to the United States. Over ten nations now have launch capabilities and publically sell these launch services. Furthermore, many nations also now have the ability to manufacture satellites, and strong international competition now exists in the satellite manufacturing arena.

Figure 1 illustrates how widespread these satellite manufacturing capabilities are as demonstrated through orders for new commercial satellites. This data as compiled by the Futron Corporation on behalf of the Satellite Industry Association for 2010 shows for this year United States companies had 54 % of the market share, European companies 27 %, Russia 12 %, and India 8 %. Manufacturing capability also exists

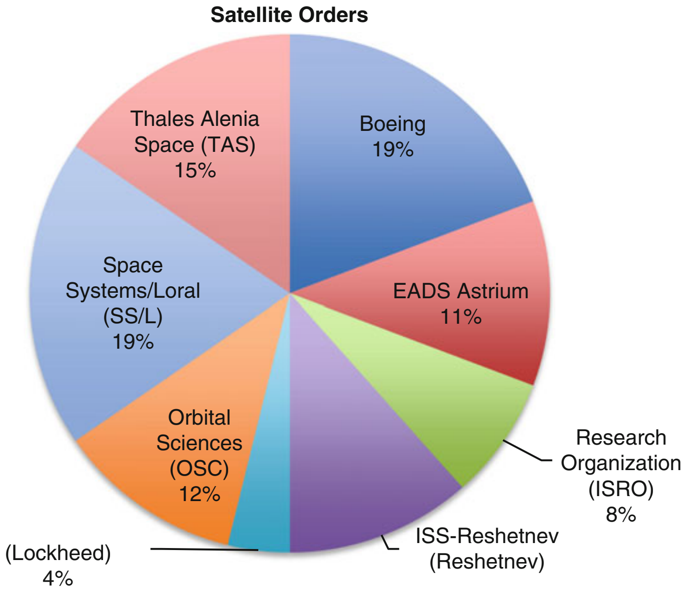

**Fig. 1** Commercial GEO satellite orders in 2010 (Futron Corporation: 2010a Year-End Summary)

in China and Japan, and these could expand in international importance in future years.

Initially international telecommunications via satellite were the preserve of a consortium that was set up as an international organization with open-ended membership of the different governments involved. Financing for this entity called Intelsat was provided through the many governments that participated in the consortium. It began with just a dozen members but expanded to over 100 countries. Beginning in the 1980s, this international monopoly approach began to be questioned and there were efforts to create competitive international systems. As the communications satellite sector developed to a more mature, reliable, and developed stage, private companies emerged and increasingly sought to offer GEO-based telecommunications services competitive with Intelsat. In the late 1990s, there were also plans for private LEO telecommunications satellites (These included the proposed Teledesic system for FSS-type offerings and the Globalstar, and Iridium for mobile satellite services, for example).

Although the satellite telecommunications industry has matured and produced many profitable and long-lived systems, it was not without risks and business failures. With the technology sector collapse in 2000, the Teledesic system was never completed, Globalstar had to file for bankruptcy protection; Iridium (owned by Motorola) also went into bankruptcy. Today, nearly 20 years later, large-scale low Earth orbit satellites such as Skybox, OneWeb and SpaceX constellations are being deployed or seriously planned. It is too soon to assess their profitability and long-run success but three things have radically changed in recent years: (1) the ability to develop small satellites with large capabilities and the ability for the satellites in these constellations to communicate with each other, (2) the total cost of manufacturing and launching a small satellite is far less than that for launching a large satellite (even though the cost per kilogram of launching remains very high), and (3) the regulatory structure in nations is adopting to accommodate and incentivize private sector ventures in space.

This is now an extension of the trend that began in the mid-1980s toward the privatization of the satellite communications industry. At that time the industry was also threatened by competition with fiber-optic cables. By 2001, not only had Intelsat been privatized, so had Inmarsat (in 1999) as well as Eutelsat (also in 2001). This was a time of enormous change in the business and economic structure of the satellite communications industry. Along with the privatization was the influx of new companies, the creation of substantial debt equity, the purchase of Comsat by Lockheed, the end of the technology "bubble," and the "dot com" collapse (Mechanick 2011).

This radical and relatively fast change in the way the satellite communications industry was organized and structured created economic benefits as well as added business risks. Bankruptcies (e.g., Iridium, Globalstar, Teledesic, and ICO), new mergers, and international telecommunications conglomerates all became part of a constant flux in companies and market positions. These mergers and acquisitions and the transfer of ownership from governments to equity finance institutions has led to dominance in the international FSS business by Intelsat (headquartered in Bermuda), SES (headquartered in Luxembourg), and Eutelsat (headquartered in Paris). International mobile satellite service is dominated by Inmarsat (headquartered in London), but the reconstituted Iridium and Globalstar still offer key services around the world. The largest industry in terms of revenues is the direct broadcast satellite television services and these are spread around the world. Many smaller satellite companies also continue to operate but with a small part of the global revenues. Most of the satellite commercial business is concentrated in about a dozen satellite operators around the world. There are changes in satellite technology occurring that seem likely to change the economics of satellite communications services moving forward. These are the new high throughput satellites and the new Internet-optimized satellite constellations with a large number of smaller satellites that are now planned to be deployed in low Earth orbit. As mentioned above, it is still too early to assess the impact that these two new trends will ultimately make. (The appendices at the end of the handbook provides information with regard to the many different commercial satellite communications entities providing domestic, regional, or international services.)

## Trends in Access to Space and in Manufacturing Satellites

### Access to Space

There has been a long-standing expectation in the space community that the cost of access to space (i.e., launch vehicles) will drop exponentially. A major breakthrough in launch technologies has been a goal of numerous unsuccessful R&D programs such as the NASA/Lockheed-Martin X-33 effort that was canceled in 2001 as well as other similar efforts such as the X-34, the X-37, the X-38, and the X-43 (Pelton and Marshall 2006). The corollary of a dramatic drop in cost of access (and prices for launching) is that a floodgate will open and that markets will suddenly develop for new uses of the space environment. Profitable private ventures will flourish and government agencies will be able to purchase inexpensive launches for research satellites and payloads.

This call for inexpensive access illustrates the dramatic way in which economic factors could influence the demand for space. To date, their influence can only be found in the negative hypothesis: that expensive access to space has capped the demand for space activities and created a barrier to entry that is virtually insurmountable for most activities. This is an example of a “technology push” where the emphasis is on the supply side – providing access cheaply. There really is no economic reason to develop the technology unless there is a sufficient market demand to do something of value in space. There may be other reasons – social, political, or security – to go to space often and cheaply which could provide a public-goods stimulus for additional investments in cheap access technologies.

The assumption that cheaper access to space is the key to the future growth of space activities should be subjected to a closer analysis. The results may be very mixed, that is, cheaper access to space will clearly benefit both suppliers of space products and services as well as consumers of those products. But there are current and future space activities that will exist whether or not the cost of access is significantly decreased. Telecommunications is one of these.

First, consider the types of space applications that are not very price sensitive to launch costs. Essentially they require very large up-front investments that are recovered and exceeded relatively quickly over time from project revenues. Typically the services are sold to end users and therefore have a large mass market where the stream of revenues is relatively easily foreseen. In telecommunications, the existing large demand for voice and other transmissions existed before communications satellites were developed. Once a space satellite or facility is launched and placed into the desired orbit, it can have an expected lifetime of 15 years. This is a life expectancy double that of a telecommunications satellite built just a couple of decades ago, which will result in a noticeable decrease in the demand for future satellite manufacturing and launches. Of course other unpredictable factors such as the future demand for telecommunication services and the crowding of the most profitable geostationary orbits and spectrum bands will also affect future launch demand.

Also future in-orbit servicing and re-fueling could also have an impact on the industry. If successful, these types of services will enable the extension of the life of many operating satellites (through refueling techniques) as well as enable the monitoring and repair of some satellites by using advanced maneuvering techniques along with cameras to diagnose problems. Farther into the future, if satellites are designed with docking technologies, true “plug and play” upgrades may be possible and economically feasible.

Numerous business cases have demonstrated that even the high cost of building the satellite system and the high cost of launching it are relatively small percentages of the total revenue over its operational lifetime. Cheaper access to space might mean higher profits for the owner or operator of the system, but today’s profits are sufficiently large that expensive up-front costs have not deterred companies from making these investments. These costs have made it more difficult for satellites to compete with high-capacity and high-cost-efficiency fiber-optic networks.

Second, consider the types of activities have the best opportunity to grow if there is cheap access. The largest opportunity in this respect might be activities that require multiple and regular trips to space and return to Earth. This implies one of three things:

1. That there is something to do in space itself (e.g., manufacturing or transporting people to space and providing for their return)
2. That point-to-point Earth transportation through space at high speeds could be proven to be technologically feasible and safe
3. That a true market for space adventurism or tourism exists and, as above, people will hopefully have something useful to do there

Third, consider the opportunities related to private research and development (R&D) involving space activities. Such activities are presently far too expensive for most companies or universities (The availability of direct government subsidies and other incentives for space research has been the standard practice for many years. With the current budget deficit coupled with the increasing complexity and cost of research equipment, future government aid is not likely to match the demand for this type of research effort). Private capital markets for high-risk R&D funds are often not large enough for a space project, since the cost of a launch is usually included in the cost of a corporate or university research program. In today's environment, an expensive launch can be the deterrent to proceed with the project.

Fourth, consider government programs or project activities that are subject to major budget pressures. There is, of course, a difference between an agency's budget and the project's budget. Many government project managers are advocating cheaper access in order to carry out their projects on a cost-effective basis since their individual funds are constrained. The agency-level huge capital requirements to fund a technology program that might lead to reducing launch costs are outside of the scope and capability of the project offices that are generally most concerned with current operating costs. Even though they are within the same government organizations, the role of a project manager is more similar to that of any final demand consumer.

Fifth, consider that there is a limit to how much launch costs can be lowered. Even if the cost of the launch vehicle is reduced dramatically, a number of other economic factors are not likely to change. Among them are:

- The high costs of launch facilities, payload integration, storage, testing, etc.
- For the foreseeable future, only launches from a coastal location or a very sparsely populated and remote area will be permitted because of safety considerations. This will make it necessary to transport, at considerable cost, payloads a significant distance from the point where the business is located or the product is manufactured to the launch site. The same delay will also exist at the delivery site. These costs will not be reflected in the launch price itself but are real costs in time and transportation to the customer (Sea launch operations or manufacture and launch from the state of California where many manufacturers are located, however, could possibly mitigate these considerations.).
- Delays in launches will frequently occur and add to launch costs.
  - Launch vehicles are complex machines, and mechanical problems will occur with some frequency.
  - Weather will delay launches as it does today for both space launches and even normal airline traffic.
  - Security issues may cause delays.
  - Regulatory issues (safety, financial, environmental, etc.) will also likely continue to be complex and costly.

Payloads bound for space will need to carry very valuable commodities where the speed of delivery is of the highest priority. This means that a launch schedule has to have a high degree of reliability with little variance, otherwise alternatives will be financially more attractive. The time value of money, therefore, becomes a large expense, unrelated to the hardware costs of physically getting to space and returning. Export control issues will continue to dominate launches and will become particularly difficult if landings and relaunch occur in different nations. The demand for launches may never reach a level where economies of scale in manufacturing and launching will be realized. Insurance and liability issues will continue to be problems, particularly since the cost of insurance is related not only to the safety record of launch vehicles but also to the general level of claims payouts of all insurance and reinsurance policies. And, finally there is always the probability of an accident and the risks of suspended operations for a long period of time until the cause of the accident is determined and fixed.

Sixth, and last, one must consider the economics of the cost of developing a new and cheaper launch system. What will the government or private organization pay for the very expensive development of a new system? Who will bear the risks? Will the costs be amortized over the lifetime of the vehicles (and result in higher launch prices) or will a government underwrite the costs? Who benefits from such a system, and will taxpayers be willing to assume the burden of the cost?

The answers to these questions are not just an academic exercise. They go to the root of the linkages between economic and social motivations for future space activities, and how they are answered will shape much of future space development.

It is interesting to note that a 1975 study of the next 200 years in space made an assumption that access to space would be much cheaper by the year 2000 (Brown and Kahn 1977). The study analyzed many scenarios for the future using a variety of different assumptions. One of these assumptions stands out prominently. By extrapolating the rapid trend in technological improvements, most noticeably in integrated chips and computers, and transferring that to launch vehicle improvements during the 1950s and 1960s, the report concluded that this trend of increased productivity and efficiency coupled with rapid decreases in prices would continue. Clearly, it has not. Space access is nearly as expensive today as it was in 1975.

A common thread of the literature on space commercialization is that cheap access is key to the future development of space. Given the above-mentioned parameters and the very difficult hurdles that will have to be overcome in many more areas than simply new launch technologies, this assumption comes into question and thus should be studied much more closely. It very well may be that some important activities will occur if launches are dramatically cheaper. But, history has already demonstrated that profitable space activities, particularly in telecommunications and related services that have large and mature terrestrial markets, are possible even with expensive launches. Likewise, it is possible that new launch systems using tethers, so-called space elevators, rail guns, or nuclear or electrical propulsion (as opposed to chemical propulsion) may be developed in future years, but such alternatives are not near-term prospects, and the implications of such alternative launch systems are not clear at this time.

In addition, telecommunications companies are experimenting with new technologies, cost, and operating structures. Intelsat General, for example, has announced a new capability with its Epic$^{ng}$ satellites due to be launched in 2016. Technological improvements will enable multi-spot beams that will enable a pricing structure to customers that reflects their actual use of mobile equipment rather than the current systems that lease a fixed amount of transponder capacity to a geographic area. Not only will this allow pricing to reflect use and likely result in lower prices to consumers, but it will also free up bandwidth so that the company can better serve surge requirements or geographic shifts in demand.

## Comparisons of Productivity in Manufacturing Satellites

Satellites have become more efficient for companies to manufacture by using state-of-the-art production techniques and by a steady demand enabling the realization of economies of scale. Satellites have also become larger, more powerful, and longer-lived (An exception to this is the development of microsatellites and nanosatellites for LEO applications. This discussion is primarily focused on the large GEO telecommunications satellites. In the future, it is possible that some telecommunications applications will be possible with very small satellites).

As noted earlier, the expected lifetime of a new GEO satellite is now more than double what it was 20 years ago. Not all satellites are the same, and the following discussion documents the important differences between manufacturing a government satellite from those made for commercial purposes. Such satellites are different products: commercial satellites are produced relatively quickly and efficiently in response to for-profit pressures, while the government satellites are often pushing the new technology edge and are also subject to government-mandated oversight and audits. Many military satellites have special requirements for radiation hardening, encryption capabilities, and redundancy or protective switches. Often the same companies produce both types of satellites. A comparison, discussed below, of manufacturing productivity and efficiency has documented that the commercial satellites are made faster and more efficiently (Coonce et al. 2010). But the study also highlights a number of important financial and economic characteristics of the manufacturing process and concludes that improvements in the efficiency of producing government satellites would also be possible without major systemic changes.

Three types of satellite systems are compared. First are commercial telecommunications satellites manufactured for private customers. Second are civilian government telecommunications and research scientific satellites. Last are the military satellites for communications and Earth observations.

To compare systems of similar content or classes across agencies, a normalizing metric is necessary. Although some simple metrics, such as cost per kilogram, can be used to compare different systems, such a metric does not provide an assessment of the overall capability and complexity of a system. To assess the relative efficiency of different systems, the Complexity Based Risk Assessment (CoBRA) approach was chosen to assess a “dollar per unit complexity” metric.

The CoBRA complexity index is based on the order of 50 different system parameters, including mass, power, data rate, the number and type of instruments, solar array size, etc., and is used to determine the relative ranking of a system

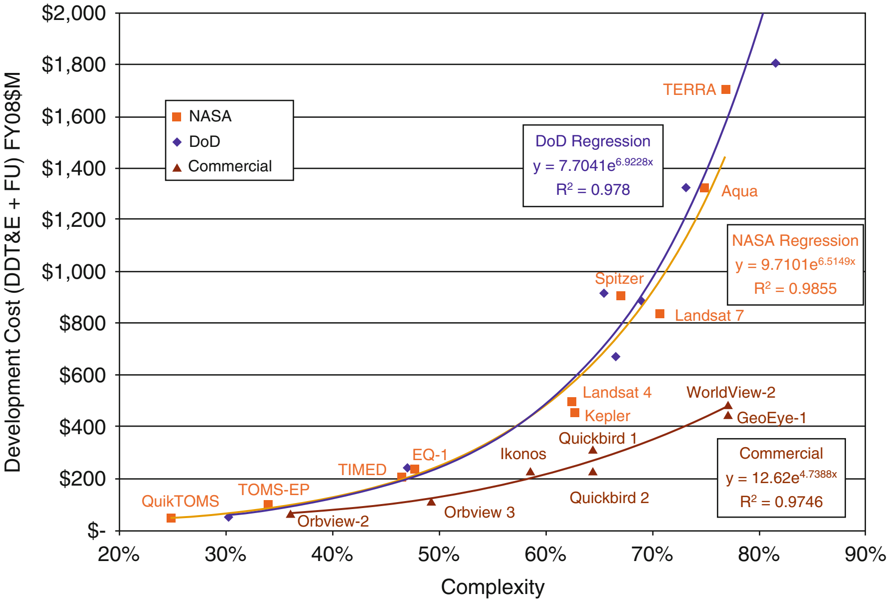

**Fig. 2** Efficiencies in DoD and NASA production are similar but less than commercial

compared to over 120 other satellites. The measure is on a scale of 0–1.0, with the low values having the least capability relative to all of the spacecraft in the database, and a high value representing the most capable system (Bitten et al. 2005).

A regression of complexity versus cost for different customers reveals insights into relative efficiencies. Figure 2, shows the plot of a regression of complexity versus development cost for the DoD, NASA, and commercial imaging. Figure 2 above shows a substantially higher cost for a given level of complexity, relative to similar commercial systems.

A potential explanation for such a trend can be shown when looking at a similar regression for the same systems relative to the time schedule of production as shown in Figure 3 above. The regression for NASA and DoD missions are similar to the cost regression shown previously where schedule increases as the complexity increases. This makes intuitive sense as the development cost typically increases as schedule increases and both are greater with higher levels of complexity (Fig. 3).

This trend, however, is not the same for commercial imaging systems. As shown, the regression for schedule relative to the increasing complexity for commercial systems is similar regardless of the level of complexity.

Commercial systems show cheaper costs and shorter manufacturing times because they rely on the same payload and spacecraft bus for each successive satellite. The commercial satellite manufacturers tend to develop “platforms” that can be used with a series of progressively larger satellites. This is in some ways comparable to the “platforms” that automobile manufacturers now use. Establishing

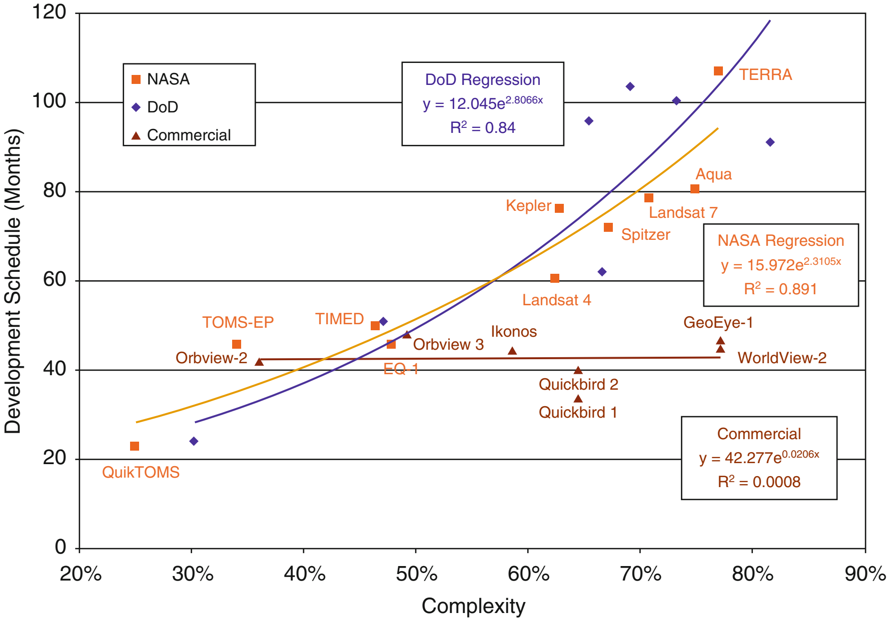

**Fig. 3** Schedule increases with complexity for government systems

a long-term commitment and partnership with industry providers enables this evolutionary approach where teams can build upon past experience to become more efficient for more complex future systems (An example of such a system is the QuickBird, WorldView 1, and WorldView 2 evolutionary approaches that migrated a 0.6 m imaging system on a standard bus [BCP 2000 for QuickBird] to a more capable 0.6 m imaging system on a larger, standard bus from the same provider [BCP 5000 for WorldView 1] to a 1.1 m imaging system [WorldView 2] on the same bus as used for WorldView 1. This evolutionary approach minimized risk and maximized team efficiencies).

The evolutionary approach was developed because commercial satellites are able to take advantage of a number of options not usually applicable to government satellites, including:

- A fixed-cost tight time schedule
- A much less complex design and instrumentation than government research and development satellites
- An evolutionary approach to cutting-edge technology
- A ground system that is an integral component
- An unambiguous set of technical requirements which demand lower skill levels
- A payment schedule based on progress and in some cases incentives for efficient, timely, and reliable performance

The analysis in the study as well as comments from industry and government reviewers had the following conclusions:

- NASA and DoD spacecraft require about twice the systems engineering staff relative to what is done on commercial ventures.
- NASA and DoD spacecraft require about 1.5 times longer for assembly, integration, and testing than commercial ventures.
- On a cost per pound basis, DoD projects cost about four times as much as commercial projects, while NASA projects cost about twice as much as commercial projects.
- On hours per drawing basis, DoD projects require more than three times as much time as commercial projects while NASA projects two times as much time.
- At least one company ranks productivity as follows (highest to lowest): commercial, performance-based government contracts, cost-plus-award-fee government contracts, and DoD classified projects.
- Government-sponsored special communications satellites take more than twice as long to manufacture than comparable commercial communications satellites (over 5 years, compared to 2.5 years) and are even less efficient to manufacture because:
  - They have more reporting requirements that need formal approval.
  - They have to undergo more testing.
  - They have more on-site government and other personnel.
  - They are designed to carry out more functions.

Manufacturers of commercial satellites use proven component parts. They assemble and test them rather than invest in new technological development. They also noted the use of standardized processes and that customers do not change requirements once a contract is signed. This allows them to produce their satellites within a 24–36-month timeframe, which, as mentioned above, is approximately half the amount of time required for government projects. They also noted that commercial fixed-price contracts are easier to finance and administer than cost-plus government contracts since contract and payment schedules are negotiated between client and customer without restrictions imposed by complex government procurement regulations. Up-front and progress payments are scheduled according to milestones that are generated to encourage schedule compliance. Commercial entities also purchase risk insurance because they have incentives to deliver on time. They noted that government programs impose far more technical reviews, changes in design, and oversight than commercial customers.

Another conclusion is that there is not that much difference in productivity among different government programs (although some of the data presented suggest that unclassified projects are more "productive" [in terms of cost efficiency] than the classified ones). Table 1 in chapter "▶ Introduction to Satellite Navigation Systems," summarizes the full set of differences in producing satellites for the government compared to private customers. Although this study only examined the US experience, there is a reasonable expectation that similar results would be found if commercial, governmental, and military satellite projects were compared in other regions such as Europe (Table 1).

**Table 1** Commercial satellite and government-sponsored projects compared

| Category | Commercial | Government |
|---|---|---|
| Development trend | Evolutionary | Revolutionary |
| Production | Standardization and reuse of building blocks. Build multiple units | Unique designs. Build one of a kind |
| Requirement definition | Well understood before project start | Not well understood at project start |
| Requirement stability | Stable | Unstable |
| Stakeholders | Single customer/stakeholder | Many stakeholders |
| Performance specification | Specifies only performance requirements | Specifies performance requirements and methods |
| Design incentive | Profit driven | Science driven |
| Design approach | Satellite buses viewed as product line and are a known entity | Changes, especially after the start of the project, drives the design of the satellite bus |
| Cost and schedule | Based on known similar historical data (buy mode) | Cost and schedule estimates are optimistic (sell mode) |
| Funding stability | Stable | Potential annual changes (often a result of budget pressures) |
| Portfolio management | If a project gets into trouble, it typically gets canceled | Projects allowed to continue and usually cause collateral damage to the portfolio (a very inefficient outcome) |
| Procurement process | Streamlined | Long and complicated |
| Contract type | Incentives for early delivery and late delivery penalties | Cost-plus-type contracts |
| Oversight and reporting | Minimal oversight of subcontractors | Extensive oversight of primes and subcontractors |
| Test philosophy | Deletes non-value-added processes (profit driven) | Tends to avoid seeking waivers. Success valued on success of mission, not cost or schedule overruns |

In short, although both commercial satellites and government satellites share many technologies, commercial products are built and operated with profit as the objective. Government satellites, and in particular NASA satellites, are for research and development purposes and are often typically designed as first of a kind, using cutting-edge technology and with knowledge or support of other government programs as the goal.

Because of the above reasons, there is no a priori reason to conclude that a comparison of commercial satellites and government satellites, even though they may be designed for similar purposes, should or will result in equivalent costs and performance.

## Conclusion

The economics of communications satellite has evolved from a government-controlled, privately operated system to a heavily regulated, oligopolistic, somewhat competitive essential part of our economic infrastructure. From the early voice and data transmissions, there are now a wide variety of satellite services ranging from direct broadcast television to the rapid transmission of data and information for the global financial network.

The space system continues to be expensive and risky. Only relatively large companies can effectively compete for manufacturing satellites, launch services, and operations. The large number of mergers over the past 20 years is strong evidence of this, coupled with the emergence of only a few dominant firms. However, terrestrial services using the satellite-based relay and transmission are spread over many different sectors, many different companies, and many different end users. It is truly competitive and is the fastest growing part of the satellite communications business.

Also evidenced by the maturity of the industry is the international and global dimension of the industry. One of the main advantages of using satellites for communications centers on their global or at least broad regional coverage and their ability to broadcast information simultaneously from one point to many points on Earth. In the 1960s, the United States had developed the technology and had the ability to launch these satellites. This was matched only by the Soviet Union, mainly by their launch capabilities, not their advanced technology in telecommunications. Because of the strategic importance of this capability, the United States dominated the industry. Today that has changed. The United States still has many capabilities in terms of advanced telecommunications satellite technology, but very capable and competitive systems, particularly for civilian purposes, can be bought from commercial suppliers in many parts of the world and launched by many other countries as can be seen in Fig. 1 in chapter "▶ Introduction to Satellite Navigation Systems" and in the Appendices to this handbook.

From an economic perspective, there are a number of challenges facing the future of the industry. First, there are competing forms of transmission such as fiber-optic cables that did not exist when satellites were first deployed. Second, the available spectrum is limited and scarce.

Allocating spectrum for communications purposes is both an international and diplomatic exercise as well as an economic one. Nationally, it is handled differently in each nation, some using sophisticated economic means such as auctions and others using more political and less market-driven allocation schemes.

Space itself is more crowded with human-made objects. Some are controllable and working and others are older abandoned satellites or debris. These represent potential hazards to orbiting satellites. Furthermore, there are still no agreed-upon effective means of controlling the growth of the debris or ensuring that there will be a sustainable and secure future for satellite operations.

One of the more daunting and important issue facing the satellite communications industry is this increasing risk of serious damage and consequent service interruptions and the liability due to a collision due to debris or a derelict satellite. There are costs associated with developing better space sustainability. First, hardening a spacecraft when it is being built to minimize damage is expensive and adds weight to the launch payload, which entails additional expense. Second, while the spacecraft is in orbit, fuel must be reserved for additional maneuvers to avoid a collision with oncoming uncontrolled objects. Third, additional fuel must be reserved for end-of-life deorbiting or boosting to a graveyard orbit (Or, in the future, servicing satellites may provide alternatives for end-of-life maneuvers. But at present, the cost of these still-to-be-developed services is undetermined. These types of in-space services will also face major regulatory issues, and the combination of expense and administrative hurdles may not produce a viable economic business). Fourth, additional personnel must be dedicated to minimizing debris during manufacture, operations, and possibly even when the satellite is no longer in use.

The manufacturing and operating firms would largely be the entities to incur these costs. In addition, governments now face monitoring, mitigation, regulatory costs associated with satellite communications and satellite applications. In the future, if technology permits, they may face cleanup costs. These can range from relatively trivial routine monitoring to very expensive in-orbit activities. The funds for these activities may come from a combination of governmental funds, insurance companies, and the owner/operator firm’s themselves.

Although economics – the allocation of resources and the opportunity to make a profit from an investment in satellite communications businesses – will drive many aspects of this business, the involvement of governments will continue to add cost, risk, and political dimensions to any private sector activity in space. However, government’s involvement has diminished somewhat as the industry has matured, and current trends indicate that the industry will continue to grow rapidly, and the degree of influence governments have over private satellite communications activities may thus also continue to diminish.

It is likely that current and future developments in this industry will be apparent on both the supply side and the demand side. On the supply side, private firms will develop new technologies and operating systems that will reduce costs. It is likely that prices to consumers will also decrease. Smaller but more numerous smaller satellites will be developed that will also contribute to cost efficiencies, particularly for launching into space.

On the demand side, both the expansion of markets into developing nations and the growth and merging of the earth observations, telecommunications, and navigation satellite services into the overall information sector, coupled with the advent of “big data” systems, will increase demand for space-based services as well as provide both government and private customers measurable improvements in productivity and in services.

## Cross-References

- ▶ An Examination of the Governmental Use of Military and Commercial Satellite Communications
- ▶ Fixed Satellite Communications: Market Dynamics and Trends
- ▶ History of Satellite Communications
- ▶ Mobile Satellite Communications Markets: Dynamics and Trends
- ▶ Satellite Applications Handbook: The Complete Guide to Satellite Communications, Remote Sensing, Navigation, and Meteorology
- ▶ Satellite Communications Overview
- ▶ Satellite Communications Video Markets: Dynamics and Trends
- ▶ Satellite Orbits for Communications Satellites
- ▶ Space Telecommunications Services and Applications

## References

R.E. Bitten, D.A. Bearden, D.L. Emmons, A quantitative assessment of complexity, cost, and schedule: achieving a balanced approach for program success. in *Sixth IAA International Conference on Low-Cost Planetary Missions*, Kyoto, 11–13 Oct 2005

W.M. Brown, H. Kahn, in *Long-Term Prospects for Developments in Space* (A Scenario Approach) (Hudson Institute, New York, 1977). NASW-2924, 30 Oct 1977

T. Coonce, J. Hamaker, H. Hertzfeld, R. Bitten, NASA productivity. J. Cost Anal. Parametric. **3**(1), 59–73 (2010). Society of Cost Estimating and Analysia – International Society of Parametric Analysis

Futron Corporation, Futron corporation state of the satellite industry report 2010 (2010a), sponsored by the Satellite Industries Association, http://www.futron.com/resources.xml#tabs-4. Accessed 29 May 2011

Futron Corporation, Futron forecast of global satellite services demand – overview (2010b), http://www.futron.com/resources.xml#tabs-4. Accessed 29 May 2011

Futron Corporation, Telecommunications report (2010c), http://www.futron.com/resources.xml#tabs-4. Accessed 29 May 2011

M.J. Mechanick, *The Politics of the Establishment and the Eventual Privatization of the Three Major International Satellite Organizations.* (White & Case, LLP, 2011), (unpublished manuscript)

J.N. Pelton, P. Marshall, *NASA's Unsuccessful X-Projects, Space Exploration and Astronaut Safety* (AIAA, Reston, 2006), pp. 149–178

Satellite Industries Association: Satellites 101, http://www.sia.org/satellites.html. Accessed 20 May 2011

## Further Reading

D. Cavosa, Satellite Industries Association, COMSTAC presentation (2004), http://www.sia.org/present.html. Accessed 29 May 2011

European Satellite Operators Association, Economics of satellites (2010), http://www.esoa.net/Economics_of_satellites.htm. Accessed June 2011

B. Henoch, Satellite technology basics, March (2007), http://www.sia.org/present.html. Accessed 29 May 2011

Z. Szajnfarber, M. Stringfellow, A. Weigel, The impact of customer–contractor interactions on spacecraft innovation: insights from communication satellite history. Acta Astronom. **67**, 1306–1317 (2010)