Building Technological Capability within Satellite Programs in Developing Countries

by

Danielle Renee Wood

S.B., Aeronautics and Astronautics, Massachusetts Institute of Technology, 2005
S.M., Aeronautics and Astronautics, Massachusetts Institute of Technology, 2008
S.M., Technology and Policy, Massachusetts Institute of Technology, 2008

Submitted to the Engineering Systems Division
In Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy

In Engineering Systems at the Massachusetts Institute of Technology
February 3, 2012

Author____
Engineering Systems Division
February 2012

Certified by____
Annalisa Weigel
Assistant Professor of Aeronautics & Astronautics and Engineering Systems
Dissertation Supervisor

Certified by____
Alice Amsden
Professor of Political Economy, Department of Urban Studies and Planning
Dissertation Committee Member

Certified by____
Hamsa Balakrishnan
Assistant Professor of Aeronautics & Astronautics and Engineering Systems
Dissertation Committee Member

Accepted by____
Olivier de Weck
Associate Professor of Aeronautics & Astronautics and Engineering Systems
Chair, ESD Education Committee

Building Technological Capability within Satellite Programs in Developing Countries
by
Danielle Renee Wood

Submitted to the Engineering Systems Division on February 3, 2012,
in Partial Fulfillment of the Requirements for the
Degree of Doctor of Philosophy in Engineering Systems

ABSTRACT

Global participation in space activity is growing as satellite technology matures and spreads. Countries in Africa, Asia and Latin America are creating or reinvigorating national satellite programs. These countries are building local capability in space through technological learning. They sometimes pursue this via collaborative satellite development projects with foreign firms that provide training. This phenomenon of collaborative satellite development projects is poorly understood by researchers of technological learning and technology transfer. The approach has potential to facilitate learning, but there are also challenges due to misaligned incentives and the tacit nature of the technology. Perspectives from literature on Technological Learning, Technology Transfer, Complex Product Systems and Product Delivery provide useful but incomplete insight for decision makers in such projects. This work seeks a deeper understanding of capability building through collaborative technology projects by conceiving of the projects as complex, socio-technical systems with architectures. The architecture of a system is the assignment of form to execute a function along a series of dimensions. The research questions explore the architecture of collaborative satellite projects, the nature of capability building during such projects, and the relationship between architecture and capability building. The research design uses inductive, exploratory case studies to investigate six collaborative satellite development projects. Data collection harnesses international field work driven by interviews, observation, and documents. The data analysis develops structured narratives, architectural comparison and capability building assessment. The architectural comparison reveals substantial variation in project implementation, especially in the areas of project initiation, technical specifications of the satellite, training approaches and the supplier selection process. The individual capability building assessment shows that most trainee engineers gradually progressed from no experience with satellites through theoretical training to supervised experience; a minority achieved independent experience. At the organizational level, the emerging space organizations achieved high levels of autonomy in project definition and satellite operation, but they were dependent on foreign firms for satellite design, manufacture, test and launch. The case studies can be summarized by three archetypal projects defined as "Politically Pushed," "Structured," and "Risk Taking." Countries in the case studies tended to start in a Politically Pushed mode, and then moved into either Structured or Risk Taking mode. Decision makers in emerging satellite programs can use the results of this dissertation to consider the broad set of architectural options for capability building. Future work will continue to probe how specific architectural decisions impact capability building outcomes in satellite projects and other technologies.

Dissertation Supervisor: Annalisa Weigel
Title: Assistant Professor of Aeronautics & Astronautics and Engineering Systems

Acknowledgements

This dissertation is about partnership and collaboration. It would not have been possible for me to complete the project without the partnership of many people. I wish to express deep appreciation to them. My husband, Jonathan, provided great support and personal sacrifice to give me the opportunity to study for a PhD. He also joined me for the extensive data collection field travel and participated in many interviews, site visits and conferences. I greatly enjoyed having him as part of the research team. It has been a joy and honor to work with my advisor, Prof Weigel, whose unique combinations of skills, interests and personality suited me and this project so well. Thank you for supporting my ideas and aspirations so consistently. I also thank my committee members, Prof Balakrishnan and Prof Amsden, who joined me in formulating and executing this project. I wish to express thanks to the many organizations that hosted during the data collection process. Their stories and hospitality are at the heart of this dissertation. My thanks go to the Engineering Systems Division community. I found this department to be my ideal doctoral setting. Finally, I thank my family for their belief, support, love, flexibility and patience through this long journey.

Author Biography

Danielle Wood, formerly Danielle Adams, combines skills in aerospace engineering, technology policy and international development to explore the intersection of space with societal challenges. Danielle received two Master of Science degrees from the Massachusetts Institute of Technology in 2008: one is in Aerospace Engineering; the second is in Technology Policy. Danielle also received her Bachelor of Science degree from MIT in Aeronautics and Astronautics in 2005. During her studies at MIT, Danielle worked as a Research Assistant in the Center for Aerospace Systems, Policy and Architecture Research (2007-2012) and the Space Systems Laboratory (2003-2006). Danielle also served as an Undergraduate Teaching Assistant for Unified Engineering (Fall 2001) and a Graduate Teaching Assistant for Introduction to Technology and Policy (Fall 2006) and the Fundamentals of Systems Engineering (Fall 2011). Outside MIT, Danielle pursued diverse experiences as an intern and volunteer. With the National Aeronautics and Space Administration, Danielle worked as a Student Ambassador doing outreach for the Office of Education (2009-2012), an intern in the Innovative Partnerships Program/Office of the Chief Technologist (2010-2011), a guest researcher in the Mission Systems Engineering Branch of Goddard Space Flight Center (2006), the Operations Manager for the Goddard NASA Academy Internship Program (2005), and a Research Associate in the Goddard NASA Academy (2004). In 2009, Danielle spent several months as an intern and researcher in the United Nations Office of Outer Space Affairs. Her work contributed to establishing the Basic Space Technology Initiative for developing countries. Danielle's research has been inspired by volunteer work on several occasions in Kenya and South Africa. Danielle is a recipient of several federal research fellowships including NASA's Harriett Jenkins Pre-doctoral Fellowship, the National Science Foundation Graduate Research Fellowship, and the National Defense Science and Engineering Graduate Fellowship. Danielle also achieved research and travel support from MIT's Carroll Wilson Award, MIT's Graduate Student Council, NASA's Office of Education, the MIT Public Service Center and the Secure World Foundation. Danielle was honored with NASA's Student Innovator Award in 2010. She has presented her research at international conferences and United Nations symposia in Europe, Africa, Asia and the United States and published in journals such as *Acta Astronautica* and *Space Policy.*

Table of Contents

List of Figures

List of Tables

List of Abbreviations

African Resource Management Satellite Constellation...........................ARMS-C
Agence Spatiale Algerienne (Algerian Space Agency)..........................ASAL
Agencia Espacial Brasileira (Brazilian Space Agency)..........................AEB
Astronautic Technology Sendirian Berhad (Incorporated).......................ATSB
Attitude Control System..ACS
California Polytechnic State University...CalPoly
Cape Peninsula University of Technology...CPUT
China-Brazil Earth Resources Satellite..CBERS
Centro Regional de Educacao em Ciencia y Tecnologia Espacial Para America Latina e Caribe (Regional Center for Space Science and Technology Education for Latin America and the Carribean)..CRECTEALC
Complex Product Systems..CoPS
Corruptions Perceptions Index...CPI
Emirates Institute for Advanced Science and Technology.........................EIAST
French-South African Institute of Technology..F'SATI
Geostationary Orbit...GEO
Geo-Informatics and Space Technology Development Agency...............GISTDA
Group on Earth Observations...GEO
Human Development Index..HDI
Human development Report..HDR
Information and Communication Technology Development Index............IDI
International Telecommunication Union...ITU
Istituto Nacional de Pesquisas Espaciais (Brazil's National Institute for Space Research)...INPE
Korea Aerospace Research Institute...KARI
Low Earth Orbit...LEO
Centro de Investigacion en Geografia y Geomatica (Mexico's Center for Research in Geography and Geomatics)..CentroGeo
Microbial Check Valve...MCV
National Authority for Remote Sensing and Space Sciences of Egypt ....NARSS
National Aeronautics and Space Agency of Indonesia..........................LAPAN
National Space Research and Development Agency of Nigeria...............NASRDA
Space and Upper Atmosphere Research Commission of Pakistan............SUPARCO
Regional Centre for Mapping of Resources for Development in Kenya......RCMRD
South African National Space Agency...SANSA
Surrey Satellite Technology Limited...SSTL
Thai Earth Observing Satellite...THEOS
United Nations Committee on the Peaceful Uses of Outer Space.............UN COPUOS
United Nations Office of Outer Space Affairs..................................UN OOSA
United Nations Programme on Space Applications.............................UN PSA
United Nations Platform for Space-based Information for Disaster Management and Emergency Response...UN-SPIDER
World Meteorological Organization..WMO

1 Introduction and Background

Chapter 1 explains foundational concepts relating to the nature of satellite technology, national development through technological capability building and global space activity.

1.1 Overview of Dissertation

International collaboration is a potentially powerful tool to enable developing countries to learn to design and manufacture new technologies; however, the approach to collaboration must be chosen carefully because it impacts the learning process. This study explores the opportunities and challenges facing emerging space nations that are initiating new satellite programs. By exploring this topic, it also contributes to the broader questions about technological learning in developing countries. The study combines literature from economics, development and technology policy with approaches from system architecture to bring unique insights about a poorly understood phenomenon. The heart of the study is a set of inductive, exploratory case studies about satellite projects. The satellite projects are unique because they represent the first time that specific countries buy remote sensing satellites and include local engineers in the design and manufacturing process. These developing countries aspire to establish local capability to design, build and operate satellites. The countries view satellites as tools that provide useful information for environmental management as well as catalysts for national development via technological learning.

This section summarizes key ideas which are further developed later in the dissertation. The study is grounded on the notion that technology plays a key role in national development. Development is defined as progress in four areas, namely, technological capability, economic activity, the human condition and sustainability. Space technology is one example of a tool that can both increase a country's capability and contribute to economic, human and sustainable aspects of development. Space can bring benefit through five types of activity: applying satellite services, building technological capability, enabling economic activity, inspiring technology applications and building scientific knowledge. A number of international actors and national governments recognize this. They have long term programs and policies to harness the benefits of space for developing counties. New nations on every continent are also establishing indigenous satellite programs. Owning and operating satellites was once the purview of a few advanced countries. Now many countries own domestic satellites for communication and remote sensing. This is partly enabled by the emergence of smaller, less expensive satellites with useful capabilities. Some countries pursue their first satellite project by procuring a satellite from a foreign firm and paying that firm to train local engineers. This study explores a set of projects that follow this model of collaborative satellite development. Projects of this type face some inherent challenges due to differences in incentives, experience, culture and access to information between the customer and supplier. The literature on technological learning, technology transfer, project management provides some high level insights into projects such as these. These areas of literature lack implementation details about how the customer that is buying the satellite and training program makes strategic choices. The dissertation applies concepts from Systems Architecture to help elucidate such implementation details.

The study explores five research questions that are designed to identify and organize information about the challenges and opportunities of these collaborative satellite projects.

> Research Question 1: What are the Architectures of Collaborative Satellite Projects?
> Research Question 2: How are the Architectures of Collaborative Projects Similar and Different?
> Research Question 3: What Capability Building Experiences do Individuals Have?
> Research Question 4: What Capability Building Achievements do Organizations Have?
> Research Question 5: How are project architecture and capability building related?

To address these questions, the research design uses inductive, exploratory case studies. The data for the dissertation is collected via long term field work. Data sources include interviews with project participants, observation via site visits and conferences, as well as primary documents. The interviewees include representatives from the national space organizations that initiated the satellite projects, government leaders and the engineers and managers from the supplier firms that delivered the satellite. The findings from Research Question 1 elucidate the specific decisions that decision makers in national space organizations face when pursuing a collaborative satellite project. Research Question 2 shows that there is great variety in the approaches taken for each project, even when nations are faced with a similar set of options. Research Questions 3 and 4 show the progress that individual engineers and organizations make in building new capability. Research Question 5 categorizes the case studies into three Archetypal Project Architectures. This lays a foundation for future work that will describe how decisions made to define these collaborative satellite projects impact technical and social outcomes. To summarize, Research Questions 1 and 2 examine implementation approaches in the collaborative satellite projects using an Architectural Analysis. Next, Research Questions 3 and 4 examine progress in learning the new technology using a Capability Building Analysis. Finally, Research Question 5 synthesizes to find that the impact of Architecture on Capability Building is driven by contextual factors such as political support, leadership style and experience level of the customer country.

1.2 Description of Satellite Technology

Satellites are electro-mechanical devices that deliver services while orbiting in space as semi-independent robots. Each satellite is custom designed to perform a unique service, but most satellites acquire and transfer information. The following discussion describes the services satellites provide, key aspects of satellite technology, the satellite engineering process and the nature of the satellite industry. The final sections discuss specific aspects of small, earth remote sensing satellites. These types of satellites are the focus of the case studies in the doctoral thesis research.

1.2.1 Satellite Services

Satellites provide valuable services by transmitting information and supporting infrastructure. Most earth-orbiting satellite missions can be classified into four major categories: remote sensing, communication, positioning, and space science. Remote sensing satellites carry cameras or other sensors to collect information about the state of the land, sea, atmosphere or water. The information from remote sensing satellites is used to generate maps and reports to help governments and organizations make decisions about environmental management and disaster response. Communication satellites transfer information from a user at one point on the globe to a user on another point. This information may be in the form of a phone call, radio broadcast, internet link or video or other data stream. Positioning satellites provide information that helps users precisely defining the time, determine their position and plan navigation routes. Space science satellites carry instruments to observe space – both near the earth and in distance parts of the universe. These satellite missions deliver data to scientists that could not be collected from earth. The four satellite services introduced above –remote sensing, communication, positioning and space science – are highly relevant to the requirements of organizations in countries around the world that need such information or infrastructure to make decisions, perform analysis or execute projects. In the United States, for example, satellite services are vital to the everyday activities of banks, gas stations, news agencies, taxi companies, paramedics, weather analysts, urban planners and logistic service providers. The same can be said about developing countries. Even though many developing countries do not have local technical capabilities to build and operate satellites, they are consumers of satellite services. Earth remote sensing satellites are the key focus of this section because they are the types of satellites examined in the dissertation case studies.

1.2.2 Satellite Technology

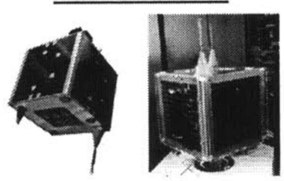
Satellites are generally characterized by the type of service they provide. A few other distinguishing characteristics are their weight, expected lifetime and distance from which they orbit the earth (known as orbital altitude). These four characteristics (size, lifetime, service type and orbital altitude) are related by physical constraints. Satellites that offer higher quality service for a longer lifetime are generally larger and more expensive than satellites that offer lower quality service for a shorter lifetime. Figure 1-1 gives examples of three types of satellites that could be used for earth remote sensing. Each satellite can carry a camera to take images of the earth or sensors to collect data. On the right is the traditional satellite developed by commercial firms for high performance requirements. The traditional commercial satellite is large – weighing between 2000 to 4000 pounds (about 900 to 1800 kilograms). The large size is necessary to carry the fuel, communication equipment and batteries necessary to ensure a long lifespan of 7 to 10 years. These large satellites are designed to carry multiple cameras or scientific instruments.

Traditional commercial satellites are normally built with expensive electrical components that were specifically designed to operate in space. The commercial satellites are also expensive because they provide highly detailed data. The figure of merit for satellite imagery is the resolution of the picture. Commercial earth remote sensing satellites are capable of delivering very high resolution pictures that can clearly show objects of a few feet in size (or less than one meter). In the center of Figure 1-1 is an example from a category known as "small satellites." Small satellites are simpler, lighter and less expensive than the traditional commercial satellite. Small satellites are designed to carry fewer instruments for a shorter lifespan – perhaps five years or less. Small satellites are often built with electrical components that were designed for normal, earth-bound use. This may give them a shorter functional period in space, but it also brings the system cost down. In general, small satellites also provide lower resolution images, although their quality is improving. A special type of small satellite is the CubeSat, shown on the left in Figure 1-1. This tiny satellite has very limited capability, but is very affordable. CubeSats were first developed by universities for low-cost missions. They weigh less than 3 pounds (about 1 kilogram) and last for a short time – usually less than one year. CubeSats are useful for testing new technology and providing opportunities for students to participate in satellite projects. The infrastructure requirements to build and operate CubeSats are low; thus universities and amateur groups around the world are building them.

CubeSat

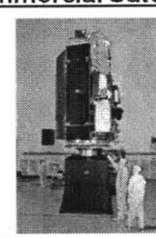
Weight	< 3 pounds
Capability	Technology demonstration and Education
Lifetime	< 1 year
Cost with launch (USD)	$50,000 – $200,000

Small Satellite



Weight	200 to 600 pounds
Capability	Earth Remote Sensing and Space Science
Lifetime	~ 5 years
Cost (USD)	$10 - $100 Million

Commercial Satellite



Weight	4000 pounds
Capability	High Quality Earth Remote Sensing and Space Science
Lifetime	7 to 10 years
Cost (USD)	$100 - $500 Million

Figure 1-1: Examples of Three Types of Satellites

All satellites have two basic sections. One section is known as the payload. The payload is the part of the satellite that provides service to an end user. For earth remote sensing satellites, the payload is a camera or other sensor. The other main section of a satellite is called the bus. This section takes up the majority of the size and weight of the satellite. The bus includes all the systems that support the payload by providing a physical structure, controlling the temperature, communicating with the operations team on earth, and pointing the satellite in the appropriate direction. Each of these functions is performed by a particular part of the satellite bus called a subsystem. A complete satellite system includes the spacecraft as well as the supporting facilities on earth. For earth remote sensing satellites, the supporting facilities include the communication equipment and personnel to monitor the status of the satellite and send commands describing what data the satellite should collect. There are also equipment and personnel on earth to receive the data that is produced by the satellite. The data is stored in computers and converted into useful information.

1.2.3 Satellite Engineering

Each new satellite goes through a rigorous and time consuming design and production process. For traditional commercial satellites, it takes three to ten years to produce a customized satellite once a customer has placed an order. Small satellites are often built more quickly, in one to three years. This speed is achieved because small satellite manufacturers often reuse previous designs and components. The typical satellite production process includes phases for specification of customer requirements, design, manufacture, test and launch. During the requirements specification phase, there is intense dialog between the supplier and potential customer to discuss the customer's unique needs and the technical specifications of a satellite that will meet those needs. Although all suppliers rely on previous experience, they view each project as fundamentally unique. During the design phase, a large team of engineers uses specialized software tools and a variety of physics-based disciplines to create models showing all aspects of the satellite. A separate team of technicians works to implement the engineers' design. The test phase is very important. This phase ensures that the satellite functions properly and that the satellite can operate successfully in the harsh environment of space. The test phase requires the use of expensive and highly specialized equipment and facilities. For example, the satellite is put inside special chambers that simulate the temperature and pressure of the space environment. Other facilities are used to ensure the satellite is structurally sound. Finally, after months of testing, the satellite is loaded into a rocket and launched into space where it is operated by the customer or a contracted operations team. Once a satellite completes its useful lifetime, it should be destroyed or moved out of the range of operational satellites. For many earth remote sensing satellites, this can be achieved by allowing the satellite to gradually drift into the atmosphere where it burns harmlessly.

The team required to complete a satellite production project requires many players. For large firms building traditional commercial satellites, there may be hundreds of people involved. Small satellites are often built with teams closer to 50 to 100 people. There are engineers that focus on the payload (i.e. cameras and sensors) and engineers that design specific aspects of the satellite bus. There is also a team of managers to monitor cost, schedule, personnel and facilities.

1.2.4 Satellite Industry

The satellite industry has several unique aspects. In the language of economics, there are multiple market failures in the industry that reduce competition. There is imperfect competition due to the small number of customers and suppliers. The industry is dominated by governments and large firms as customers and another set of large firms as suppliers. Traditionally, these suppliers have been concentrated in the US, Europe and Japan. There is, however, a current trend for smaller, more innovative firms to enter the industry from around the world. Many of these new firms build small satellites. For small and large firms, each satellite is manufactured as a customized product in response to an order from a specific client. Satellites are craft products that are manufactured by hand. The manufacturing process is highly capital intensive and requires large teams with several types of specialized knowledge. The nature of the industry is highly dependent on the type of service provided by the satellite. Satellite communication is the most commercially driven service. In the areas of earth remote sensing, navigation and space science, governments are the main customers that by and operate satellites. Governments often invest in these satellites and provide their services to their citizens as public goods. Risk is a key aspect of the satellite industry. There are many risks that may cause a satellite project to fail. Failure comes at high cost to the customer and suppliers. The most significant risk is the launch process. If there is a failure during launch, the satellite may be completely lost. There is also risk of failure due to technical problems on the satellite once it is in space. Satellites are normally insured against such loss. Since there are relatively few launches and the technical risk of failure is high, satellite insurance rates are high. In the satellite industry, it is highly impractical to do maintenance on the spacecraft after launch into space. Thus, the original design of a satellite needs be excellent. The risk of technical failures during operations leads the overall industry to change technology slowly. Once specific electronics or materials are demonstrated to work well in space, many satellite engineers are hesitant to change to new, unproven designs or technologies.

The satellite industry is highly political due to its origins. Satellite and launch vehicle technology were developed as part of the Cold War struggle between the United States and the Soviet Union. The initial motivation for creating these technologies was purely defense oriented. Satellites provided both the US and USSR with new capabilities for reconnaissance by sending back images from space. The technology and science principles required to launch satellites are nearly identical to the technology of missile launchers. Space technology has matured in close association with nuclear technology. Space technology is inherently "dual use" for both military and civil applications. Today the Armed Forces of the United States depend heavily on space assets for communication, navigation, weather and surveillance services. Due to these realities, the United States has thus taken a highly protectionist approach to trade in the space arena. The US classifies most space-related technology as a defense technology. This highly restricts the trade of space technology outside the country. The result is that the US space manufacturing industry depends heavily on the US government as a customer. US firms can sell satellites or launch services to foreign customers, but they cannot share any information about how the technology works with their customers. Countries around the world monitor and restrict the export of space technology, but the level of restrictions is often more severe in the United States. This means that the types of satellite training projects that are studied in the dissertation cannot happen in the US. Countries from Africa, Asia and Latin America that want to buy training in space technology must seek this service outside the US. They find the training in Europe and Asia.

1.2.5 Focus on Small, Remote Sensing Satellites

The above discussion provides an overview of key aspects of the overall satellite industry. There are unique characteristics of the programs for small satellites studied in this dissertation. These programs are interesting precisely because they break many of the assumptions of the traditional satellite industry. The space era started in the 1950s as the Soviets and United States raced to achieve space milestones by orbiting satellites and people. For the next forty years, space technology remained highly concentrated in the control of a relatively small number of countries. Major space activity was undertaken by the US, Europe, Japan and later India and China. In the background, an amateur satellite community was developing. This community used simple, affordable technology to develop satellites based on volunteer labor and expertise. Amateur satellites flew which carried simple communication payloads that allowed the global amateur radio community to interact. The traditional satellite community emphasized rigorous engineering and testing to reduce the risk of failure. The space industry evolved to become highly capital intensive and risk averse. In the 1980s and 1990s, several universities added to the activities of the amateur satellite community to create another approach to satellite engineering. They began to develop what became known as small satellites. Small satellites have quickly advanced in performance. They were initially built primarily for research and education, but more of them are being used for commercial applications to compete with larger satellites. The small satellite community is not just defined by the size of their satellites. They pursue satellite engineering with a fundamentally different philosophy than the traditional space industry. They view risk, failure and technology differently than the traditional space industry. The small satellite community seeks to build satellites that have lower performance expectations, can accept greater risk of failure and use newer technology than traditional satellites. Whereas the traditional community tends to put as many payloads on one satellite as possible to save launch costs, small satellites are often designed with only one payload. Whereas traditional satellites rarely rely on electronic technology that has not been proven to operate in space, the small satellite community wants to take advantage of the fast pace of innovation in the micro-electronics industry. They see that technologies such as cell phones and other consumer electronics lead to highly capable and small electronic packages. These consumer electronics are not guaranteed to work for long periods in space due to the impact of radiation. The small satellite community accepts that risk and designs shorter missions in order to use these new electronics. The small satellite community also tends to apply different management approaches.

Large, traditional satellite projects are executed by highly bureaucratic teams with many levels of hierarchy and complex reporting chains. They generate large amounts of documentation to enable the bureaucracy to communicate and to ensure the quality of their products. Small satellite projects are typically executed by small teams which are much more agile and less formal. They tend to produce less documentation and have more flat organizations. They may also have less clearly defined team roles. People do whatever is required to complete the project. Small satellite teams often define their own standards for testing and design quality that is not based on traditional engineering. In this dissertation, three out of four of the case study satellite projects are implemented with this small satellite philosophy. Thus, not only are the developing countries entering a technical field that is new to them, they are joining a community that is currently trying to redefine the field of satellite engineering.

2 Contributions of Space to Development

Space Technology has the potential to provide information, infrastructure and inspiration that meets national needs in developing regions. Many countries recognize this; in response they are investing in new national satellite programs to harness satellite services. This section discusses the relationship between space technology and development. The findings in this section are drawn from foundational research pursued by the author while defining the core study of collaborative satellite projects. The section first explains the methods used in the foundational research for data collection and analysis. Having established the methods, the next few sections build a chain of ideas that begins broadly and gradually narrows to introduce the motivation for the core research on collaborative satellite projects. The argument begins by evoking technology as a key ingredient in national development. Technology related to space is one example of a tool that can contribute to development both by addressing societal challenges and by advancing a nation's technological capability. The research has reveals five specific ways that space has the potential to promote national development. A number of international organizations, including the United Nations, have recognized the opportunity for space technology to serve developing countries. They have consistent activities to promote this potential. Meanwhile governments in many developing countries also view space an important tool for their development. Most nations have on-going activities to ensure that space is harnessed in their country. A smaller number of nations are establishing programs to operate nationally owned satellites. This trend is enabled by the increasing performance of small satellites. Several countries seek to transition from owning satellites purchased abroad to attaining national capability to design and build satellites. Among this group of countries, a set of them have taken a similar policy to partner with foreign firms as they buy a satellite and pay for training of local engineers. This policy is the core phenomenon that is studied in the dissertation. This chain of ideas is explored more below.

The ideas presented in this section serve as motivation for the core study of six collaborative satellite projects. In their own way, however, they are findings from a broader research program that seeks to understand the relationship between space technology and national development, especially for countries that are pursuing domestic space activity. The next section explains the approaches to collect and analyze data to develop these findings about connections between space and development. The foundational research builds on work from the Master's degree thesis by the author, which included similar efforts to capture data and perform analysis about the use of satellite-based technology in developing countries.[i]

2.1 Data Collection Methods for Foundational Research

The data collection discussed here has two purposes. The first purpose is to provide broad understanding for the potential and barriers shaping the use of space technology for development. As part of this process, the foundational analysis helps identify trends and future research questions in this area. Secondly, the foundational research provides serves as a pilot study to help solidify the core research plans and select case studies. The data collection and analysis methods presented here are only for the foundational work. The methods for data collection and analysis for the core case studies will be discussed later.

Researching the relationship between space technology and national development involves answering two broad questions: 1) In what space activities do developing countries participate? and 2) How is space technology applied to support development? The data that addresses these questions is limited and difficulty to find. A key step in the academic study of these issues is to creatively identify and access data that describes the activities in developing countries that are influenced by space. The information present here is based on a multi-year effort that combines conference participation, field interviews and document review. The foundational data collection process is highly exploratory and adaptive. The approaches evolve throughout the study as new insights emerge. In order to answer the two broad questions introduced here, evidence is sought that describes policies, programs and activities related to space and development.

Conference participation

Each year, several international organizations put on conferences and workshops that discuss the relationship between space technology and development. There are on-going workshops organized by the United Nations, the International Academy of Astronautics, the International Astronautical Federation and professional societies such as International Society for Photogrammetry and Remote Sensing. There are also national and regional organizations in developing countries that discuss space issues. Part of this data collection involves participating in conferences like these that bring together stakeholders concerned with the impact of space on development. The formal conference presentations provide useful facts about projects and organizations working in this area. The informal dialog with stakeholders provides useful perspective. Table 2-1 shows a list of conferences in which the author participated while preparing the research presented here. The conferences vary from large, general events that bring together thousands of people from many space disciplines, to small, focused workshops that convene hundreds of people to discuss the role of space in development. During each conference, the author is both an observer and a presenter. These events provide an opportunity to receive feedback on the research from practitioners that are familiar with the issues under study.

Table 2-1: List of meetings attended related to the interaction of space technology and development

#	Event	Focus	Organizer	Year	Location
1	International Astronautical Congress	Large, general space conference with sessions focused on space for developing countries	International Astronautical Federation, International Academy of Astronautics, International Institute of Space Law	2008	Glasgow, Scotland
2	International Astronautical Congress	Large, general space conference with sessions focused on space for developing countries	International Astronautical Federation, International Academy of Astronautics, International Institute of Space Law	2009	Daejeon, South Korea
3	International Astronautical Congress	Large, general space conference with sessions focused on space for developing countries	International Astronautical Federation, International Academy of Astronautics, International Institute of Space Law	2010	Prague, Czech Republic
4	International Astronautical Congress	Large, general space conference with sessions focused on space for developing countries	International Astronautical Federation, International Academy of Astronautics, International Institute of Space Law	2011	Cape Town, South Africa
5	Symposium on Small Satellite Programmes for Sustainable Development	Focused meeting convening practitioners from governments, industry and academia involved with small satellite programs	United Nations Office of Outer Space Affairs	2011	Graz, Austria

6	Symposium on Small Satellite Programmes for Sustainable Development	Focused meeting convening practitioners from governments, industry and academia involved with small satellite programs	United Nations Office of Outer Space Affairs	2010	Graz, Austria
7	Workshop on Space Technology Applications for Socio-Economic Benefits	Focused workshop convening practitioners from governments, industry and academia concerned with social benefits of space	United Nations Office of Outer Space Affairs	2010	Istanbul, Turkey
8	1st Annual South African Space Association Congress	Meeting of space professionals in South Africa	South African Space Association	2010	Cape Town, South Africa
9	International Symposium on the Equatorial Plane	Meeting with policy makers and researchers to discuss how equatorial countries can participate in space technology and science	International Academy of Astronautics & Nigerian National Space Research and Development Agency	2010	Abuja, Nigeria
10	African Leadership Conference on Space Science and Technology for Sustainable Development	Gathering of space-related policy makers from African countries as well as representatives from industry and academia	Governments of Kenya, South Africa, Nigeria, Algeria	2011	Mombasa, Kenya

Field interviews and observation

In addition to participation in ten conferences, this foundational research builds on data collection through field interviews and observation in multiple countries. Between July 2009 and December 2010, the author visited 7 countries in Europe, Africa and Asia to conduct interviews and site visits for foundational data collection. The field visits lasted from several days to several months. Additional field work was done for the core case study data collection. The foundational field visits were held at organizations that contribute to the application of space technology to development. In addition to this international field work, several meetings were held with related organizations in the author's home country of the United States during 2011. Table 2-2 gives an overview of the foundational field work by describing the countries, interviews and organizations. In each country, field visits were pursued with organizations representing governmental, academic or industrial sectors. The government organizations included agencies or departments within the national government that pursue research or operate programs related to space. The university representatives were involved with space research and education or aspired to initiate such involvement. The industrial organizations were firms that participate in some aspect of space technology. The European organizations included universities that have partnered with developing countries on space-related projects. The "multilateral governmental" organization in Europe refers to the United Nations Office of outer Space Affairs, which works to promote awareness and activity regarding space resources for development. The Regional Government referenced in Belgium refers to the European Commission. At the regional level, European countries collaborate in multiple programs that facilitate the application of space technology for development. Some of these are funded and led by the European Commission. In the United States, relevant government organizations include the Department of State, the US Agency for International Development and the National Aeronautics and Space Administration. Several meetings were held with representatives of these organizations.

In Kenya and South Africa, a relatively large number of interviews were conducted with representatives of a variety of organizations related to space. These sets of field visits provided a helpful overview of the national ecosystem of government offices, universities and firms that participate in deriving value from space through various means. Interview questions with these organizations sought to understand how organizations originally became involved with space, what their space-related activities they perform, how they train personnel in space related skills and how they work with foreign and domestic partners. In Singapore and Turkey, a more narrow view of national space activities was afforded from the perspective of one university.

Table 2-2: Summary of Foundational Data Collection Field Visits

Country	# Sites Visited	# of People Interviewed	Types of Organizations Visited
		North America	
United States	3	6-10	• National Government
		Europe	
Germany	1	1-5	• University
Austria	1	1-5	• Multilateral Government
Belgium	1	1-5	• Regional Government
		Africa	
Kenya	7	11-20	• University

			• National Government • Regional Government • Industry
South Africa	19	21-30	• National Government • Industry • University
		Asia	
Singapore	1	1-5	• University
Turkey	1	1-5	• University

The set of countries shown in Table 2-2 reflects the exploratory nature of this foundational data collection process. They do not represent a complete sampling of relevant countries, but all the sources provide useful information. The countries and organizations were chosen through a combination of relationships and enabling circumstances. South Africa and Kenya were selected for in-depth study because both countries currently face major policy transitions with regard to national space activity. South Africa inaugurated a national space agency in 2011, while Kenya is preparing to do the same. In both countries, a government office served as a liaison and helped the research team arrange meetings and site visits.

Document Analysis

The third source that supports the foundational data collection is documentation. The documentation provides additional information and perspective to describe how organizations participate in space activities related to development. Some documentation is accessed during field travel and some is available from anywhere via the internet. Several major categories of documents are summarized in Table 2-3. The table indicates for each type of documentation the level of review and the availability. Level of Review refers to the extent to which the authors ensure that the documentation contains up to date, factual information. The document types with higher levels of review include reports by the United Nations and other organizations, research papers and published books. Some types of documentation - such as organizational websites, brochures, conference papers and new articles – may face a less intense review process. With both types of documents, the researcher must be wary because information from documentation may be out of date or incomplete. The "Availability" column in the table refers to how the document type may be accessed. Some types are regularly on the internet, especially United Nations reports, organization websites and news articles. For other types of documents availability varies; it may be necessary to request them during field visits. The United Nations reports deserve special mention. After each UN meeting or workshop about the role of space in development, the convening UN office generates a report that provides useful information for academic research. For each meeting, the reports describe the nations that were represented, summaries of key presentations and discussions and recommendations. Reports from the United

Nations also tend to reference related UN documents, thus providing useful context for academic study.

Table 2-3: Summary of Foundational Document Data Sources

Type of Documentation	Level of Review	Availability
United Nations Reports	High	Internet
Organizational Reports	High	Varies
Research Papers	High	Varies
Books	High	Varies
Organizational Websites	Low	Internet
Organizational Brochures and Newsletters	Low	Varies
Conference Papers	Low	Varies
Conference Presentations	Low	Varies
News Articles	Low	Internet

2.2 Role of Technology in Development

National development is a multifaceted process through which countries progress in four areas, namely: 1) Technological Capability; 2) Economic Activity; 3) Human Condition; and 4) Sustainability. Table 2-4 defines each of these four components of national development by drawing from literature and from the author's reflection. Progress in Technological Capability means empowering people with skills and harnessing technology to facilitate productive activity. Technology has a duality. It refers to the intangible knowledge, skills, process and techniques used by people and organizations as well as technology in the form of tangible tools, equipment and facilities. Amsden defines progress in technological capability as a transition from productive activity that is driven by natural resources and raw materials to productive activity that is at higher value step in the chain of production. In her words, it is "moving from a set of assets based on primary products, exploited by unskilled labor, to a set of assets based on knowledge, exploited by skilled labor."[ii] Progress in economic activity means improving institutions in order to improve the way a country functions in the global economy, manages national debt, competes in foreign exchange, and balances the effects of population movements. Stiglitz highlights that economic activity may be hampered in less developed countries due to market failures such as imperfect and costly information. In such cases, economic progress may require government intervention to formulate policies to address such failures.[iii] Progress in the Human Condition is made by addressing basic human needs such as security, health, shelter, nourishment, education and self determination. As the United Nations Human Development Report summarizes, progress in this area increases the chances for people to attain "a long and healthy life, knowledge and a decent standard of living." Finally, progress in sustainability focuses on the relationship between the environment and the other three areas of development. Progress in this area means managing the natural environment to balance short and long term needs. A well accepted definition of sustainable development from the Brundtland Report under the United Nations Commission on Environment and Development states, "Sustainable development…meets the needs of the present without compromising the ability of future generations to meet their own needs."

Table 2-4: Definition of Four Areas that Contribute to National Development

Development as Progress in Four Areas				
Type of Progress	**Focus**	**Author's Definition**	**Definition from Literature**	**Source**
Progress in Technological Capability	Technology	Empowering people with skills and harnessing technology to facilitate productive activity	"…[M]oving from a set of assets based on primary products, exploited by unskilled labor, to a set of assets based on knowledge, exploited by skilled labor."	Amsden, A. *Rise of "The Rest:"* 2001.
Progress in Economic Activity	Institutions	Improving institutions to function in the global economy, managing national debt, stay competitive in foreign exchange, and balance the effects of population movements.	Formulating policies and non-market interventions to address failures that impeded the functioning of the market.	Stiglitz, J. "Markets, Market Failures, and Development." *Perspectives on Economic Development,* 1989
Progress in Human Condition	People	Addressing basic human needs such as security, health, shelter, nourishment, education and self determination.	Focuses on the human experience, emphasizing "a long and healthy life, knowledge and a decent standard of living."	United Nations. "Statistics of the Human Development Report." http://hdr.undp.org/en/statistics/
Progress in Sustainability	Environment	Managing the natural environment to balance short and long term needs	"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs…." Concerned with economic competitiveness, environmental wholeness and employment (Ashford and Caldart)	Brundtland Report, United Nations Commission on Environment and Development

The four areas of development defined in Table 2-4 are all mutually related as shown in Figure 2-1. The figure shows connections between each of the four areas of development progress. It also includes examples of references that describe the relationships.

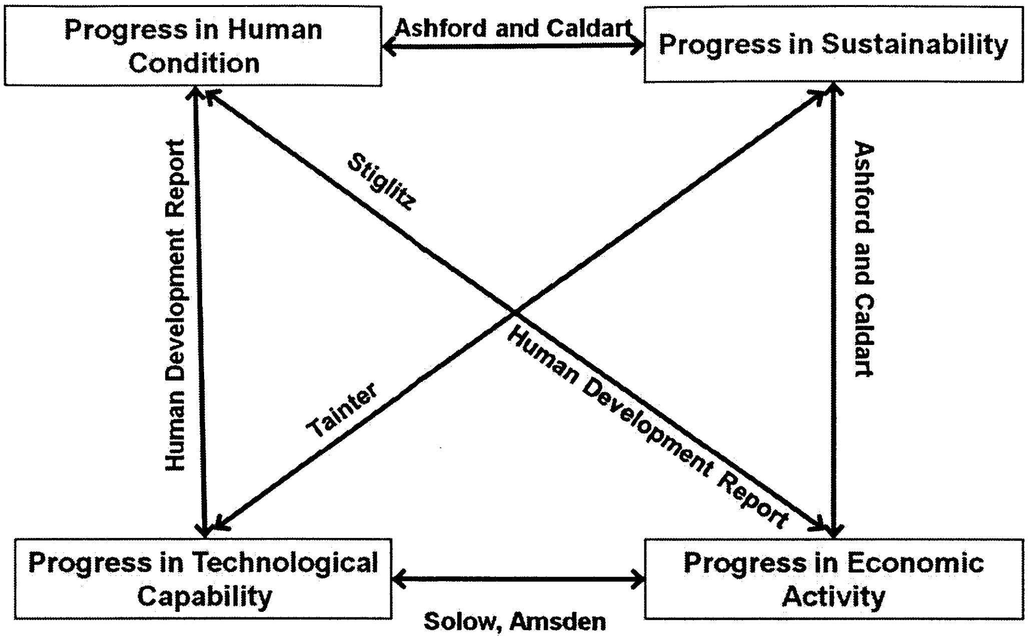


Figure 2-1: Relationships between the four areas of development

Beginning in the bottom left side of Figure 2-1, the first consideration explores relationships between progress in technological capability and progress in the other areas of development. Solow's Nobel Prize winning research shows that technological progress is a dominant factor in long term economic growth.[iv,v] Amsden's extensive body of empirical work follows the post-World War II histories of many late-industrializing countries to find links between their progress in technological capability and progress in economic institutions. Amsden's work considers the institutional and policy approaches pursued by a number of countries in order to foster technological capability building and enable economic competitiveness. As one example, Amsden studied the phenomenon of import substitution. Especially between 1950 and 1980, many countries prospered under import substitution using various policies.[vi,vii] There were two basic motivations for import substitution: trade balance and capability building. Developing countries realized that many consumer items such as refrigerators, televisions and air conditioners were in high demand as imports. This harmed the balance of payment as imports greatly exceeded exports. In order to improve the balance of payments while increasing local manufacturing capability, developing countries chose to manufacturer what was formerly imported. The governments created tariffs that penalized the import of certain goods and then make capital available to private or state owned enterprises who could manufacture these goods. Support for firms often came from development banks, in places such as Mexico, Brazil, India, Korea, Taiwan, Thailand, Malaysia and Turkey. Development banks financed both infrastructure and new manufacturing efforts. Other policy options included providing tax rebates to encourage specific industries (Malaysia and Thailand). If a country could not yet build an entire product, they sometimes started with assembly on behalf of foreign firms and gradually moved into full production. This was the case for electronics in Taiwan. Other countries attracted labor intensive manufacturing in partnership with foreign firms (Hong Kong, Singapore, Korea, Taiwan, Malaysia, Indonesia, etc). The story of Korea's efforts in Textiles shows the range of policies that finally led to a viable industry. Korea competed with Japan's high-skill/high wage textile industry. Some of the policies pursued by Korea included the following: laws against trade unions to keep wages down; tariffs to protect Korean firms; hiring foreign experts; and forming a university program on textiles. Overall, the countries that benefited the most from import substitution had either large internal markets that could support nascent industries (i.e. India) or had flexible policy makers who could respond to success and failure and change policies dynamically if necessary (i.e. Taiwan). The second link is between technological capability and sustainability. Tainter's book, *The Collapse of Complex Societies,*[viii] describes this link. Tainter provides a broad definition for sustainability by contrasting it with the collapse of a complex society. The current global society fits into Tainter's definition of a "problem solving organizatio[n], in which more parts, different kinds of parts, more social differentiation, more inequality, and more kinds of centralization and control emerge as circumstances require."[ix] The complexity provides benefits in terms of social control and productivity. In the past, some societies grew too complex to continue to exist based on their institutional, environmental and economic resources. This led to collapse, in which the societies returned to a less complex state. According Tainter, such a pattern is inevitable due to decreasing marginal returns from investments in complexity, unless technical progress can find new strategies for growth. Thus, technical progress is necessary for societies to continue to flourish according to Tainter's definitions. The third link moves from the bottom left corner of Figure 2-1 to the top left corner, showing a connection between progress in technological capability and the human condition. The United Nations Human Development Report (HDR) defines human development as "the expansion of people's freedoms and capabilities to lead lives that they value and have reason to value."[x] When individuals gain new technological capability, this can help empower them with more opportunities to pursue the outcomes highlighted by the HDR.

The next set of relationships focus on Progress in Sustainability. Ashford and Caldart propose a broad approach to Sustainability that shows the links back to the Human Condition and Economic Activity. Their writing focuses on strategies for regulating industry so as to reduce harm to people and the environment from industrial products and processes. They argue that sustainability is concerned with economic competitiveness, environmental wholeness and employment. Employment is a key factor in Human Development. As Ashford and Caldart show, an environmental policy agenda is narrower than a sustainability policy agenda.[xi] The final link to discuss from Figure 2-1 is between the Human Condition and Economic Activity. The Human Development Report includes Gross National Per Capita Income as a key indicator of the Human Condition. This approach connects the individual experience to the national economic situation. Stiglitz gives some examples of how national economic policies and institutional realities can impact opportunities for individuals to earn incomes.[xii] Stiglitz discusses the role for government intervention in establishing non-market institutions to address market failures such as imperfect information. He also warns that in some cases government barriers are causing market failures. Non-market institutions are discussed further by Douglas North, who focuses on the role of institutions in allowing markets to function.[xiii] North notes that because transactions are not costless (another market failure), institutions such as contracts, legal enforcement and brand names are needed to facilitate impersonal, non-repeated exchanges. North further explains that the development of healthy institutions to facilitate market transactions is not an automatic process in a society. It requires often requires conscious government strategies, which ultimately allow individuals to earn the incomes that contribute to their human condition.

Development is thus defined here as progress in four mutually related areas: technological capability, human condition, sustainability and economic activity. Underlying the progress in all these areas is the concept of governance. Progress in national development relies on a functional government that provides an effective public system. With governance as a foundation, governments can play other key roles in promoting development – including enabling international collaboration, promoting domestic safety and setting national vision. Dirk Swart highlighted the role of the government to promote development via effort in governance, collaboration, safety and vision.[xiv] His ideas parallel the above discussion, but focus on government initiative. In Swart's language, governance refers to the efforts by a government to be politically transparent, provide services to the public, facilitate economic growth and help their citizens achieve basic human needs. Collaboration means looking broadly and strategically for partnerships that can enhance a country's technological potential and market opportunities. As an example, the regional integration of countries in Eastern, Southern and Western Africa has the potential to provide larger markets. This would provide a buffer from the volatility and competition of the global market. Such approaches could help businesses grow, assuming there is proper coordination. The third key factor for governments to create an enabling environment for harnessing technology is safety. Lack of security influences the way people view the future. When people feel insecure, they spend less time on the long term planning that is necessary to solve complex problems. Insecurity also discourages highly trained people from settling in a community. Countries must create an environment where talented people with technical training feel comfortable building a life. Finally, governments can foster technology via Vision. In this role, governments must seek opportunities to inspire their citizens to value the role of technology and sustainability in development. Referring back to Figure 2-1, this study is particularly interested in development as progress in technological capability and the potential impacts that such progress can make on other aspects of development in the figure.

The above discussion addressed the definition of development. The next consideration is the definition of a developing country. Development involves gradually progress in four different areas. It is a process, and there is not a simple way to distinguish between a developed and developing country. Development level is a continuum. For each of the four areas of development introduced in Table 2-4, the development community has created multifaceted indices to compare the performance of countries to each other and over time. None of the indices are perfect or complete, but all provide helpful references. The progress that a particular country has made toward development may be different in the four areas. Table 2-5 provides examples of indices that are relevant to each of the four development areas. The Information and Communication Technology Development Index (IDI), published by the International Telecommunication Union, is one reference point to understand the progress of a country with regard to technological capability.[xv] While the index only captures one category of technology, it is a category that has become pivotal to economic activity in the globalized marketplace. The IDI is a composite index that accounts for performance related to access, use and skills with Information and Communication Technology. Access is measured by considering the availability of ICT hardware and service; ICT use measures the percentage of the population that harnesses ICTs; and skills relates to education and literacy. The Global Competitiveness Index gives information about technology capability and economic activity.[xvi] It is a composite index that combines dozens of national indicators in twelve categories, namely: institutions, infrastructure, macroeconomic environment, health and primary education, higher education and training, goods market efficiency, labor market efficiency, financial market development, technological readiness, market size, business sophistication and innovation. Some of these twelve pillars – especially infrastructure, education, technological readiness and innovation – relate directly to progress in technological capability. Others – such as macroeconomic environment and financial market development – are highly relevant to progress in economic activity and institutions. The Corruptions Perceptions Index (CPI) is more focused on social institutions that can impact economic activity.[xvii] Transparency International generates annual CPIs for about 180 countries using surveys and expert assessments. They summarize the results by ranking the countries on a scale of 0 to 10. The UN Human Development Report features the Human Development Index (HDI). In 2011, 187 countries received an HDI score between zero and one. There are four categories of HDI scores, ranging from very high to low development. The HDR views development in terms of human experience. The most important dimensions they consider are lifespan, education access and income.[xviii] The HDI focuses more heavily on the social conditions of a country than on the characteristics of its economic system. The Environmental Performance Index gives evidence of national progress toward sustainability.[xix] It assigns rankings to 163 countries using 25 indicators of achievement with regard to environmental public health and the state of ecosystems in the country. The environmental health indicators include the burden of environmentally driven diseases, air pollution, human access to water and sanitation. Ecosystem Vitality is measured with indicators in the areas of climate change, agriculture, fisheries, forestry, biodiversity, water quality and air quality.

Table 2-5: Overview of Development Indices in Four Areas

Examples of Measurement Efforts to Track Progress in Development			
Type of Progress	**Focus**	**Index**	**Source**

Progress in Technological Capability	Technology	Information and Communication Technology Development Index	International Telecommunications Union http://www.itu.int/ITU-D/ict/publications/idi/2011/index.html
		Global Competitiveness Index	World Economic Forum http://gcr.weforum.org/gcr2010/
Progress in Economic Activity	Institutions	Corruption Perceptions Index	Transparency International http://www.transparency.org/policy_research/surveys_indices/cpi
Progress in Human Condition	People	Human Development Index	United Nations. "Statistics of the Human Development Report." http://hdr.undp.org/en/statistics/
Progress in Sustainability	Environment	Environmental Performance Index	Yale and Columbia University http://epi.yale.edu/

Countries develop in the four areas of technology, human condition, sustainability and economics. The indices introduced in Table 2-5 provide approach for comparing the development level of countries using quantitative indices. The historical context of a country is also relevant. For example, a country may score well above the Human Development Index in 2011, after gradually moving up from scoring near the world average over several decades. This country's story is qualitatively different from a country that has consistently scored several points above the world average for human development. The first country is "less developed" compared to the second in the sense that its rate of change of development scores is higher than the second country.

Having discussed the nature of development and tools to compare the development levels of different countries, the next step is to further explore the mechanisms by which technological progress contributes to economic, human and sustainable development. Several historical and theoretical explanations emphasize the importance of knowledge, division of labor and innovation.

In *The Gifts of Athena,* Joel Mokyr, argues that one must consider the role of advances in human knowledge in order to understand the economic growth of the modern age.[xx] The book uses this central thesis to interpret important historical eras such as the Industrial Revolution in order to better understand how society arrived at its present state. Mokyr begins by formulating a "theory of useful knowledge" that is the foundation for all the discussion to follow.[xxi] He defines two kinds of knowledge: descriptive knowledge (known as Ω) and prescriptive knowledge about techniques (known as λ). Descriptive knowledge includes awareness of phenomena in nature and "an ability to make sense" of these natural phenomena.[xxii] Additions to Ω are thought of as discoveries. Prescriptive knowledge includes the methods that are used to make and do useful things. An addition to λ is an invention. Mokyr further proposes that society knows something as long as at least one individual knows it. Knowledge is more "tight," however, if many people know and believe it.[xxiii] This basic framework is used in several chapters to explain the historical progression from the Enlightenment to the Industrial Revolution to the rise of the factory. These historical changes can partly be understood by changes in the amount, tightness, and access to useful knowledge. Mokyr's historical progression proposes the following relationships. In the 17th and 18th centuries, science gained an increasingly important role as Western Europe "sought to rationalize and spread knowledge."[xxiv] This partly explains why the Industrial Revolution was able to emerge, starting around 1760. Growth in the amount and tightness of descriptive knowledge led to an increase in inventions and techniques that could be economically valuable. "As the two forms of knowledge [prescriptive and descriptive] co-evolved, they increasingly enriched one another."[xxv] Eventually, the amount of knowledge needed to run a production facility was so high that the cost of moving people was lower than the cost of moving information. This partly explains why factories became so common, and household craft gradually declined. Although there was not instantaneous economic growth during the Industrial Revolution, the modern standard of living in the western world can be traced to the technology developments of that era.

Adam Smith made similar observations to Mokyr when he wrote *The Wealth of Nations*[xxvi] in 1776. This was in the midst of the transition that Mokyr describes in hindsight. Smith explains both how and why a region moves from a subsistence economy to an industrial economy. Smith argues that people have a natural tendency to exchange with each other in order to benefit from differing abilities. Trade leads to a division of labor, which is helped along when there is also growing population density and large markets. Smith notes that when labor is divided, it increases productivity for three reasons: 1) each specialized worker is an expert in their task; 2) time is saved because people are not switching between tasks; and 3) specialists often to innovate better ways to do their job.

Schumpeter provides more detail about the relationship between invention, technology adoption and their impact on the overall economy in his series of books on development and business cycles. In *The Theory of Economic Development,* Schumpeter creates a theoretical model by which to explain endogenously why economies change rather than remain statically in equilibrium.[xxvii] He begins by assuming a static economy that experiences gradual growth due only to population growth and savings. Goods and services are produced in the economy by combining land (natural resources) and labor in a "circular flow".[xxviii] People generally do the same kind of work repetitively; there is very little incentive to change. No external crises cause change in the economy. Given these assumptions, Schumpeter argues that no change or major growth will occur in this economy unless there is innovation. Schumpeter carefully defines innovation as distinct from invention. Innovation is not when a technology is first developed or a scientific breakthrough is made. Innovation occurs when someone changes the way inputs are combined to make outputs in economic activity. Schumpeter further proposed that innovation happens because an individual called an entrepreneur takes a leadership role and challenges the status quo in order to bring about change. Once one person takes this risk, other people imitate the original entrepreneur and a cluster of innovations results. This cluster fundamentally changes the technical rules by which the economy operates. The economy moves into a period of increased prosperity because the innovations increase the capacity to create wealth. Schumpeter claims that "the mechanisms of economic change in capitalist society pivot on entrepreneurial activity".[xxix] He terms such activity "creative destruction"[xxx] or "creative response".[xxxi] Schumpeter's model of business cycles continues the story. From the static state, the economy begins to experience increased prosperity due to innovation. This does not last, however. Eventually some of the firms who do not adjust to the new technical rules of the economy are not able to compete. Some firms have to reorganize while others simply close. This transition leads to a recession and ultimately a depression. The economy suffers until a new wave of entrepreneurs initiate innovations. Thus, the economy cycles continuously through periods of prosperity, recession, depression and recovery, as shown in Figure 2-2. With each wave of innovation and prosperity, though, the overall level of wealth increases so that the economy is on an increasing wave of cycles. Schumpeter cites the work of other economists on cycles and shows that there are multiple cycles happening to the economy simultaneously at different time scales and levels of severity.[xxxii,xxxiii]

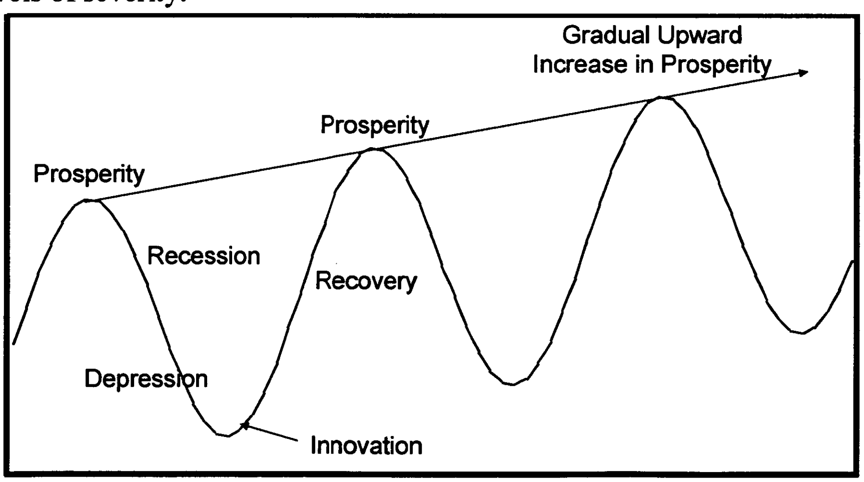


Figure 2-2: Schumpeter predicts economic cycles from innovation to prosperity to depression to innovation (Original Figure summarizing concepts from Schumpeter 1939)[xxxiv]

Finally, Drucker provides a neat summary of the historical interaction between technological and economic progress in his work *Post-Capitalist Society.*[xxxv] Drucker describes how the western world moved from an Industrial Revolution in the 18th century to a Productivity Revolution in the 19th century to a Management Revolution in the 20th century. The Industrial Revolution put technology and capital at the center of economic activity. The Productivity Revolution created the bourgeois middle class as a powerful social force. The Management Revolution, in the era since World War II, has been dominated by the importance of knowledge as a factor of production. Knowledge has become a more vital factor than capital and labor.

These historical and theoretical reflections show how technological progress is integrally linked to economic activity at both micro and macro scales. An individual or small team can initiate innovation in their organization by adopting a new technique or product that changes their economic activity. The aggregation of many such innovations led historical to major transitions in the operations of society. Technology plays a key role in development because it dictates the rules for what inputs and processes are required to achieve outputs. The rules, inputs and outputs in turn dictate the opportunities and costs to progress in economic, human and sustainable development.

2.3 Five Ways that Space Can Contribute to Development

The discussion above addressed the relationship between all technology and national development. Development is defined to include four areas – human, economic, technological and sustainability. This section shows how space technology in particular has the potential to contribute to the four areas of national development. Table 2-6 introduces five types of space activity and shows which areas of development they have the greatest potential to directly impact. The rest of the section provides further explanation and examples.

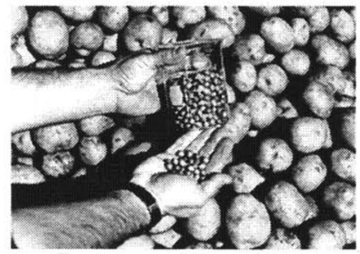
Table 2-6: Space activity can provide benefit to the global community through five activities

Five Types of Space Activity that Provide Global Benefit	*Human*	*Economic*	*Technological*	*Sustainable*
Applying Satellite Services	x	x	x	x
Building Technological Capability			x	
Enabling Economic Activity		x		
Inspiring Technology Applications	x		x	
Building Scientific Knowledge	x	x	x	

The first type of space activity that contributes to development is applying satellite services. Three major satellite services are remote sensing, communication and positioning. Satellite remote sensing enables earth observation and monitoring of the environment. This can help respond to problems such as disease outbreaks, drought, fires and deforestation. Satellite communication is a part of the global infrastructure that allows the world to share information seamlessly. Satellite navigation and positioning have become integrated into the global transportation infrastructure, while the timing function serves many industries and communities. Satellite services are ubiquitous in the global community and less developed countries are part of the user-base for these services.[xxxvi] This activity has demonstrated the potential to promote all four areas of development. In the short term, it promotes human development by providing information and infrastructure that improves quality of life. This is particularly evident when satellite communication, imaging and positioning are used during disaster response. Also in the short term, satellite services can enable economic development when organizations create business models based on satellite capabilities. Many firms currently build business around satellite communication and positioning. In the long term, applying satellites services can promote technological and sustainable development. The technological progress will come if countries continuously learn about the technology they are applying and seek opportunities for innovation. The sustainability progress can be achieved if satellite-based environmental data harnessed as part of forming policies and strategies to manage natural resources. The second type of space activity is building technological capability. The risks and challenges associated with operating technology in space sharpen the skills of the global community of innovators. When a country begins new activities with space technology, they necessarily enter a posture of learning and self-improvement for both individuals and teams. This aspect of space activity directly impacts the technological area of development. The third type of activity through which space brings benefit is enabling economic activity. As space resources and information bring value to customers, new organizations can be formed that create jobs and products that leverage space. Several examples were given above in the area of satellite services. Economic activity also includes firms or universities selling products and services related to the production of satellites.

The fourth activity area is inspiring technology applications. This can impact both human and technological development. When engineers and technologists solve problems to allow operations or innovation in a space system, the new invention is often relevant to terrestrial applications as well. The unique environment of space often inspires unique approaches and innovative solutions. Such spinoff solutions can be harnessed both on earth and in space – providing double benefit. For example, several NASA technology spinoffs have great relevance to social needs in developing countries. Two technologies related to agriculture and food production are shown in Figure 2-3. NASA does research on food technology in order to prepare for long duration human spaceflight. Due to this research effort, NASA created technology that slows the decay of food by removing a specific chemical from the air. This is helpful to reduce food waste and allow food to be transported over long distances while retaining freshness. The technology was commercialized and is now used in many applications by private sector actors. Another outcome of NASA's food research was a type of potato with increased crop yield and disease resistance. The pictures on the bottom row of Figure 2-3 show an application of NASA technology to water purification. NASA worked with an external partner to develop a technology called the Microbial Check Valve (MCV). This valve was incorporated into the water purification system of the Space Shuttle. The MCV was spun out of NASA and repackaged in a ground-based water cleaning system. This new system can be transported by truck and used to pump clean water from a large, contaminated water source such as a lake or well. The ground-based system has been deployed in multiple developing countries. For a more detailed survey of NASA technologies that have been harnessed to address needs in the developing world, see the 2009 paper by Comstock.[xxxvii]

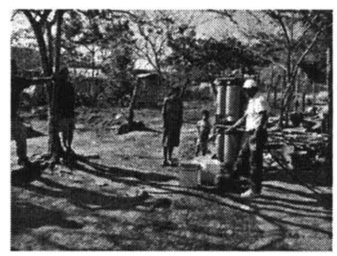
AiroCide helps farmers avoid rotted crops by extending the time to market in India and elsewhere.



Minitubers resist disease and increase crop yield throughout the world.

Kampang Salak, Malaysia

Kendala, Iraq



Chiapas, Mexico

Figure 2-3: These NASA spinoff technologies support food production (Figure credit: NASA http://www.sti.nasa.gov/tto/pdf/Spinoff_dev.pdf)

There are also examples from space organizations within developing countries that make spinoff connections based on their space activity. In South Africa a company called Space Commercial Services was established by engineers with years of experience on the domestic satellite industry. These engineers and a broader team of employees from other fields work to apply space-based resources and knowledge to social applications. This represents a spinoff both because the team has space experience and because of the business model to use space for social needs. Space Commercial Services works in diverse areas, including geospatially enabled knowledge, socio-economic development, program management and telecommunication infrastructure management.[xxxviii] In Malaysia, the company called Astronautic Technology SB (ATSB) is the primary implementer of national satellite projects. ATSB was initially founded in the late 1990s order to establish a national capability for satellites, but they have diversified during their history. By building on their skills in satellite design and fabrication, ATSB has also developed terrestrial projects such a tsunami early warning systems, radiation monitoring systems, differential satellite navigation systems, as well as sensors and information systems for airport runways.[xxxix] This is a spinoff example because a company whose core business model was built around space used their knowledge and training to apply advanced technology to terrestrial projects.

Finally, space activity builds the scientific knowledge of society. This can impact the human, economic, and technological progress toward development. By venturing into space, the global community has made immense discoveries. New players in space can achieve local scientific progress with their own space activities. Even with limited resources, it is possible to access and analyze space science data collected on satellite platforms. There are valuable measurements that can be taken using terrestrial sensors that provide insights about the relationship between the earth and sun. Human spaceflight and suborbital operations open the opportunity for scientists all over the world to engage in microgravity research. All of these represent practical opportunities to harness the benefits of space for improved infrastructure, valuable information and global inspiration.

2.4 International activity to promote space for development

The potential for space activity to benefit developing countries has been recognized by the global space community for decades. Early in the space era, just as the Soviet Union and the United States made initial achievements to operate in space, the United Nations reacted to the global impact of the new field of technology. The United Nations Office of Outer Space Affairs (UNOOSA) and the Committee on the Peaceful Uses of Outer Space (COPUOS) were established in 1958.[xl] The UNOOSA office serves as a full time UN organization to support the COPUOS committee as it meets several times per year, gathering representatives from UN member states. Both organizations were created with the dual role of encouraging all nations to harness space for non-military purposes and to ensure that the benefits of space were shared by all mankind, rather than a few technologically advanced nations. The COPUOS committee contributed to maintaining space for peaceful ends by developing five space treaties which were eventually adopted by the General Assembly. The treaties also addressed potential conflicts that could arise from global space activity, such as the liability of Party A due Party B if a space object owned by Party A damages property owned by Part B. The five space treaties are summarized in Table 2-7.

Table 2-7: Summary of United Nations Space Treaties[xli]

Short Name	Long Name	Year entered into force
Outer Space Treaty	Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies	1967
Rescue Agreement	Agreement on the Rescue of Astronauts, the Return of Astronauts and the Return of Objects Launched into Outer Space	1968
Liability Convention	Convention on International Liability for Damage Caused by Space Objects	1972
Registration Convention	Convention on Registration of Objects Launched into Outer Space	1975

Moon Agreement	Agreement Governing the Activities of States on the Moon and Other Celestial Bodies	1984

The five space treaties impact the opportunities for space to contribute to development because they established a global consensus early in the space era on several key concepts. One concept was that locations in space (including earth orbit, the moon or other planets) could not be appropriated exclusively by a particular country. Unlike the colonial era during which powerful countries took over weaker countries, the treaties specified that all countries should have, at least, theoretical access to space. The UN treaties promoted "arms control, the freedom of exploration, liability for damage caused by space objects, the safety and rescue of spacecraft and astronauts, the prevention of harmful interference with space activities and the environment,... scientific investigation and the exploitation of natural resources in outer space."[xlii]

Another step by the United Nations to promote space for development was the initiation in 1971 of the Programme on Space Applications (PSA). The purpose of the PSA is to ensure that the benefits of space technology are applied around the world. The PSA is implemented by the members of the Office of Outer Space Affairs. They hold a series of workshops throughout the year to provide information about the use of satellites services, satellite technology and space science for development. They also partner with other organizations to implement practical projects, such as scholarship programs or the establishment of local space organizations in developing countries. The themes of the PSA include Basic Space Science, Basic Space Technology, Human Space Technology, Global National Satellite Systems, Natural Resource Management & Environmental Monitoring, Satellite Communications, as well as Space Technology & Disaster Management. The Programme on Space Applications has consistently spread awareness about the five types of space activity that promote development. They also bring together experts from all over the world who work in these areas.[xliii]

The UNOOSA office is not the only United Nations body that is concerned with applying space technology for development. UNOOSA plays a central role in developing policy and involving developing counties. Many other United Nations organizations apply space technology as part of their routine work to support development. The UN-SPIDER program (United Nations Platform for Space-based Information for Disaster Management and Emergency Response) has the goal to "[e]nsure that all countries and international and regional organizations have access to and develop the capacity to use all types of space-based information to support the full disaster management cycle."[xliv] Other UN bodies that use space as integral parts of their missions include the UN Framework Convention on Climate Change; the World Meteorological Organization (WMO); the International Telecommunication Union (ITU); the UN Educational, Scientific and Cultural Organization; and the UN Economic Commission for Africa. The WMO and ITU use space technology and they coordinate the global use of satellites for communication and weather monitoring.

Outside of the United Nations, many other international organizations promote the use of satellites and other space technology for development; Table 2-8 gives more examples. The organizations described in Table 2-8 include several types. None of these organizations exists exclusively to promote the application of space resources for development. All of them, however, have specific programs, committees or events designed to increase space awareness or capability among developing countries. One category of relevant organizations is the international professional societies in fields related to space. Examples not shown in the table include the International Society of Photogrammetry and Remote Sensing (http://www.isprs.org/) and the International Union of Geodesy and Geophysics (http://www.iugg.org/). Groups like these provide resources through which space professionals from developing countries can integrate with the global network of people in their field.

Table 2-8: Examples of International Organizations that Promote Space for Development

Organization	Type	Overall Purpose	Promotion of Space for Development	Website
Committee on Space Research	Committee of Non-Governmental Organization	Promote international scientific research in space	Hosts several Capacity Building workshops per year that teach scientists from developing countries skills in space research	http://cosparhq.cnes.fr/About/about.htm
International Charter: Space and Major Disasters	Collaboration by formal Agreement	"Providing a unified system of space data acquisition and delivery to those affected by natural or man-made disasters"	Creates a mechanism whereby developing countries can request satellite data during disasters via partnerships with Charter Members.	http://www.disasterscharter.org/home
International Academy of Astronautics	Honorific Professional Society	Recognize distinguished individuals in astronautics and create platform for international collaboration.	Hosts committee and study groups that prepare events and reports related to the application of space for development. Includes members from developing countries	http://www.iaaweb.org/
International Astronautical Federation	International federation of space organizations	Advocate knowledge, development and application of space assets	Connects member organizations from developing countries with international community; host workshops and trainings for space professionals and educators from developing countries; provide scholarships for young professionals and students to attend major space conferences.	http://iafastro.org/index.html?title=Main_Page
International Astronomical Union	Professional Society	"Promote and safeguard the science of astronomy in all its aspects	Hosts an office of Astronomy for Development dedicated to identifying and promoting the links between astronomy and national development.	http://www.iau.org/

		through international cooperation."		
Group on Earth Observations	International Coordinating Body	Coordinating development of Global Earth Observation Systems of Systems	Working towards enhancing capacity in developing countries to use earth observations from satellites and other sources. Offering internet-based training opportunities.	http://www.earthobservations.org/index.shtml
ESRI	Company	Develops Geographic Information Systems	Host user conferences in developing regions to promote their software tools and provide training.	http://www.esri.com/

2.5 National activity to harness space for development

The previous section discussed efforts from international organizations to promote activity in space by and for developing countries. Within developing countries there are also domestic efforts to harness space for development. This section focuses on the use of satellite services, space research and space-related commerce. The next section will specifically discuss national satellite programs in developing countries. Governments in many developing countries have established regional or national organizations to manage satellite remote sensing, communication, positioning and scientific data for the benefit of the country. In the area of remote sensing, these organizations often have a primary purpose of ensuring that national and local government agencies have access to satellite data; as a secondary purpose they may also support private organizations and academics in accessing data. One example of a regional organization that supports the use of satellite remote sensing and positioning services is the Regional Centre for Mapping of Resources for Development (RCMRD) in Nairobi, Kenya[xlv]. Although it is located in Kenya, RCMRD represents fifteen member states in southern and eastern Africa. RCMRD's purpose is to support the governments of their member states in the use of geographically reference information technology – much of which is enabled by satellites. The RCMRD does not own or operate satellites, but has agreements with international partners to obtain satellite remote sensing data. One recent partnership that RCMRD established is the SERVIR project with NASA which provides access to many types of scientific data. One example of a national organization is South Africa's Earth Observation section within their National Space Agency (SANSA Earth Observation). Part of this organization's expertise is creating customized tools that apply satellite data to specific national challenges – such as fire detection – for users in South Africa. SANSA Earth Observation also plays a role to ensure that other government organizations have access to satellite data and techniques. In other regions, Thailand's GISTDA (Geo-Informatics and Space Technology Development Agency) and Mexico's CentroGeo (Centro de Investigacion en Geografia y Geomatica) are examples of government organizations that play a role at the national level in obtaining, distributing and applying satellite remote sensing, positioning and scientific resources. Here are several more examples of national efforts to harness space activity within Brazil and South Africa.

Brazil

Given Brazil's large territory and many natural resources, satellite remote sensing brings great value to the nation. Brazil has been actively involved with remote sensing activities since 1969. The Agencia Espacial Brasileira (AEB) partners with the Istituto Nacional de Pesquisas Espaciais (INPE) to develop and operate remote sensing satellites that provide useful information to decision makers in Brazil. AEB also collaborates with partner nations to access additional data or conduct missions. Brazil has worked with China since 1988 on the CBERS (China-Brazil Earth Resources Satellite) series of remote sensing satellites. The series is ultimately planned to include 5 satellites with optical cameras and imagers that can pick up infrared light. The cameras are useful for monitoring land use, water resources and soil erosion, while the infrared imager can identify potential fires. CBERS images are used in a program called CANASAT, which applies satellite imagery to monitor sugar-cane growth.[xlvi] Brazil also works with the United States Geological Survey agency to acquire imagery from the Landsat series of satellites via a local ground station. Landsat imagery is used throughout the world for mapping and resource monitoring.[xlvii] Satellite data is also used by Brazilian organizations in studying areas such as weather, UV radiation, and the effects of space radiation on earth.[xlviii] The Embratel company provides satellite communication services in Brazil, including television broadcast and two-way voice or data lines. This allows users to access the internet, make international calls and manage business information[xlix]. Satellite communication has also been used to enable distance learning in isolate regions such as the State of Amazonas, where schools have limited resources[l]. In addition to the services that Brazil receives from satellites, Brazil is active in space research, education and exploration. Brazil has a number of facilities for research in space science. Several of these facilities are within INPE, such as the site at Fortelza which focuses on studies the magnetic and gravitational fields of the earth[li]. Another example is the radio astronomy observatory of Itapetinga[lii]. Brazil also uses space as also a tool to inspire the public and youth to engage in science. One of INPE's observatories is set up to give public presentations about space and astronomy[liii]. Brazil also hosts a Centro Regional de Educacao em Ciencia y Tecnologia Espacial Para America Latina e o Caribe (Regional Center for Space Science and Technology Education for Latin America and the Carribean - CRECTEALC). The regional center offers course in remote sensing, satellite communication, satellite meteorology and space science[liv]. CRECTEALC works to connect Brazil to the international space community. Marcos Pontes is the first Brazilian to enter space. He flew in a Russian spacecraft to the International Space Station in 2006.

South Africa

Satellite remote sensing services are being used to meet societal needs for South Africa in areas such as agriculture, environmental management, food security, water, disaster response, housing development, utilities and infrastructure planning and national security. South Africa has only operated two domestic satellites, however, the government works with partner nations and firms to gain access to data from a variety of satellites. As mentioned above the SANSA Earth

Observation center is a key player in accessing, archiving, processing and distributing remote sensing data. They use data from satellites such as Terra and Aqua (United States), Earth Resource Satellite 2 (Europe) and the SPOT series (France)[lv]. South Africa also contributes to the international organization called the Group on Earth Observations (GEO); a representative from South Africa served as a Co-Chair of GEO's Executive Committee. As seen in Table 2-8, GEO is an international effort to improve the coordination and application of remote sensing data.[lvi] The South African government uses satellite imagery to enforce and plan environmental regulations, in areas including water usage, fishing activity and land use.[lvii] The Council for Geoscience uses satellite images as part of their process to map precious metals and stones in South Africa[lviii] and to explore potential sites for exploitation of groundwater in Limpopo.[lix] South Africa is also the home of a project called MARA, a collaboration of scientists throughout the continent that seeks to map malaria risk in Africa. The MARA project uses remote sensing data as part of their analysis process because the spread of malaria is affected by environmental variables such as moisture.[lx] Meanwhile the South African National Disaster Management Center uses satellite data to publish an online map showing locations in danger of wild fires.[lxi] Information from satellite remote sensing systems is used by many South African organizations to produce useful information for government, industry and the public. Satellite navigation has been applied to local activities in South Africa, such as wildlife management, the national census and geological research. Wildlife is one of South Africa's valuable natural resources, and satellite navigation is used for wild life research and management. In one case, small satellite transmitters were attached to wild South African Karoo Blue Cranes as part of a research study. The location data from the transmitters will help improve conservation efforts.[lxii] The South African census agency, Statistics South Africa makes use of satellite remote sensing data and satellite location information as part of data collection and planning for the national census.[lxiii] Also, geological researchers from the Council for Geoscience use the timing signal from GPS to synchronize research instruments that are placed in the ground for data collection. Satellite communication impacts education, business and entertainment in South Africa. A non-profit, South African organization called Mindset develops educational materials for schools, health workers and under-developed communities. They distribute their material via satellite and provide technical support to their end users.[lxiv] Some universities in South Africa use satellite communication as part of the infrastructure that allows students from all over the country to study.[lxv] Communication service providers such as Telkom offer satellite-based internet service for businesses and homes that have limited connectivity options.[lxvi] Meanwhile, broadcasters such as MultiChoice provide many South Africans with local and international television programming via satellite.[lxvii] South Africa is also active in the areas of space research, education and exploration. South Africa contributes richly in astronomy and space science research through facilities such as the South African Astronomical Observatory, the Hartebeesthoek Radio Astronomy Observatory and the Southern African Large Telescope.[lxviii] Space related facilities such as the Planetariums in Cape Town and Johannesburg serve to educate the public.[lxix] At the Boyden Observatory near Bloemfontein, members of the Astronomical Society of Southern

Africa volunteer to teach the public about astronomy and telescopes.[lxx] At the university level, students have made space milestones in South Africa. A team of students and professors from the University of Stellenbosch designed and built the first South African satellite to fly in space. The project, called SunSat, lead to the establishment of the company SunSpace and Information Systems. Sunspace recently built South Africa's second satellite, SumbandillaSat.[lxxi] For younger students, the University of Pretoria has held several Space and Aviation Camps, in which learners from Grade 11 and 12 are exposed to the theory and technology in the space sector.[lxxii] Finally, the first African to fly in space was a South African named Mark Shuttleworth who flew to the International Space Station with a Russian team. One of Shuttleworth's goals is to use his experiences in space to inspire South Africans to study science.[lxxiii] A number of South African firms build their business around space services or technology. SunSpace and Information Systems designs and builds satellite systems. Denel – a major aerospace and defense firm – operates the Overberg Test Range, which has the potential to be used as a satellite launch facility.[lxxiv] Firms such as Sentech, Space Television and Tellumat depend on satellite-enabled technology to deliver their products. Sentech, a state owned enterprise, depends on satellites for offering radio, television and internet services to consumer's homes and businesses.[lxxv] Space Television manufactures satellite transmission and receiving equipment to enable communication.[lxxvi] Meanwhile, Tellumat supplies equipment that allows consumers to use satellite-based information systems.[lxxvii] In the navigation area, firms like Optron Geomatics and Laipac Africa distribute the ground-based systems that enable positioning and mapping applications.[lxxviii]

2.6 National satellite programs

Space benefits all countries, but countries differ in the level to which they make direct investments in local satellite activity. This concept is summarized in Figure 2-4. The broad base of the figure represents the reality that every country is a user of satellite services – remote sensing, communication, positioning and space science. These services have of their global reach and decentralized operational models. As the levels rise on the pyramid, fewer countries make direct investments in domestic satellite hardware (owning satellites or launch vehicles), local satellite expertise or the infrastructure required to build and operate satellites.

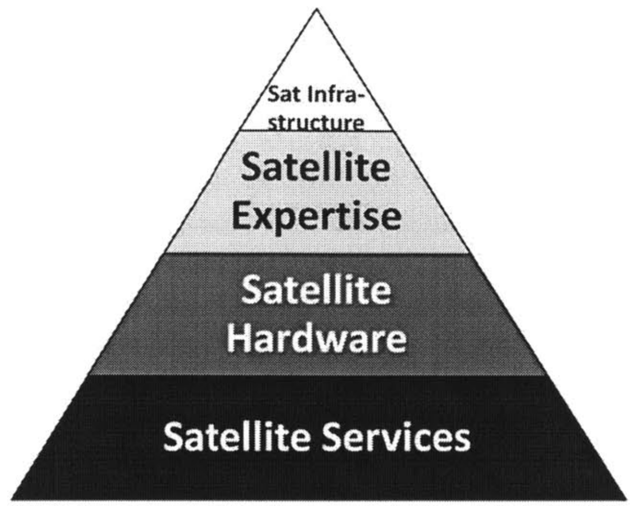


Figure 2-4: All countries use satellite service, but fewer invest in local space hardware, expertise and infrastructure.

There are both objective (technically-based) and subjective (value-based) motivations for countries in every part of the world to invest in these various levels of the pyramid. Meanwhile, the question of whether governments in developing countries should invest in owning and operating national satellites is an area of debate. The terms of the debate are different for each of the four satellite application areas: earth observation, communication, navigation and space science. In the area of earth observation, some argue that there is enough data available on the international market to meet the needs of developing countries. They conclude that developing countries should not invest in satellite hardware, but should buy or share data from other sources. With this approach, the country is focusing resources on utilization of the data for local needs rather than production of the data. This is often a reasonable approach. Most developing countries are currently in this situation. Their efforts to use satellite earth observation data are facilitated by many international initiatives such as the Global Earth Observation System of Systems, which seeks to integrate worldwide data sources.[lxxix] During disasters, developing countries can activate the International Charter: Space and Major Disasters, with the help of the United Nations as described in Table 2-8. In the area of satellite communication, one can make a similar argument. There are many commercial companies that own and operate communication satellites for a profit. They provide service throughout the developing world. Does their presence supersede the need for national governments to operate communication satellites? The argument seems even clearer in the area of satellite navigation. The United States currently operates the Global Positioning System. It is a constellation of 24 navigation satellites that freely broadcast their location. Users can triangulate from multiple GPS satellites and calculate their own location.[lxxx] Several other GNSS projects are currently underway. Russia is revitalizing their GLONASS constellation; Europe is developing the Galileo constellation; and countries such as India, China and Japan are planning to operate regional or global satellite navigation systems.[lxxxi] If at least one of the global systems offers a free signal, it can serve all developing countries. It seems very likely that during the next few decades, the freely available navigation services will increase for developing countries. Finally, in the area of space science, developing countries do not need to invest in national satellite projects to access scientific data. They can collaborate with other space players to fly hosted payloads or share data.

All of these facts apparently lead to the conclusion that governments in developing countries do not need to own and operate their own satellites. There are subtle realities, however, that challenge this conclusion. In the area of earth observation, it is true that there are many government programs through which data collected by the international community can be shared with countries that do not own satellites. There are also commercial providers such as Digital Globe, GeoEye and SpotImage that sell high resolution satellite imagery. The problem remains, however, that developing countries cannot always get the data they need when they need it. This may be because the data collected by other countries does not account for the technical requirements of a particular user in a developing country. Such requirements can include temporal frequency, spatial resolution, spectral frequency or geographic coverage. Also, the global political infrastructure of data sharing policies is not yet complete. Organizations from developing countries that wish to share international data may be obliged to establish bilateral agreements with each data producer and keep those agreements up to date in order to ensure access. This is a laborious and expensive process. Meanwhile, high resolution optical data, which is particularly useful for projects in urban planning, is very expensive and mainly available from commercial providers. It may not be cost effective for developing country governments to buy high resolution imagery regularly. In the area of communication, one could argue that the need for this service is provided by commercial vendors. It is common economic wisdom that a company in a competitive market can offer a consumer service more efficiently than a government can. This seems to imply that governments should open their markets to allow competition among communication providers and not be involved as a service provider. Such an economic prescription may not meet social goals, however. There is room to consider government involvement to ensure that the neediest communities benefit from satellite communication service. In the area of satellite navigation, developing countries do not need to invest in their own global satellite constellations. The opportunities offered by the GPS, Galileo and GLONASS systems are great. There are limitations, however. The free signals from this publicly available infrastructure do not have high enough resolution for many applications. They are adequate for consumer use in driving and walking. They are not precise or consistent enough for safety-of-life applications, such as landing a plane. Also, for applications such as precision agriculture and construction, highly detailed information may be needed. For these reasons, developing countries cannot be passive consumers of satellite navigation signals in the long term. They need to seek out ground-based and space-based systems to augment and improve the navigation signals they receive.

Given all of this discussion, the framework in Figure 2-5 is helpful for organizing the motivations for governments in developing countries to pursue satellite programs. The framework considers separately the short term versus long term motivations for a country's actions. It also divides national investments into the four areas from Figure 2-4. The framework specifically considers objective, technically rational motivations, rather than including political or cultural motivations, which are more subjective. In general, both objective and subjective motivations co-exist. National governments are influenced by many non-technical factors when they consider space policy decisions, including factors such as geo-political relationships, regional status, military postures and national pride. There is plentiful evidence, from both more developed and less developed countries, that both technical and non-technical motivations play a key role in motivating countries to pursue satellite activities. Paikowsky provides a deeper discussion on the role of political motivations in shaping national satellite programs for emerging space countries.[lxxxii] While acknowledging the importance of these non-technical factors, this section is focused on objective, technically driven motivations.

Investment Area	**Satellite Service:** *Using satellite services in earth observation, communication, navigation and science*	**Satellite Hardware:** *Owning and operating a spacecraft and supporting ground system*	**Satellite Expertise:** *Training personnel in satellite engineering*	**Satellite Infrastructure:** *Establishing local facilities to fabricate satellites*
Short Term Motivation	• Address time sensitive national needs for information	• Meet unique, local requirements for information with specific temporal frequency, spatial resolution, spectral coverage	• Develop knowledge to be an informed consumer of satellite services	• Increase technical involvement of local personnel in satellite activities
Long Term Motivation	• Enable informed regional planning • Enhance infrastructure and industry	• Gain operations experience • Decrease dependence on uncertain technology sources • Ensure service continuity	• Inspire young scholars • Enhance education and research opportunities • Build up industrial capability	• Use infrastructure to facilitate long term series of satellite projects

Figure 2-5: Potential Motivations for Developing Country Investment in Satellite Service, Hardware, Expertise and Infrastructure

Consider the four areas of investment in the two time dimensions shown in Figure 2-5. The first investment area is in satellites services – including earth observation, communication, navigation and science. In the short term, countries pursue satellite services because the applications meet time sensitive needs for information to support the work of government, military and civilian organizations. In the long term, these services from satellites facilitate improved infrastructure and better informed regional planning. Satellite service can also improve the functioning of commercial activity over time, in areas such as mineral exploitation, real estate development and logistics. The second area of investment is in owning a satellite system – including the spacecraft and related ground equipment to receive data and control the spacecraft. In the short term, a developing country government may choose to own domestic satellite hardware because they are not getting a particular type of required data or service from the international market. Owning satellite hardware allows the country to specify the technical characteristics of the service they receive such as how often the information is updated and the level of detail. In the long term, operating a national satellite or set of satellites offers several benefits. It provides local personnel the opportunity to understand satellite operations. This investment also ensures that service continuity, even if foreign service providers change their offerings. Ultimately, this allows a country to lessen their dependence on uncertain foreign technology sources. The third area of investment is developing local satellite expertise. Such an investment in space expertise can take many forms, such as university programs, government research projects, or training for civil servants and companies related to satellite technology. Countries can choose to buy a national satellite by procuring a turn-key system from a foreign company. This can be done with little knowledge about how satellites are designed, manufactured or operated. At times it is logical for a developing country to buy a turn-key system and forego any foray into learning satellite technology. However, there are also rational reasons to invest in developing satellite expertise at some level within developing countries. In the short term, such expertise help makes that country an informed, savvy consumer of satellite hardware. Buying a satellite is a complex process; each satellite is custom designed to perform a specific mission for the customer. It is not a commodity product. A technically savvy customer can more effectively specify what kind of system they need to solve local problems. In the long term, it is beneficial for developing countries to invest in building local technological capability about satellites because it is good for the overall scientific system in the country. Such experience can inspire young scholars to study in new areas and help pave the way for other scientific and technical activities. Personnel trained in the satellite field may also contribute to other industry sectors, such as electronics, information technology and advanced manufacturing. The fourth area of technology investment is in infrastructure to design, manufacture, integrate and test satellites. The decision to invest in satellite services, hardware and expertise may not imply an investment in local fabrication facilities. Such facilities include clean rooms, optical laboratories, environmental test facilities and electronics laboratories. In the short term, a country may install this infrastructure as a way to increase the technical involvement of local engineers beyond the satellite operations team, such as engineers, construction personnel and technicians. In the long term, if a country has a sustained satellite program, they can make use of these facilities during many projects and continually reap the benefit of the investment.

Recently, several new countries in Africa, Asia and Latin America are pursuing independent capability with satellite hardware, local satellite expertise and domestic satellite infrastructure. Examples of such countries include Nigeria, Algeria, Egypt, South Africa, the United Arab

Emirates, Turkey, Malaysia, Thailand, Vietnam, Mexico, and Chile. Many of these countries have defined a national policy to achieve local capability to design, manufacture and operate nationally owned satellites. This section summarizes the emerging space activities of sixteen developing countries in Asia, Africa and Latin America. These countries were chosen because they have demonstrated – or they are preparing for – a long term commitment to national-level space activity. The discussion includes short paragraphs discussing the activities of each country; this is followed by tables that summarize the information. The tables show, in the third column, the national office in each country that plays a central role in space activities. In some cases, such as Egypt, more than one organization shares this responsibility. Not all of the organizations listed in the third column are formal "space agencies;" they are listed because they have operational, procurement or regulatory involvement in space projects. Columns 4 through 8 list potential technical milestones that the countries have reached. The milestones represent increasing technical achievement, moving from left to right. Generally speaking, Low Earth Orbit (LEO) satellites refer to small or medium sized earth observation or scientific satellites. Geostationary (GEO) satellites in these examples are usually large, communication satellites that require greater cost and complexity. An "X" in the boxes in columns 4 to 8 indicates that the country has achieved the milestone at least once. If the country is currently pursuing a given milestone, and the boxes are labeled, "In process." Note that Brazil, India, China and Japan are excluded because of the relative maturity of their satellite programs. The data for the tables was drawn from both the websites of the relevant agencies, news articles as well as field research in Africa and Asia by the author.

Africa

- **Algeria**: Algeria established a formal space agency, Agence Spatiale Algerienne (ASAL) in 2002. The country bought three remote sensing satellites: one from Surrey Satellite Technology Ltd (United Kingdom) and two from EADS Astrium in Europe. Algeria is actively working to develop local capability to design and build satellites locally.[lxxxiii]
- **Egypt**: Egypt's remote sensing activity is lead by NARSS (National Authority for Remote Sensing and Space Sciences). They oversaw the purchase of EgyptSat-1, an earth observation satellite, from Ukraine's Yuzhnoe State Design Office.[lxxxiv] Meanwhile, the NileSat organization – a quasi-commercial entity owned partly by the state – has procured communication satellites from EADS Astrium.[lxxxv]
- **Kenya**: Kenya does not currently own national satellites. They have made ministerial level agreements with Nigeria, South Africa and Algeria to invest in an African Resource Management Satellite (ARMS) Constellation.[lxxxvi] They are also moving toward establishing a national space agency. For now they have a Space Secretariat under the Ministry of Defense.[lxxxvii] Kenya also has many local organizations with the ability to use satellite data.
- **Nigeria**: Nigeria established the National Space Research and Development Agency (NASRDA) in 1999. NASRDA has taken the lead in procurement of three small, remote sensing satellites from the Surrey Satellite Technology LTD (United Kingdom). As part of

the procurement, Nigerian engineers are learning skills in satellite engineering. Nigeria also set up a quasi-commercial company called NigComSat to procure and operate a communication satellite from China. NigComSat-1 launched in 2007, but failed in 2009. China launched a replacement for the communication satellite in 2011.[lxxxviii]

- **South Africa**: South Africa established the new South African National Space Agency in 2010.[lxxxix] South Africa built and operated two remote sensing satellites using local talent and facilities. SunSat launched in 1999; SumbandilaSat launched in 2009. SunSat was built by the University of Stellenbosch. The SunSat team started SunSpace and Information Systems to market their skills.[xc]

Figure 2-6 provides a summary of African satellite programs.

Region	Country	National Space Agency Or Office (Year Est.)	Buy LEO Sat. (Launch Year)	Buy GEO Sat. (Launch Year)	Build LEO Sat. Locally (Launch Year)	Build GEO Sat Locally (Launch Year)
Africa	Algeria	ASAL (2002)	2002		In process	
	Egypt	NARSS (1994) & NILESAT	2007	1998	In process	
	Kenya	National Space Secretariat (2009)				
	Nigeria	NASRDA (1999)	2003	2007	In process	
	South Africa	SANSA (2010)			1999	

Figure 2-6: Summary of African Satellite Programs (Dates show years of first achievement of each milestone)

Latin America

- **Argentina:** Argentina's National Commission for Space Activities (CONAE) was founded in 1991, but it builds on work dating back to the 1960s. Since the 1990s they have worked to build scientific and earth observation satellites.[xci] They invited US, Brazilian or European organizations to supply instruments on their satellites. More recently, they worked to build the first local communication satellite – ARSAT-1.[xcii,xciii] The satellites are built with INVAP, a national technology company.[xciv, xcv]
- **Chile:** In the 1990s Chile worked with the Surrey Satellite Technology LTD firm (United Kingdom) to build 2 small, remote sensing satellites and train local engineers. They formed a space agency in 2001 (Agencia Chilena Espacial).[xcvi] The nation's third remote sensing satellite was built by European firm EADS Astrium and launched in 2011.[xcvii, xcviii]

- **Mexico**: Mexico recently established a national space agency,[xcix] the Agencia Espacial Mexicana. Meanwhile, several Mexican universities have worked on micro-satellite projects. Some of these satellites have been launched and operated.[c, ci] Mexico has also been involved commercially with operating satellite communications for decades. The SatMex communication satellite firm, formerly owned by the Mexican government, is now owned privately.[cii]
- **Venezuela**: The main project of Venezuela's Bolivarian Agency for Space Activities has been the purchase of the Venesat-1 (Simon Bolivar) communications satellite from China. It was launched in 2008.[ciii]

Figure 2-7 provides a summary of Latin American satellite programs.

Region	Country	National Space Agency Or Office (Year Est.)	Buy LEO Sat. (Launch Year)	Buy GEO Sat. (Launch Year)	Build LEO Sat. Locally (Launch Year)	Build GEO Sat Locally (Launch Year)
Latin America	Argentina	CONAE (1991)			1996	In process
	Chile	ACE (2001)	1998			
	Mexico	AEM (~2010)		1985	1996	
	Venezuela	ABAE (~2008)		2008		

Figure 2-7: Summary of Latin American Satellite Programs (Dates show years of first achievement of each milestone)

Asia

- **Indonesia:** The National Aeronautics and Space Agency of Indonesia (LAPAN) was founded in 1963.[civ] LAPAN worked with the Technical University of Berlin in Germany to build a small remote sensing satellite called Tubsat, which carried a video camera. It was launched by India in 2007.[cv] They are working toward building a small satellite independently.[cvi] In parallel, Indonesia has been active in buying and operating commercial communication satellites. The first was built by Orbital and launched in 1997.[cvii,cviii] Indonesia is a member of the Asia-Pacific Regional Space Agency Forum.
- **Malaysia:** Malaysia's national space agency, ANGKASA, was established in 2002. Malaysia worked with Surrey Satellite Technology LTD (United Kingdom) to build their first remote sensing satellite; it launched in the early 2000s. Malaysia later worked with a Korean firm called SaTReC Initiative to build a second remote sensing satellite, launched in 2009. The Malaysian firm called ATSB implements the satellite projects and builds up local capability

in satellite engineering. In parallel, the commercial firm MEASAT has been buying communication satellites since 1996. Some of these communication satellites were bought from the US.[cix] Malaysia is a member of the Asia-Pacific Regional Space Agency Forum.

- **Pakistan:** Pakistan's SUPARCO (Space and Upper Atmosphere Research Commission) was established in 1981, after some early work on sounding rockets with NASA.[cx] During the 1990s, Pakistan sent engineers to the University of Surrey (United Kingdom). The Pakistani team contributed to several of the university's satellite projects. The SUPARCO team then built the BADR-1 experimental satellite.[cxi] SUPARCO plans to buy more advanced remote sensing satellites.[cxii] SUPARCO initially leased an existing communication satellite, but then they purchased a replacement from China which launched in 2011.[cxiii,cxiv,cxv] Pakistan is a member of the Asia-Pacific Regional Space Agency Forum and the Asia-Pacific Space Cooperation Organization.
- **South Korea:** In just two decades since the founding of KARI (Korea Aerospace Research Institute) in 1989, South Korea has achieved many technical milestones. They have built and purchased multiple LEO satellites since 1992. They are steadily moving toward greater technical independence. The COMS satellite, launched in June 2010 by Arianespace,[cxvi] is their first GEO satellite. It was built by EADS Astrium. A small firm in South Korea, called SATREC-Initiative, exported several remote sensing satellites. KARI is developing LEO launch capability. South Korea is a member of the Asia-Pacific Regional Space Agency Forum.[cxvii]
- **Thailand**: Thai satellite activity started with a commercial communications company (ThaiCom) purchasing satellites from the American company Hughes (now Boeing).[cxviii] The ThaiCom-1 satellite was launched in 1993.[cxix] A Thai university worked with the University of Surrey (United Kingdom) to build a small LEO satellite and train Thai engineers in satellite engineering.[cxx] This satellite was launched in 1998.[cxxi] Building on previous work in remote sensing, Thailand established its current space office, the Geo-Informatics and Space Technology Development Agency (GISTDA), in 2000. In 2008, Thailand's THEOS (Thai Earth Observing Satellite) satellite was launched from Russia. GISTDA bought this earth observation satellite from EADS Astrium.[cxxii] Thailand is a member of both the Asia-Pacific Regional Space Agency Forum and the Asia-Pacific Space Cooperation Organization.
- **Turkey:** TUBITAK UZAY is a public research organization in Turkey that implements national satellite projects. It was founded in 1985.[cxxiii] Tubitak has executed two remote sensing (LEO) satellite projects. The first was BilSat, launched in 2003. Tubitak bought Bilsat through a training package from Surrey Satellite Technology Limited (SSTL in the United Kingdom). SSTL also helped Tubitak set up local satellite manufacturing facilities. Based on this experience, they have built RaSat in Turkey (launched 2011)[cxxiv]. Meanwhile, a commercial company called TurkSat operates a fleet of communication satellites, which were built by European firms.[cxxv] Their first satellite was launched in 1994.[cxxvi]
- **United Arab Emirates**: In the UAE, the first satellite project has been executed by the Emirates Institute for Advanced Science and Technology (EIAST), which was founded in

2006.[cxxvii] They purchased a satellite and training package from the SATREC-Initiative firm in South Korea. Their first satellite – DubaiSat-1 – launched in 2009.[cxxviii]

Figure 2-8 provides a summary of Asian satellite programs.

Region	Country	National Space Agency Or Office (Year Est.)	Buy LEO Sat. (Launch Year)	Buy GEO Sat. (Launch Year)	Build LEO Sat. Locally (Launch Year)	Build GEO Sat Locally (Launch Year)
Asia	Indonesia	LAPAN (1963)	2007	1997	In process	
	Malaysia	ANGKASA (2002)	2000	1996	In process	
	Pakistan	SUPARCO (1981)		In process	1990	
	South Korea	KARI (1989)	1992	2009	1993	
	Thailand	GISTDA (2000)	1998	1993		
	Turkey	TUBITAK (1985)	2003	1994	2011	
	United Arab Emirates	EIAST (2006)	2009			

Figure 2-8: Summary of Asian Satellite Programs (Dates show years of first achievement of each milestone)

There are several key messages from the tables that summarize satellite activities in developing countries. The first message relates to national space leadership. All the countries listed in the tables either have established or are in the process of establishing an organization at the national level to lead space activities. The organizations take various forms. Some are formal space agencies; others are national remote sensing agencies or are national research organizations. The specific roles of these national organizations vary, but they have the opportunity to consider how their country will handle space technology transfer. The second message is that a wide variety of countries are pursuing domestic capability to build satellites locally. Countries such as Brazil, Argentina and South Korea have made extensive progress in creating local capacity and facilities to build satellites. Other countries are still developing the local capability. In all of the examples, the space activity will bring new technology into the country. The countries in these regions view space technology as an opportunity to address domestic social needs via both satellite services and technology advancement of the country.

2.7 Enabling technology: Small Satellites

Some of the national satellite activity described above is enabled by new technical trends in small satellites. There are new opportunities for capacity building in space technology because of the gradual maturity of satellite technology. It is increasingly possible to build a new type of satellite that is smaller, lighter and less expensive than traditional spacecraft, but that provide valuable services. Small satellites, defined here as less than 1000 kilograms in mass, are increasingly capable and offer potential for lower cost missions than traditional satellites. Small satellites provide opportunities for efficient applications in areas such as remote sensing, space science and non-real time communication. Because small satellite projects are relatively less complex, they allow for flexibility in areas such as the following: building up local technology infrastructure, including educational aspects in satellite missions, involving local industrial actors in a project and expanding local scientific base. There are many opportunities for international collaboration via small satellite projects. Creative collaboration models such as distributed ownership of a constellation of satellites or a network of mutually supportive ground stations have already been demonstrated. These new approaches to satellite engineering are lowering the barriers to entry for new actors.[cxxix]

One specific type of small satellites, called CubeSat, is particularly accessible to universities and organizations outside of government space programs. CubeSats are satellites that conform to a standard size of ten cubic centimeters. The standard was developed by a joint team at California Polytechnic State University (Cal Poly) and Stanford University in the United States. Because the creators of the standard share it freely, they open the opportunity for anyone to build on their idea and implement a satellite project. The Cal Poly team demonstrates by example that the CubeSat approach is accessible to teams without previous space experience. They were new to the area when they joined Stanford to work on this concept. The Cal Poly and Stanford teams serve as the nexus of a global network of teams that build CubeSats. Each team designs their satellite to perform a unique function. More and more types of organizations – including universities, governments and companies – are participating in CubeSat projects. New companies are emerging to supply parts designed especially for the CubeSats. All of these factors make it possible for virtually any team to get involved. Although CubeSats have technical limitations due to their small size and power capabilities, they have many advantages. CubeSats allow new people to get directly involved with a space mission at a low cost. They also provide a venue for space experiments which are high risk and infeasible on more expensive missions. Thus CubeSats in particular, and small satellites in general, are enabling technologies that increase the opportunities for emerging countries to participate in space.[cxxx]

In addition to the government programs described above, there are also many new university or private satellite programs around the world. For example, in South Africa the Cape Peninsula University of Technology (CPUT) uses CubeSat projects to teach graduate students about electronics. CPUT has a new postgraduate program in satellite engineering based in Cape Town.

CPUT partners with the French government in a program called F'SATI (French-South African Institute of Technology) at CPUT. Through the F'SATI program, they offer post-graduate training in satellite engineering that includes hands on work with satellites. Graduates of the program receive dual degrees from South Africa and France. The program includes academic course work, an individual research project focused on satellite subsystems and team work after graduation on a satellite project. The students that attend the program come from all over Africa and beyond. Since the program started in February 2008, 45 students have registered, 30 students have graduated and 10 students have participated in a year of professional development. During this year after graduation, the engineers-in-training work on implementing a nano-satellite based on the CubeSat standard. They execute the design and fabrication in preparation for spaceflight. At the time of writing, one nano-satellite called ZACUBE-1 had been completed and the team planned to begin a second one. The CPUT F'SATI program also reaches out to younger students in South African and neighbouring countries.[cxxxi]

2.8 Building local technological capability in satellite technology

As discussed above, space technology can promote development in a variety of ways. An increasing number of developing countries is pursuing national satellite programs in order to build local capability in the technology and increase their control over satellite services. This dissertation pursues an in-depth exploration of the process by which countries that are new to space start new satellite programs. This section presents a motivating pilot study. The study reveals that countries pursue unique paths to technological capability; however, they face a common set of strategic decisions.

2.8.1 Common Strategic Decisions and the Evolution of Satellite Programs

Once a government chooses to invest in having a national satellite program, there are several challenging decisions that must be made about the scope and implementation of the program.[cxxxii] Players outside the government may also shape satellite programs, but the focus of this discussion is on the government perspective. In some cases government decisions are made directly through a conscious policy process. In other cases, the strategy emerges organically as many independent decisions and circumstances come together. The decisions discussed in this section are highly influential in establishing the foundations of a young space program. These decisions can be categorized into three key areas. As shown in Figure 2-9, these areas encompass progressively broadening levels. First, there are narrow questions about the technical capabilities to which the country aspires. The questions at this narrow level correspond to the four types of satellite investment described above in Figure 2-4 – satellite services, hardware, expertise and infrastructure. The scope of this level includes questions about which human resources to develop and what technical facilities to procure and operate. Within this category are questions that the government can answer in numerous ways. Will the country own and operate satellites? What types of satellites do they need? How will they procure the satellites? Will they develop any of the technology using local personnel – for the satellite or for the payload? Will they develop the technology using local facilities? Each of these decisions involves complex tradeoffs and potentially large investments of resources. At the second level are decisions about how the satellite program fits into the domestic context. The new program will have some relationship with existing entities in government, academia, industry and the military. Stakeholders from each of these areas will seek to influence the program as well. Questions at this level include the following: How will existing organizations in research, administration, industry and defense be involved in the new satellite program? Will the government seek to foster specific local industries via the program? Should the satellite program be executed directly by a government entity, a commercial entity or a combination of both? Decisions at this second level are highly driven by the local economic and technology context. At the third and broadest level, the satellite program will be defined by how it relates to the international context. Most satellite programs involve relationships with foreign governments or firms. Governments who begin new satellite programs have to make strategic decisions about how and when to work with foreign players. A political partnership with a foreign government can be useful, especially when it fulfills a political objective and meets needs for both sides. It can often appear to save resources, for example if two countries collaborate on a satellite project and share the costs. There are hidden expenses to consider, however, due to the costs of coordination, travel, political delay and potential language or cultural barriers. A commercial relationship with a foreign firm is often used by developing country governments as part of their satellite program. They may buy a full satellite or specific services from the firm. A commercial relationship has the advantage of putting control in the hands of the customer. This can be more flexible than a political partnership. Commercial relationships can be limited as well, however, due to the needs of the firm to control their intellectual property and make a profit. All developing countries face these three strategic decision areas – the program context, the domestic context and the international context – if they choose to implement a national satellite program. There are important relationships between the decisions made at the three levels.

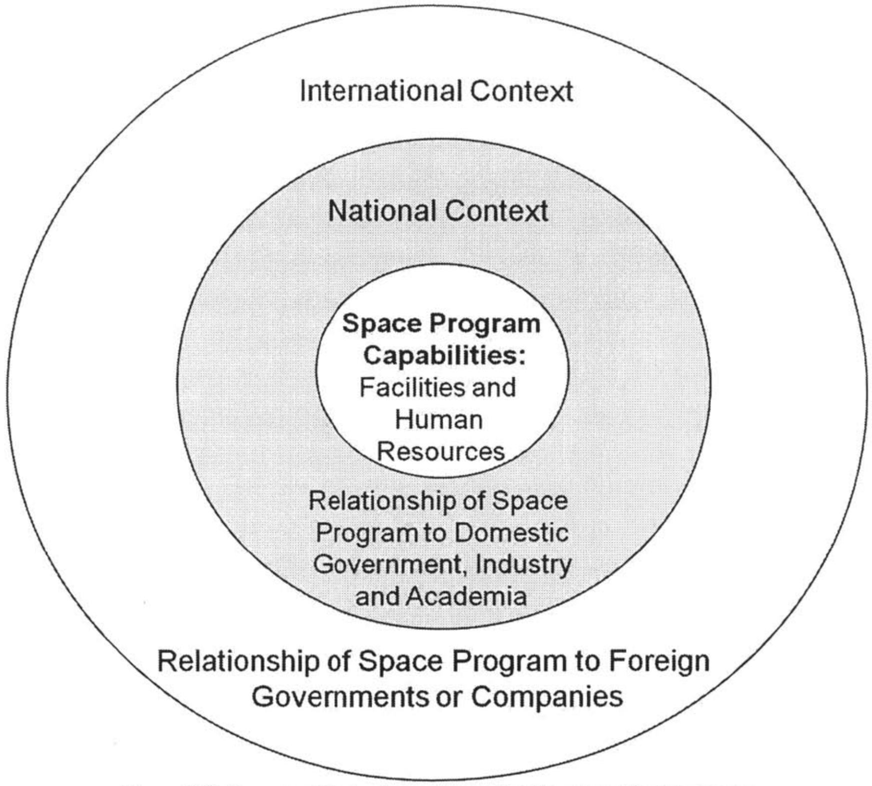


Figure 2-9: Common Strategic Decisions for New Satellite Programs

A motivating pilot study examines the experiences of eight countries that established national satellite programs as part of their development process.[cxxxiii] The countries included in the study are Argentina, Algeria, Brazil, Egypt, India, Malaysia, Nigeria and South Korea. The study compares the pathways of these countries in achieving key milestones along an idealized ladder of technical autonomy called the Space Technology Ladder. This ladder is shown in Table 2-9. It outlines a variety of implementation approaches in four areas, namely: 1) Establishing a national space office; 2) Owning and operating low earth orbit (LEO) Satellites; 3) Owning and operating geostationary (GEO) satellites; and 4) Launching satellites. Within each area, there is a vertical progression toward increasing technical autonomy. For example, Levels 3 to 7 all show methods for owning and operating a LEO satellite. At Level 3, however, the country buys the satellite from a foreign partner and at Level 7 they are able to execute the project independently in their own local facilities.

Table 2-9: The Space Technology Ladder shows levels of capability and autonomy

The Space Technology Ladder	
13	Launch Capability: Satellite to GEO

12	Launch Capability: Satellite to LEO
11	GEO Satellite: Build Locally
10	GEO Satellite: Build through Mutual International Collaboration
9	GEO Satellite: Build Locally with Outside Assistance
8	GEO Satellite: Procure
7	LEO Satellite: Build Locally
6	LEO Satellite: Build Through Mutual International Collaboration
5	LEO Satellite: Build Locally with Outside Assistance
4	LEO Satellite: Build with Support in Partner's Facility
3	LEO Satellite: Procure with Training Services
2	Space Office: Establish Current National Space Organization
1	Space Office: Establish First National Space Organization

The pilot study's approach is to construct a timeline showing the first year in which a country achieves a milestone on the Space Technology Ladder. Rather than showing every major project, the timeline highlights key moments of technical accomplishment for the eight countries. The major milestones of African, Asian and Latin American countries are shown in Figure 2-10 through Figure 2-12. The timeline highlights two pivotal ideas. First, there is a diversity of approaches among the countries. They all found unique ways to answer the strategic questions defined above and move along the Space Technology Ladder. For example, Argentina tended to partner primarily with foreign governments via political agreements in their early LEO satellite projects in the 1990s. They also contracted with an existing technology firm to do local manufacturing of the satellite buses. In contrast, Malaysia's more recent efforts in LEO satellite programs built heavily on commercial relationships with foreign firms. They also created a new commercial firm within Malaysia to manage the projects. This is just one example of the contrasts among the historical approaches to satellite programs. As can be seen in Figure 2-10 through Figure 2-12, countries do not move linearly along the Space Technology Ladder, they bounce around it and find their own unique path to technological capability. A second key idea resulting from the historical timelines of satellite programs is the importance of international collaboration as part of the process of building technological capability. As countries progress through the Space Technology Ladder, they are increasing their local level of technical expertise regarding satellites. When developing country governments begin new satellite programs, they often have limited domestic resources to help establish a technical workforce in satellites or set up satellite manufacturing facilities. The local universities may not have specialties in satellite engineering, and local industry does not yet have experience. In these cases they typically turn to foreign firms or government partnerships for technical assistance. Thus, the foreign participation in these satellite programs is a vital part of the process of technological capability building. This history shows that many countries in the past have depended on foreign partnerships to grow their capabilities in satellite technology. It is likely that many countries in the future will choose a similar course of action. An international technology partnership does not guarantee successful capability building, however. There are a number of challenges that can decrease the effectiveness of capability building via international partnership.

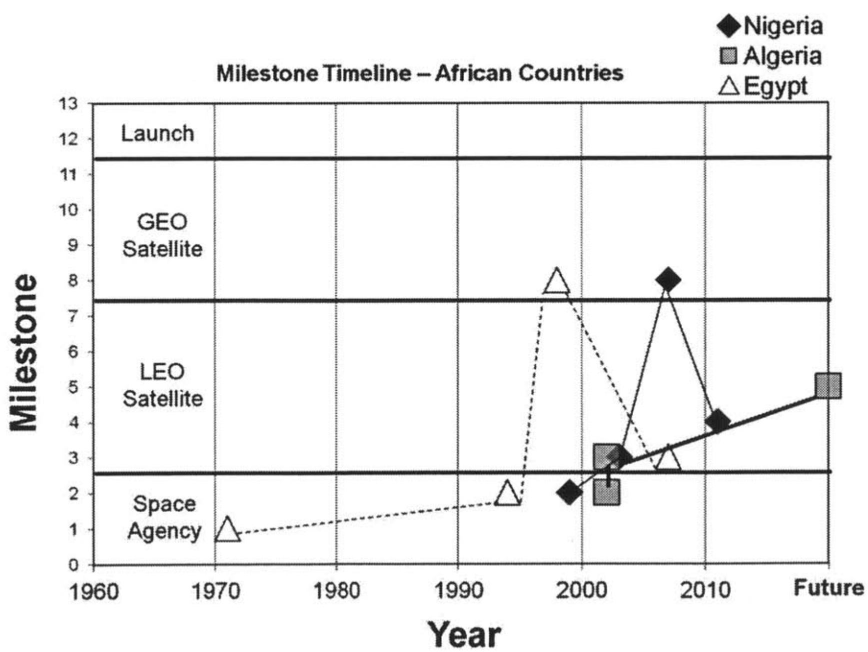


Figure 2-10: African Satellite Timelines

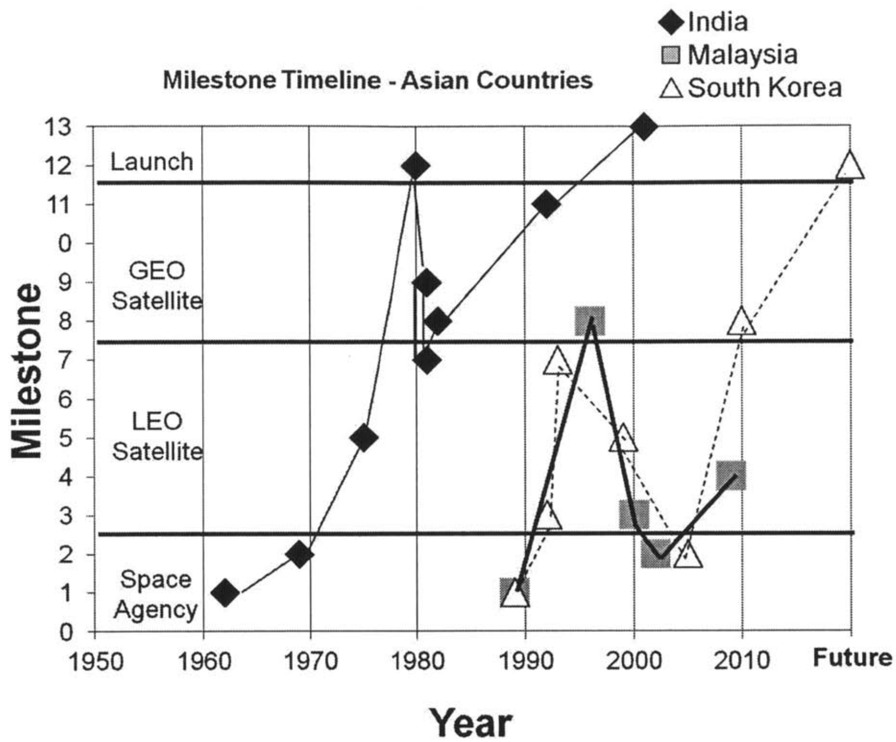


Figure 2-11: Asian Satellite Timelines

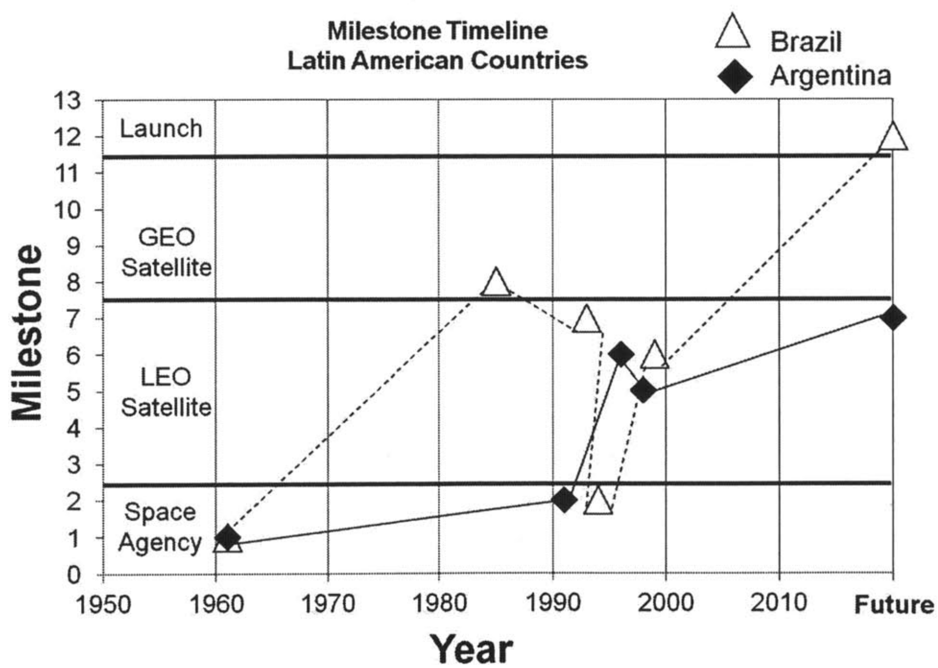


Figure 2-12: Latin American Satellite Timelines

2.8.2 Collaborative Satellite Projects with Capability Building Goals

The motivating pilot study demonstrated that many countries harness international collaboration as part of their process of building local capability in satellite technology. This common theme emerges despite the diversity of satellite timelines for each country. The core research for this dissertation is a study of four countries that each initiated national satellite programs by partnering with foreign firms. They all procured satellites from these foreign firms and paid the firms to provide long term training to local engineers in satellite engineering. A number of countries have pursued this specific model for satellite projects. Several examples are shown in Figure 2-13.

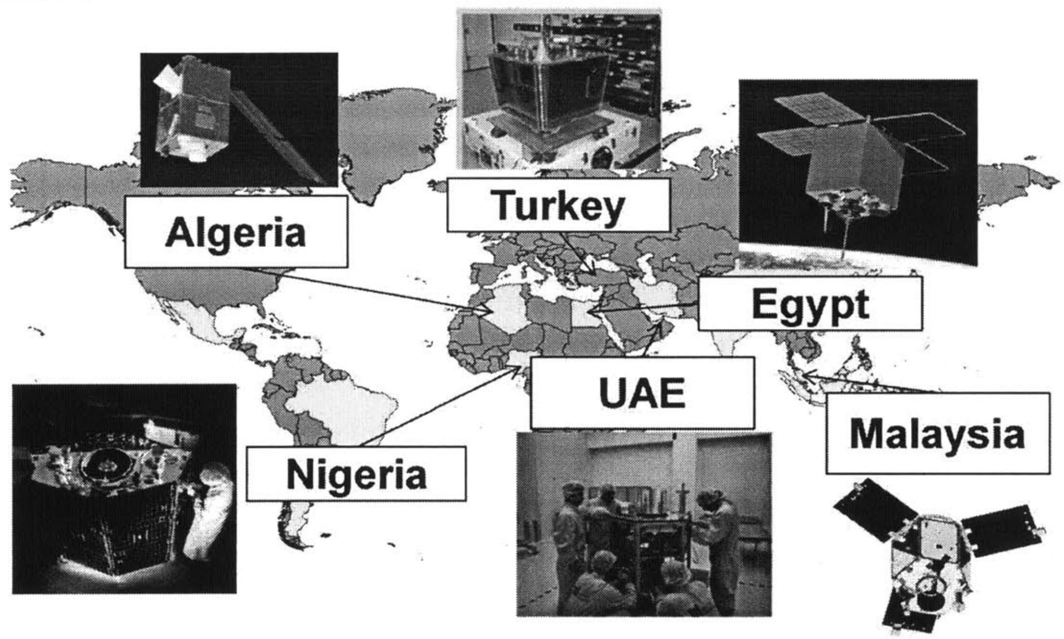


Figure 2-13: Examples of countries that have pursued collaborative satellite training projects

The experience of South Korea shows a highly successful outcome from a series of collaborative satellite training projects. Their story is summarized in Figure 2-14. For the first national satellite (KitSat-1), a university in South Korea partnered with a university in the United Kingdom. Several recent graduates from engineering undergraduate programs in South Korea's premier technical university spent time in the United Kingdom to work on the satellite. This was their first training in satellite engineering. A professor from the technical university in Korea formed the team to travel to Korea and a complementary team that stayed in South Korea. After the first satellite was complete, the two teams came together to build a second satellite that was identical to the first (KitSat-2). The South Korean university purchased the components from the UK university, but they assembled the satellite independently at home. The same university team worked independently to design and build a third satellite over the next few years (KitSat-3).[cxxxiv] This university satellite team eventually spun out from academia and formed a company to design and build satellites.[cxxxv] Several of the original trainees that went to the United Kingdom took on leadership positions in the company. Within a decade, the new Korean satellite developer exported several small remote sensing satellites to foreign customers. In parallel to the evolution of this firm, the Korean government was forming a national space program. An government organization called the Korean Aerospace Research Institute was created in 1989 to lead national space activity. Later, in 2005, the National Space Committee was established as the leader for Korean space policy.[cxxxvi] The government agency, KARI, pursued highly sophisticated satellites in partnership with foreign firms. They also worked to develop local launch capability.[cxxxvii] In Figure 2-14, South Korea's mission timeline is shown using two axes. Time proceeds to the right along the horizontal axis; and satellites are positioned on the vertical axis to show their relative technical complexity. The early remote sensing satellites developed by the Korean university were not highly complex, but they did represent success efforts to gradually establish autonomy in satellite engineering. The government satellites were more complex and required external partnerships. The satellites exported to foreign governments by the Korean firm were of medium complexity, but they represented a high degree of autonomy.

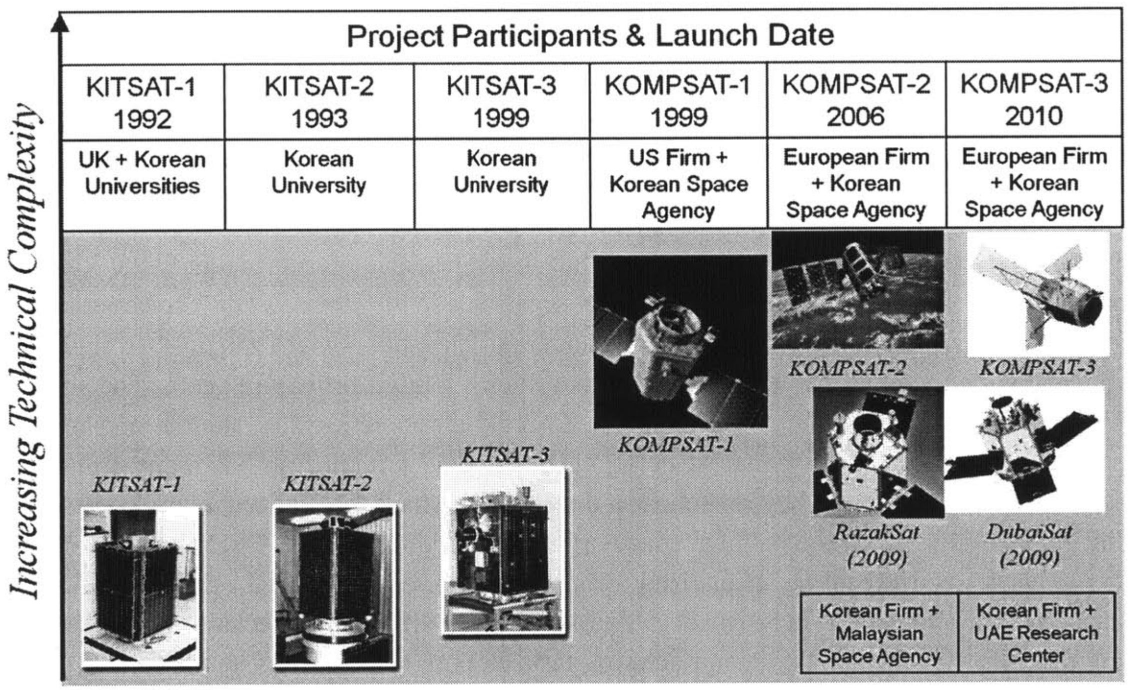


Figure 2-14: South Korea used collaborative satellite training projects to initiate a national satellite program

The Korean experience with domestic satellite projects is impressive. In less than two decades, they transitioned from learners with little space experience to trainers that were manufacturing satellites for foreign customers and mentoring new engineers. In addition, both the commercial and government space actors in Korea have achieved a sustained level of activity with satellites. They not only pursue satellite projects, but also long term satellite programs. The Korean experience is not typical. Their ability to build a satellite independently so soon after the first project and to move to a higher level of technical complexity on their third project both stand in contrast with the experiences of other countries. Korea achieved this despite inherent challenges of pursuing technological capability through collaborative satellite projects. There are challenges in these types of projects in the areas of incentives, information, priorities and culture.

The issue with incentives relates to the objectives of the firms that provide training as compared to those of the government customers. It is in the firm's interest to keep the space agency as a dependent client, while the space agency is working toward independent capability. The difficulty of incentives is further explained by the concept of the Principal-Agent problem in economics. The concept applies to scenarios in which an individual or organization (the principal) hires someone else (the agent) to perform a task on their behalf based on the agent's specialized capability. Several dilemmas are inherent in such arrangements. The principal hopes the agent will act according to their wishes, but such performance is not guaranteed. The utility-maximizing agent may or may not have incentives to act according to the wishes of the principal. There is a cost to the principal to monitor the agent's activities or provide incentives to encourage compliance. The cost is increased by the fact that the agent has some knowledge about the activity in question that is not available to the principal. The commonly cited characteristics of an imperfect market – such as asymmetric information, unmatched risk aversion, imperfect commitments and costly monitoring – combine to create tension in the relationship between principal and agent. Incentive theory proposes that principals can attempt to ameliorate the challenges of the principal-agent problem by designing a contract that provides incentives for the agent to act as the principal desires. Much of the writing in this area formulates the kinds of incentives that would be required under various scenarios.[cxxxviii] The satellite projects that are studied in this thesis have the potential for engendering Principal-Agent Problems. In this case, the principal is the national space organization that hires a foreign firm as an agent. The agent is hired to accomplish two primary tasks, namely, to build a remote sensing satellite and to train engineers who work for the national space organization. The foreign firm has many archetypal characteristics of an agent. They are chosen because they have specialized knowledge about satellite engineering, which the national space organization does not have. Because the firms are in other countries and executing specialized techniques, it is very difficult for the national space organization to monitor their performance. The monitoring difficulty is perhaps greater for the training task than for the satellite manufacturing task. In both cases, however, the final proof of the quality of work comes only after the project is completed. Also important to the principal is the fact that the relationship with the agent is not repeated many times. The principal needs excellent performance from the agent for each specific project, not average performance over many projects. The national space organization needs to select a firm and create a contractual relationship with them while operating in a state of imperfect information. They need to define what the firm should deliver to them at a particular level of quality for a particular price; this is challenging. Finally, these collaborative satellite projects are bringing together organizations from different countries. They potentially have different cultures and first languages as well. The cultural aspects of the collaboration can bring challenges.

On a larger scale, there are also issues with the broader concepts introduced throughout this section. This discussion has outlined the potential of space technology to promote development in countries that have traditionally had limited involvement with the field. The possible benefits from emerging satellite programs include information and infrastructure to enhance social services as well as growth in technological capability. Research is needed on this topic because it is poorly understood and poorly documented. Research may reveal sterling examples of surprising technology success in developing countries; it may also reveal cases of unmet potential from technology or cases of mixed outcomes that need to be explained. Whenever technology is applied as part of a development solution, there is a need for caution about unintended consequences, the effectiveness of the solution over time in a developing environment, and the way the technology may impact social customs or values. Caution is required because the concepts of development via increased technological capability are driven by a western model of progress; the model may need to be adapted to apply to specific countries and cultures. Satellite technology does have the potential to provide useful services, but successful application is not guaranteed. In the case of remote sensing services, the data from satellites needs to be managed and processed by skilled individuals and converted into relevant information to support decision making in a variety of settings. A complex network of organizations and technologies needs to be in place to achieve this. Satellite communication service does not always provide the expected benefits because it can be more costly than alternative services. Also, it requires specific equipment that may not be available in all the places where the service is needed. As developing countries invest in national satellite programs, they face many obstacles. There may be internal criticism from people that assume the investment is not worthwhile. Satellite programs are expensive. They often require large short term investments in order to gain uncertain, long term benefits that are difficult to measure. The space leaders in any country need to work constantly to maintain political and financial support in order to have continuity. Space programs need to train personnel in a setting that does not have the required educational infrastructure. As new space actors seek to access space technology, they have to navigate the complex geo-political realities that result from the historic development of space as a dual use technology with military and civil applications. This implies that countries with space technology are careful about how they share it.

In summary, there are emerging space countries that seek to build local capability to build and operate satellites. Many of these countries choose a similar model for their early satellite projects. They hire a foreign firm to build their satellite and train engineers at the firm's location for months or years. This model of training has the potential to bring positive results as it did in South Korea's case. Most countries that used this approach did not have South Korea's rapid progress. Meanwhile, these projects face inherent challenges due to issues of incentives, information, priorities and culture. They also face the larger scale challenges that are inherent in applying space technology as part of a development solution. In response to all of these realities, this dissertation pursues in-depth case studies of six collaborative satellite projects to understand what the challenges are and how four nations have sought to address them. The next section formalizes some of these issues as part of the literature review.

[i] D. Wood, The Use of Satellite-Based Technology in Developing Countries, Master's Thesis, Aeronautics and Astronautics Dept., Massachusetts Institute of Technology, Cambridge, MA, 2008.

[ii] Amsden, A. *Rise of "The Rest:" Challenges to the West from Late-Industrializing Economies.* New York: Oxford University Press, 2001

[iii] Stiglitz, J. "Markets, Market Failures, and Development." *Perspectives on Economic Development.* Vol. 79, No. 2, May 1989.

[iv] Solow, R., "Technical Change and the Aggregate Production Function," *The Review of Economics and Statistics,* Vol 39, No. 3, August 1957, p. 312-320.

[v] Solow, R., "A Contribution to the Theory of Economic Growth," *The Quarterly Journal of Economics,* Vol 70, No. 1, February 1956, p. 65-94.

[vi] Amdsen, A. *The Rise of the Rest: Challenges to the West from Late-Industrializing Economies.* Oxford University Press, New York, 2001.

[vii] Amsden, A. *Escape from Empire: The Developing World's Journey Through Heaven and Hell.* MIT Press, Cambridge, 2007.

[viii] Tainter, J. "The Collapse of Complex Societies." Cambridge University Press, Cambridge, 1988.

[ix] Tainter, J. "The Collapse of Complex Societies." Cambridge University Press, Cambridge, 1988, p 37.

[x] United Nations Development Program, Summary: *Human Development Report 2011,* http://hdr.undp.org/en/media/HDR_2011_EN_Summary.pdf Accessed December 20, 2011.

[xi] Ashford, N., and Caldart, C., "Beyond Pollution Control and Prevention: Sustainable Development." *Environmental Law, Policy, and Economics: Reclaiming the Environmental Agenda,* MIT Press, 2008, p. 4.

[xii] Stiglitz, J. "Markets, Market Failure and Development," *American Economic Review.* Vol 79, 1989.

[xiii] North, D.C. "Institution, Transaction Costs and Economic Growth." *Journal of Economic Inquiry.* Vol 25, 1987.

[xiv] Swart, D., "Africa's Technology Futures: Three Scenarios." The Pardee Papers, No 14, July 2011. http://www.bu.edu/pardee/publications-library/the-pardee-papers/pardee-papers-14-tech/ Accessed December 20, 2011.

[xv] International Telecommunication Union, "Measuring the Information Society 2011," Geneva, Switzerland, http://www.itu.int/ITU-D/ict/publications/idi/2011/Material/MIS_2011_without_annex_5.pdf Accessed December 20, 2011.

[xvi] World Economic Forum, *The Global Competitiveness Report 2010-2011.* "Appendix A: Computation and Structure of the Global Competitiveness Index 2010-2011." http://gcr.weforum.org/gcr2010/ Accessed December 20, 2011.

[xvii] Transparency International, "Corruption Perceptions Index," http://www.transparency.org/policy_research/surveys_indices/cpi Accessed December 20, 2011.

[xviii] United Nations Development Program, *Human Development Report,* "Table 1: Human Development Index and its Components." http://hdr.undp.org/en/media/HDR_2011_EN_Table1.pdf Accessed December 20, 2011.

[xix] Yale Center for Environmental Law and Policy (Yale University) and Center for International Earth Science Information Network (Columbia University), *2010 Environmental Performance Index,* http://epi.yale.edu/ Accessed December 20, 2011.

[xx] Mokyr, J., *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton University Press, 2002, Princeton.

[xxi] Mokyr, J., *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton University Press, 2002, Princeton.

[xxii] Mokyr, J., *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton University Press, 2002, Princeton.

[xxiii] Mokyr, J., *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton University Press, 2002, Princeton, p. 6.

[xxiv] Mokyr, J., *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton University Press, 2002, Princeton, p. 29.

[xxv] Mokyr, J., *The Gifts of Athena: Historical Origins of the Knowledge Economy.* Princeton University Press, 2002, Princeton, p. 33.

[xxvi] Smith, A. *The Wealth of Nations.* Penguin, London, 1776 (Republished 1999).

[xxvii] Schumpeter, J., *The theory of economic development*. Trans. Redvers Opie. 2nd Ed. Cambridge, Massachusetts: Harvard University Press, 1936.
[xxviii] Schumpeter, J., *The theory of economic development*. Trans. Redvers Opie. 2nd Ed. Cambridge, Massachusetts: Harvard University Press, 1936.
[xxix] Schumpeter, J., "The Creative Response in Economic History." *The Journal of Economic History,* Vol 7, No 2, p149-59.
[xxx] Schumpeter, J., *Capitalism, Socialism and Democracy.* Harper Perennial, New York, 1976.
[xxxi] Schumpeter, J., "The Creative Response in Economic History." *The Journal of Economic History,* Vol 7, No 2, p149-59.
[xxxii] Schumpeter, J., "The Explanation of the business cycle. *Economica.* Vol 21, December, p. 286-311.
[xxxiii] Schumpeter, J., *Business Cycles: A theoretical, historical and statistical analysis of the capitalist process.* New York: McGraw-Hill, 1939.
[xxxiv] Schumpeter, J., *Business Cycles: A theoretical, historical and statistical analysis of the capitalist process.* New York: McGraw-Hill, 1939.
[xxxv] Drucker, Peter. *Post-Capitalist Society.* New York: HarperCollins, 1993.
[xxxvi] Wood, Danielle and Annalisa Weigel, "The Use of Satellite-Based Technology to Meet Needs in Developing Countries," *Proceedings of the International Astronautical Congress*, Glasgow, Scotland, October 2008.
[xxxvii] Comstock, D. "A Survey of NASA Technologies Benefitting the Developing World." Proceedings of the International Astronautical Congress, Daejeon, South Korea, 2009. IAC-09.E5.1.10.
[xxxviii] Space Commercial Services. http://www.comspace.co.za/ Accessed Sept, 15, 2011.
[xxxix] ATSB http://www.atsb.my/ Accessed September 15, 2011.
[xl] United Nations Office of Outer Space Affairs, "UNOOSA." http://unoosa.org/oosa/en/OOSA/index.html Accessed December 20, 2011.
[xli] United Nations Office of Outer Space Affairs, "United Nations Treaties and Principles on Space Law." http://unoosa.org/oosa/en/SpaceLaw/treaties.html Accessed January 23, 2012.
[xlii] United Nations Office of Outer Space Affairs, "United Nations Treaties and Principles on Space Law." http://unoosa.org/oosa/en/SpaceLaw/treaties.html Accessed December 20, 2011.
[xliii] United Nations Office of Outer Space Affairs, "United Nations Programme on Space Applications." http://unoosa.org/oosa/en/about_PSA.html, Accessed on December 20, 2011.
[xliv] United Nations Office of Outer Space Affairs, "About UN-SPIDER." http://unoosa.org/oosa/en/unspider/index.html Accessed December 20, 2011.
[xlv] http://www.rcmrd.org/
[xlvi] "Introduction to the CBERS Program." Instituto Nacional de Pesquisas Espaciais. http://www.cbers.inpe.br/?hl=en&content=introducao April 1, 2010.
[xlvii] "INPE along with USGS discuss applications of Landsat-8." INPE. http://www.inpe.br/ingles/news/news_not74.php April 1, 2010.
[xlviii] "Homepage." INPE. http://www.inpe.br/ingles/ April 1, 2010.
[xlix] Bill Sweetman, Ed. "Empresa Brasileira de Telecomunicacoes (Embratel). *Jane's Space Systems and Industry 2007-2008.* Alexandria, 2007.
[l] "Hughes Delivers Distance Education to the Amazon." http://news.thomasnet.com/companystory/533774 April 2, 2010.
[li] "Site of Fortaleza." INPE http://www.roen.inpe.br/index_e.htm April 2, 2010.
[lii] "Radiobservatorio de Itapetinga." http://www.das.inpe.br/radio/observatorio.html April 2, 2010.
[liii] "Miniobservatorio Astronomico." http://www.das.inpe.br/miniobservatorio/projetos/proje.htm April 2, 2010.
[liv] "Homepage." CRECTEALC Mexico. http://www.crectealc.org/ April 1, 2010.
[lv] "Earth Observation." CSIR Satellite Applications Center. http://www.csir.co.za/SAC/eo.html March 31, 2010.
[lvi] "The Executive Committee." Group on Earth Observations. http://www.earthobservations.org/ag_excom.shtml March 31, 2010.
[lvii] "Government." South African Space Portal. http://www.space.gov.za/government.php March 31, 2010.
[lviii] "New Digital Maps of Precious Metals and Stones in South Africa." Council for Geoscience. http://www.geoscience.org.za/index.php?option=com_content&task=view&id=907&Itemid=337 March 31, 2010.
[lix] "Current Projects." Council for Geoscience. http://www.geoscience.org.za/index.php?option=com_content&task=view&id=426&Itemid=401 March 31, 2010.
[lx] "Mapping Malaria Risk in Africa." http://www.mara.org.za/ March 31, 2010.
[lxi] "NDMC: South African Fire Danger Index." http://gislive.ndmc.gov.za/fdigis/ March 31, 2010.

[lxii] "Satellite Transmitters Fitted to Karoo Blue Cranes." Endangered Wildlife Trust. http://www.ewt.org.za/news_fullstory.aspx?status=0&newsID=466 March 31, 2010.
[lxiii] Basson, Carel. "The Use of Geographical Information Systems, Global Positioning Systems and Automated Demarcation Technologies in Surveys and Census Mapping at Statistics South Africa." Proceedings of the Regional Workshop on Census Cartography and Management, Lusaka. 2007. http://unstats.un.org/unsd/demographic/meetings/wshops/Zambia_8Oct07/list_of_docs.htm
[lxiv] "About Us." Mindset Network. http://www.mindset.co.za/about March 31, 2010.
[lxv] "University of South Africa." UNISA. http://www.unisa.ac.za/Default.asp?Cmd=ViewContent&ContentID=3 March 31, 2010.
[lxvi] "Telkom Internet –Satellite." Telkom. http://www.telkom.co.za/attheoffice/products/satellite/index.html March 31, 2010.
[lxvii] "DSTV." MultiChoice. http://www.multichoice.co.za/multichoice/view/multichoice/en/page45 March 31, 2010.
[lxviii] "Facilities: Astronomical Facilities." South African Space Portal. http://www.space.gov.za/facilities.php March 31, 2010.
[lxix] "Who's Who in South Africa's Space Zoo." World Space Week South Africa. http://www.space.gov.za/wsw/whoswho.html March 31, 2010.
[lxx] "Boyden Observatory." University of the Free State. http://www.ufs.ac.za/faculties/index.php?FCode=04&DCode=113&DivCode=D015 March 31, 2010.
[lxxi] "SunSpace: Innovative Satellite Solutions." http://www.sunspace.co.za/home/?url=/home March 31, 2010.
[lxxii] Plessis, Stella. "Unique Space and Aviation Photo Competition for School Learners." University of Pretoria. http://web.up.ac.za/default.asp?ipkCategoryID=2843&ArticleID=24 March 31, 2010.
[lxxiii] "Who's Who in South Africa's Space Zoo." World Space Week South Africa. http://www.space.gov.za/wsw/whoswho.html March 31, 2010.
[lxxiv] Denel, "Denel Overberg Test Range in a Nutshell." http://www.otb.co.za/ Accessed December 21, 2011.
[lxxv] "Homepage." Sentech. http://www.sentech.co.za/ March 31, 2010.
[lxxvi] "Homepage." Space television. http://www.spacetv.co.za/?loadpage=content&name=WELCOME&menuname=welcome+to+space+television' March 31. 2010.
[lxxvii] "Homepage." Tellumat. http://www.tellumat.com/ March 31, 2010.
[lxxviii] "Homepage." Optron Geomatics. http://www.optron.com/index.asp March 31, 2010.
[lxxix] Group on Earth Observations, "What is GEOSS?" http://www.earthobservations.org/geoss.shtml Accessed December 21, 2011.
[lxxx] United States Government. "Global Positioning System." http://www.gps.gov/systems/gps/ Accessed December 21, 2011.
[lxxxi] United Nations Office of Outer Space Affairs, "Report on Current and Planned Global and Regional Navigation Satellite Systems and Satellite-based Augmentation Systems," http://www.oosa.unvienna.org/pdf/publications/icg_ebook.pdf Accessed December 21, 2011.
[lxxxii] Paikowsky, Deganit. "The Space Club- Space Policies and Politics." Proceedings of the International Astronautical Congress. Daejeon, South Korea, 2009.
[lxxxiii] Agence Spatial Algerienne. www.asal-dz.org Accessed July 7, 2010.
[lxxxiv] NARSS. http://www.narss.sci.eg/ Accessed July 7, 2010.
[lxxxv] NileSat. http://www.nilesat.com.eg/default1.htm Accessed July 7, 2010.
[lxxxvi] Mostert, Sias, "African Resource Management Constellation." *African Skies.* No 12, October 2008. http://articles.adsabs.harvard.edu/full/2008AfrSk..12...53M Accessed July 7, 2010.
[lxxxvii] Kenya Gazzette. http://www.kenyalaw.org/KenyaGazette/view_gazette.php?title=3222 Accessed July 7, 2010.
[lxxxviii] NASRDA. http://nasrda.gov.ng/ Accessed December 21, 2011.
[lxxxix] South African National Space Agency. http://www.sansa.org.za/ Accessed December 21, 2011.
[xc] SunSpace and Information Systems. http://www.sunspace.co.za/ Accessed July 7, 2010.
[xci] INVAP, "SAC-B." http://www.invap.com.ar/en/projects/sac-b-satellite.html Accessed January 23, 2012.
[xcii] Arianespace. "Arianespace to launch Argentina's ARSAT-2 Satellite." http://www.arianespace.com/news-press-release/2011/3-14-2011-ARSAT2.asp Accessed January 23, 2012.
[xciii] INVAP. "ARSAT Satellites." http://www.invap.com.ar/en/projects/arsat-satellites.html Accessed January 23, 2012.
[xciv] CONAE www.conae.gov.ar July 7, 2010.

[xcv] INVAP http://www.invap.net/index-e.php July 7, 2010.
[xcvi] AEC. http://www.agenciaespacial.cl/ July 7, 2010.
[xcvii] EADS Astrium. "SSOT: High Resolution Earth Observation Satellite for Chile." http://www.astrium.eads.net/en/programme/ssto-high-resolution-earth-observation-for-chile.html. Accessed January 23, 2012.
[xcviii] "Chile to launch satellite into orbit this week." *Santiago Times.* http://www.santiagotimes.cl/chile/science-technology/23083-chile-to-launch-satellite-into-orbit-this-week Published December 14, 2011. Accessed January 23, 2012.
[xcix] "Agencia Espacial Mexicana iniciara funciones con 100 mdp." *El Universal.* Published March 2, 2011. Accessed http://www.eluniversal.com.mx/articulos_h/63158.html January 23, 2012.
[c] Romero, F. ""Actividades y política espacial de México " *Space Policy in Latin America and The Caribbean Conference.* http://www.secureworldfoundation.org/index.php?id=192 July 7, 2010.
[ci] "A Blossoming of Diverse Amateur Radio Satellites in the 1990s." http://www.spacetoday.org/Satellites/Hamsats/Hamsats1990s.html Accessed January 23, 2012.
[cii] SatMex. www.satmex.com.mx/ *Accessed July 7, 2010.*
[ciii] ABAE. http://www.abae.gob.ve/paginas/satelite_simon_bolivar.html July 7, 2010.
[civ] LAPAN. http://www.lapan.go.id/ Accessed July 7, 2010.
[cv] Santosa, N.I. "First Indonesian Built Satellite in Orbit" *Jakarta Post.* http://www.thejakartapost.com/news/2007/01/11/first-indonesianbuilt-satellite-orbit.html Accessed July 7, 2010.
[cvi] "Indonesia to launch its own weather satellite." http://www.thejakartapost.com/news/2010/06/27/indonesia-launch-its-own-weather-satellite.html Accessed July 7, 2010.
[cvii] Orbital Sciences "IndoStar-1" http://www.orbital.com/SatellitesSpace/Communications/IndoStar/ Accessed July 7, 2010.
[cviii] Djiwatampu, Arnold. "Braving the Challenge of Satellite Technologies: National Breakthroughs and Indonesia's role in International Forums."*Online Journal of Space Communications.* http://spacejournal.ohio.edu/issue8/his_arnold1.html Accessed July 7, 2010.
[cix] ANGKASA. http://www.angkasa.gov.my/ Accessed July 8, 2010.
[cx] SUPARCO. http://www.suparco.gov.pk/pages/history.asp Accessed July 8, 2010.
[cxi] SUPARCO. "History." http://www.suparco.gov.pk/pages/history.asp Accessed January 23, 2012.
[cxii] SUPARCO – Remote Sensing. http://www.suparco.gov.pk/pages/rsss.asp?rssslinksid=2 7/8/10.
[cxiii] SUPARCO- Communication. http://www.suparco.gov.pk/pages/comm-satellite.asp?commlinksid=2 Accessed January 23, 2012.
[cxiv] "Pakistan's first communications satellite PAKSAT-1R launched." *Dawn.com* Published August 11, 2011. http://www.dawn.com/2011/08/11/pakistans-first-communications-satellite-paksat-1r-launched.html Accessed January 23, 2012.
[cxv] SUPARCO "PakSat-1R." http://www.suparco.gov.pk/pages/paksat1r.asp?satlinksid=3 Accessed January 23, 2012.
[cxvi] Arianespace. http://www.arianespace.com/news-press-release/2010/06-26-2010-v195-launch-success.asp 7/8/10
[cxvii] KARI. http://new.kari.re.kr/english/index.asphttp:/www.kari.re.kr/ 7/8/10.
[cxviii] ThaiCom. "ThaiCom Overview." http://www.thaicom.net/about_to_en.asp Accessed January 23, 2012.
[cxix] Boeing. "Thailand's First Domestic Satellite System." http://www.boeing.com/defense-space/space/bss/factsheets/376/thaicom/thaicom.html Accessed Jan 23, 2012.
[cxx] Sweeting, M. and Pookyaudom, S. "TMSAT: Thailand's First Microsatellite for Communications and Earth Observation." *Acta Astronautica.* Vol 40, No 2-8, pp. 423-427. 1997
[cxxi] SSTL. "Mission Heritage." http://www.sstl.co.uk/Missions/Mission_Heritage 7/8/10.
[cxxii] GISTDA. "About Us." http://www.gistda.or.th/en/index.php?option=com_content&view=article&id=5&Itemid=2 7/8/10.
[cxxiii] TUBITAK UZAY. "About Us." http://www.bilten.metu.edu.tr/tubitakuzay/en/about/history.asp 7/8/10.
[cxxiv] "Turkey's first earth observation satellite RASAT started transmitting images from space." http://www.aprsaf.org/data/feature/Feature_RASAT.pdf Accessed January 23, 2012.
[cxxv] TurkSat. "About TurkSat." http://www.turksat.com.tr/english/v2/ 7/8/10.
[cxxvi] TurkSat. "TurkSat 1B: 31.0 degrees East." http://www.turksat.com.tr/english/v2/satellite-fleet-and-specifications/turksat-1b-313-east Accessed January 23, 2012.

[cxxvii] EIAST "About EIAST." http://www.eiast.ae/default.aspx?options={a93e7034-0baa-4e2b-be21-721a4b6feb8e}&view=Article&layout=Article&itemId=98&id=28 Accessed January 23, 2012.
[cxxviii] EIAST. "Space Program." http://www.eiast.ae/default.aspx?options={a93e7034-0baa-4e2b-be21-721a4b6feb8e}&view=Article&layout=Article&itemId=68&id=54 7/8/10.
[cxxix] Sandau, R., "Small Satellites for Capacity Building in Space Technology Development." Presentation for the African Leadership Conference on Space Science and Technology for Sustainable Development. http://www.oosa.unvienna.org/pdf/bst/ALC2010/02_Sandau_ALC-Mombasa.pdf Accessed December 21, 2011.
[cxxx] Puig-Suari, J., "CubeSat: A 'Small' Satellite Revolution." Presentation for the African Leadership Conference on Space Science and Technology for Sustainable Development. http://www.oosa.unvienna.org/pdf/bst/ALC2010/03_Mombasa_open.pdf Accessed December 21, 2011.
[cxxxi] Van Zyl, R., "Nano Satellites Africa: A Collaborative Vehicle for Socio-Economic Development." Presentation for the African Leadership Conference on Space Science and Technology for Sustainable Development. http://www.oosa.unvienna.org/pdf/bst/ALC2010/05-Van-Zyl.pdf Accessed December 21, 2011.
[cxxxii] Wood, Danielle & Annalisa Weigel, "The Evolution of Satellite Programs in Developing Countries," *Proceedings of the International Astronautical Congress*, Daejeon, Republic of Korea, October 2009. [Accepted for Publication in *Space Policy*.]
[cxxxiii] Wood, Danielle & Annalisa Weigel, "The Evolution of Satellite Programs in Developing Countries," *Proceedings of the International Astronautical Congress*, Daejeon, Republic of Korea, October 2009. [Accepted for Publication in *Space Policy*.]
[cxxxiv] "About SaTReC." Satellite Technology Research Center, KAIST University, South Korea. <http://satrec.kaist.ac.kr/english/SaTReC.html>. Accessed November 10, 2011.
[cxxxv] SaTReC Initiative. http://www.satreci.com/eng/ Accessed December 21, 2011.
[cxxxvi] Hwang, C. "Space Activities in Korea - History, Current Programs and Future Plans." *Space Policy* 22 (2006): 194-199.
[cxxxvii] "South Korea Rocket 'explodes' Moments After Take Off." BBC News June 10 2010. BBC. November 10, 2010 <http://www.bbc.co.uk/news/10281073>. Accessed November 10, 2011.
[cxxxviii] Sappington, David. "Incentives in Principal-Agent Relationships." *The Journal of Economic Perspectives.* Vol. 5, No. 2, Spring 1991, pp. 45-66.

3 Perspectives from Literature on Collaborative Satellite Projects

The literature review discusses how concepts from several areas of scholarship can inform the analysis of the collaborative satellite projects by emerging space programs in developing countries. The areas of literature are Technology Learning, Technology Transfer, Project Delivery, and Systems Architecture.

3.1 Technological Learning

Space is not the only technical area in which developing countries use international partnerships in their process of building technological capability. This process has been relevant in a variety of technical areas since the post-World War II era. Starting in that period, many developing countries were gaining independence from colonial leaders, especially in Asia and Africa. They sought to establish new industries as part of their process of economic development. Some countries wanted to be able to locally manufacture the modern appliances and tools that they were importing from more developed countries (a strategy known as import substitution). Some countries sought to build their economy by manufacturing exports that could be sold in the wealthy markets of the US and Europe (an export oriented strategy). In both cases, there was an effort to bring into the country a technological capability that had previously not existed. Often, countries used political or commercial partnerships with foreigners to build local capability. Since World War II, a number of experiments in technological capability building have been executed throughout the developing world.[cxxxix] Scholars have examined and synthesized the experiences of these countries. These scholars come from fields such as economics, political economy, management, international development and urban planning. The commentary of these scholars is diverse; there is not a unified interpretation among them. Rather there is spirited debate about what has happened and what it means. One community of scholars focuses on technological learning. They seek to understand what actions a less developed country can take to improve their chances of successful technological capability building through external relationships and through internal effort.

This literature on technological learning is dominated by a close-knit community of economists and scholars of technology policy, many of whom know each other and collaborate on research. Some of the prolific members of this community are Alice Amsden,[cxl] Paulo Figueriedo,[cxli] Sanjaya Lall,[cxlii] Linsu Kim,[cxliii] Giovanni Dosi,[cxliv] Carl Dahlman[cxlv] and Larry Westphal.[cxlvi] This community emphasizes the need for developing countries to engage in technological learning – the process of increasing their capability to use technology effectively in economic or government activity. They build on foundational concepts including Schumpeter's Entrepreneur,[cxlvii] and Nelson & Winter's Evolutionary Economics.[cxlviii] Nelson and Winter explain that the foundational unit of economic activity is the set of individual skills and organizational routines through which firms produce goods and services. Much of the knowledge required to achieve these skills and routines is tacit and therefore difficult to describe in words, formulas or instructions.[cxlix] Organizations learn and maintain routines by acting on them. The environment in which organizations act changes unpredictably, especially because of new technical inventions. Schumpeterian entrepreneurs bring innovation by using these inventions to apply new techniques to create economic outputs. As new technology innovations emerge, people and organizations need to update their skills and routines to incorporate the new opportunities. Organizations that harness and apply innovations successfully are more successful in a competitive marketplace.[cl] In parallel, countries that successfully harness new technology can improve their national development. Within a country, there is a network of related firms, research laboratories, government offices, educational institutions and non-governmental organizations that must collaborate to create an effective National Innovation System that facilitates successful technological learning.[cli,clii] The technological learning scholars develop theory and empirical evidence to craft prescriptions for how firms or organizations in developing countries can increase their level of technological capability. Amsden documented the experiences of countries such as China, India, Indonesia, Argentina, Brazil and Turkey as they moved into manufacturing consumer goods and high technology products.[cliii] Figuierdo provided a detailed account of technological learning in two steel plants in Brazil.[cliv] Hobday considered progress in the electronics industry in Singapore.[clv] Kim wrote about experiences of Korean firms in industries such as ship building and car manufacturing.[clvi] Ahmed and Humphreys wrote about Malaysia's establishment of a national car industry.[clvii]

This review explores some of the concepts and frameworks that have been proposed by the technological learning literature regarding the process of building capability via international partnerships. Technology is a broad term used here to include both tangible objects - such as capital equipment and products – as well as intangible resources – such as information, processes and organizational approaches. The definition by Bozeman is helpful, which describes technology as "knowledge-based assets that are applied to create value." [clviii] In the context of this research, technology includes products, processes and knowledge. The term technological capability means the "ability to make effective use of technology."[clix] Technological learning, then, is the process of increasing in technological capability. It is a very active word that describes a conscious effort on the part of the learning individual or organization.

Some may argue that technological learning is not important for developing countries. Perhaps they should leave the advanced technology to other countries and focus instead on exploiting their local competitive advantage such as ample labor or abundant natural resources. To this, authors such as Grieve[clx] offer disagreement. Although development strategies may include such resources as part of the portfolio, Grieve urges developing countries to also "achieve a firm grasp of modern technology, learn from it, and on this basis, seek to develop innovation and technological capabilities." Thus, firms and other organizations are advised to learn from the state of the art technology that is used in more advanced countries. In the parlance of this literature, developing countries are "latecomers," meaning that they are working behind the technological frontier.[clxi] They are also isolated from the centers of technology production, such as excellent universities and research laboratories.[clxii] The experience of technological learning for latecomers is not necessarily a repeat of the experience of the more developed countries as they discovered or invented today's technologies. Kim[clxiii] builds on work by Utterback[clxiv] that shows how latecomers may move through an innovation cycle. Utterback's seminal work shows how inventions go through a period of high product innovation until standards set in and innovation declines. Next, there is a period of active process innovation until a new product becomes dominant. Utterback's model applies to advanced countries working at the technological frontier. Kim proposes that developing countries – as latecomers – may follow a reversed technology trajectory. They enter when a product is already mature and learn from outside sources how to manufacture it. Gradually, they may be able to pursue first process innovations and later product innovations. They work toward generating new technologies in that field, after enhancing their skills by working on the mature technology. For the case of satellite technology, such an experience could apply to a latecomer's work in the area of solar panels, for example. It is a technology that is somewhat mature, but there is also room for innovation to improve the efficiency of their performance. An organization from a developing country may learn the well established techniques for manufacturing solar panels from an outside source. They may then continue to work with those methods over time and start to make small improvements in the manufacturing. Eventually, they may experiment with slightly different materials and do tests to improve the performance of the panels. Ultimately, their hands-on efforts may lead them to propose a new alloy for the solar panels. Such a transition could take decades; it may be longer if the organization does not have a solid understanding of the physics underlying the operation of the solar panels. Figure 3-1 provides a graphical description of the ideas of Utterback and Kim.

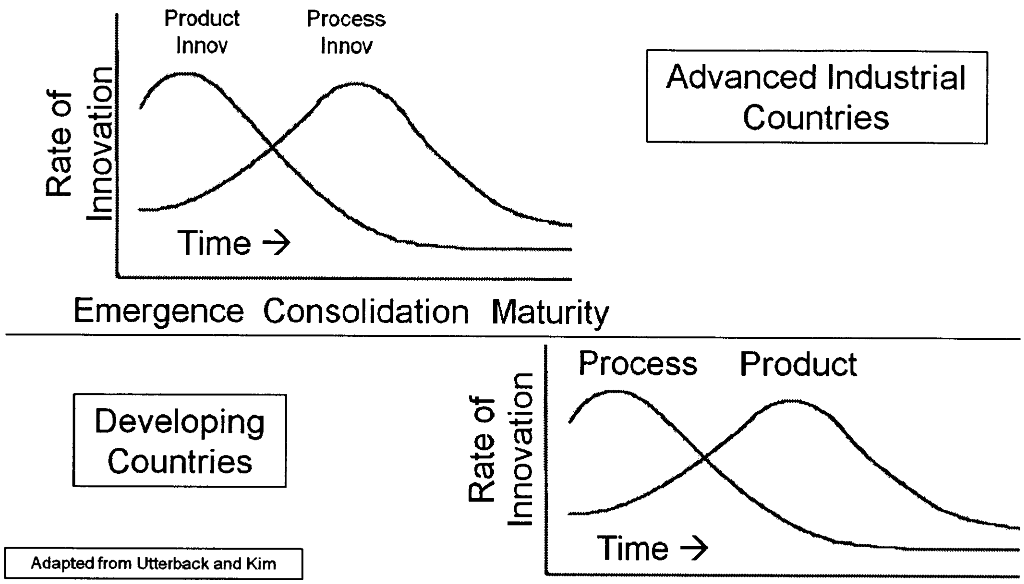


Figure 3-1: This graphic adapts work by Utterback and Abernathy and by Kim. It shows how technology trajectories differ between developed and developing countries

What allows a latecomer organization in a developing country to successfully move through the phases from manufacturer to process innovator to product innovator for a particular class of technology? Some argue that it depends largely on the organization's absorptive capacity. This concept refers to the organization's ability to take in and act on the new information about the technology they are learning. Building on Cohen and Levinthal,[clxv] Kim argues that absorptive capacity for an organization depends on prior knowledge and the intensity of effort applied to understanding the technology.[clxvi] In other words, an organization can better absorb and work with a new technology if they have more relevant prior knowledge and if they work hard to learn about it. These concepts place a great deal of responsibility on the technological learners.

What are the sources of technological information for latecomer organizations in developing countries? Kim[clxvii] provides a useful framework for dividing such sources. Generally, they represent different kinds of relationships with outside organizations or information. There are one-sided scenarios in which a latecomer organization pursues knowledge independently via reverse engineering, literature, conferences, etc. There are formal relationships with well defined contracts, such as licensing technology from foreign firms, buying turnkey products and hiring technical consultants. In less formal interactions, organizations can learn when they buy from or sell to a more advanced organization. Kim's work considers only commercial relationships of this nature, but in the space arena, such relationships might also be political agreements between governments. Figure 3-2 shows Kim's framework for technology sources; it is slightly adapted.

	Role of Foreign Technology Sources	
	Active	*Passive*
Market Mediated	Quadrant 1 • Foreign licensing • Turn-key purchase • Technical consultancy • Special-order capital	Quadrant 2 • Sale of standard capital good
Non-market Mediated	Quadrant 3 • Technical assistance from technology vendors • Political partnerships	Quadrant 4 • Imitation • Reverse engineering • Observation • Journals • Meetings

Figure 3-2: Adapted from Kim's framework on foreign sources of technology[clxviii]

The discussion thus far has addressed the process of building technological capability via learning, the reversal of the traditional technology trajectory for latecomers, the importance of absorptive capacity and potential sources of technology. What remains is to drill even deeper into the practical issues surrounding technological learning. Such learning can happen along various dimensions, but it ultimately begins with an individual learning something new. This literature emphasizes the fact that technological knowledge can be tacit or explicit. Knowledge is tacit when it is not well codified.[clxix] This may be because the knowledge is wrapped up in a routine done by a skilled person. This person knows how to do the routine, but they cannot easily explain it to someone else.[clxx] It is difficult to convey tacit knowledge from one person to another. When tacit knowledge is made explicit – for example, by writing it down – learning can happen. If much of the knowledge required to do a certain technological task is tacit, it will be much harder for individuals working independently to learn about the technology. Thus, approaches like those in Quadrants 2 and 4 above will be less effective (see Figure 3-2). In these cases, it is very important for representatives from the developing country to learn directly from people who are skilled in the technology during long term interaction. This can enable individual learning, but that may not be enough.

Some technological activities, including many satellite projects, require intensive group coordination. Individuals must understand how to achieve their own role, and the group must understand how to work together to achieve the overall goal. This requires organizational learning. Thus, organizational learning can also be an important part of technological progress for a latecomer institution in a developing country. Organizational learning is not automatic, nor is it well understood. Edmonson[clxxi] shows that when small groups work together on a complex task over time, they can naturally go through a process of organizational learning. They gradually develop a mutual understanding of how their individual contributions combine to achieve a goal. Nonaka describes four modes through which knowledge is created and shared in organizations.[clxxii] Through socialization or long term close interaction, individuals exchange tacit knowledge through practice, imitation and observation. Through combination (structured, formal interaction and discussion) individuals exchange explicit information. This can lead to new knowledge as old knowledge is consciously organized and evaluated. Through externalization, tacit knowledge is converted into explicit knowledge when people use metaphors to communicate ideas that are difficult to express. Through internalization, explicit knowledge is converted to tacit knowledge when people put codified information into practice. Nonaka proposes that during the learning process, people and organizations cycle through these four modes repeatedly.

Kim developed a framework that brings together many of the ideas summarized above.[clxxiii] The framework incorporates the nature of technology as both tacit and explicit. Learning organizations harness the new knew via technology transfer. The quality of the transfer depends on their absorptive capacity due to prior knowledge and the intensity of their learning effort. The intensity can be increased when the organization feels they are in a crisis. Crises can be created by external events or they can be constructed by leaders, such as when they set ambitious goals. Leaders encourage learning by using crisis to make the effort seem important. As the organization takes in new technology, they may be in one of several learning orientations, depending on where they fall in the technology lifecycle. The learning may focus on duplicating an existing technology, creative imitation in which they improve an existing technology or innovation of new technology. Throughout these processes, there is a need to foster both individual and organizational learning. Kim incorporates Nonaka's cycles between the four modes of socialization, externalization, internalization and combination.

Based on the discussion above, Table 3-1 provides examples of advice that can be extracted from the Technological Learning literature for organizations that are learning new technology. The advice is at three levels of application: organizations, groups and individuals.

Table 3-1: Summary of Guidance from Technological Learning Literature

Level	Theoretical Guidance	Example of Actionable Project Implementation Approach	Source
Organizations	Crisis Construction can improve team performance	• Key Leadership should set high goals to produce an atmosphere of crisis and inspire team to productivity	Nonaka 1994 and Kim 1999
Groups and Individuals	Both Individual and organizational learning need to occur	• Provide a mechanism for more experienced engineers to teach less experience engineers • Spread knowledge through organization via strategic job	Kim 1999, Nonaka 1994, Edmonson 2003

		rotation	
Individual Level	Learner initiative partly determines absorptive capacity	• Provide individuals with a variety of experiences to help them maintain creative thinking	Cohen & Levinthal 1991, Kim 199, Nonaka 1994
Organizations and Groups	Hierarchical organizational structure is better for combination (Explicit to Explicit) and internalization (Explicit to Tacit). This is better for exploitation of information	• Early in project or in life of team, use formal structure to allow people to learn new, explicit information from trainer and veterans.	Nonaka 1994
Organizations and Groups	Self organizing teams are better for socialization (Tacit to Tacit) and externalization (Tacit to Explicit). This is better for exploration of information.	• Later in project (or in life of team), use less formal organizational structure to allow more experienced engineers room to be creative.	Nonaka 1994

Consider the scope of the issues addressed in the technological learning literature. The collaborative satellite projects that are the focus of this study follow the process of space organizations working toward mastery of a new technology. As Lall points out, mastery is just the first step of a longer process of harnessing the technology as part of development.[clxxiv] After mastering the techniques for the current technology, a learning organization can continue by making changes to the technology to adapt it to local conditions and updating the technology to improve its performance. The learning organization may also work in the area of diffusing the technology in their local marketplace. This can take the form of creating links between local suppliers for inputs to their technology or links with organizations later in the value chain. For satellite systems, a key set of links is with the organizations that can use data products the system produces. Diffusion includes setting up strong linkages with data users. In the long term, a learner may grow to be able to independently develop and export the technology. The case studies about collaborative satellite projects capture a narrow segment of this long term progression, but the stories should be considered as part of this context.

The conclusions and prescriptions from the technological learning may not always apply directly to the satellite context. Recall that the ideas were developed from research about other types of technology. A first major difference between the satellite context and the case studies from technological learning is the nature of the players. The literature on learning focuses almost entirely on commercial firms. In these case studies, satellite projects may be executed by commercial firms, by government agencies or by a combination of the two. The incentive structure for a firm is driven largely by a desire for profit. This may be different in a government context. Such a difference may influence the learning dynamics. Without the pressure of maintaining a profit, how will incentives for learning in a government be different? Also the research cited above is especially relevant to commodity products that are mass produced or continuous flow products, such as steel. In these cases, the latecomer firm in a developing country can separate their learning about the manufacturing process from learning about the actual product. A manufacturing plant can produce a product without the operators understanding how to design or improve the product. Additionally, for commodity products, there is little variation on the design across customers. These factors can be quite different in satellite projects. The requirements are unique for each customer and each mission. Each product is built over a long time period, without frequent repetition that would enable learning by experience. Also, the manufacturing process is closely linked with the design, testing and verification process. It would be difficult for an organization to build a satellite without an understanding of how it works. These aspects illustrate some differences between the satellite context and that of others in the technological learning literature.

There is a community of scholars – closely linked to the technological learning community – that recognizes the need for different approaches to policy and management for technologies like satellite systems. This community – led by researchers such as Hobday and Rush – has coined the term Complex Product Systems or CoPS to describe technologies that are "high cost, engineering and software intensive...produced in projects or small batches" with a customized approach for the specific customer; the development process for CoPS requires strong emphasis on "design, project management, systems engineering and systems integration." [clxxv] The CoPS literature is not only about technology learning; it covers the management and innovation in these complex systems, which may include the learning process. Satellite systems fit into this category, as do air-traffic control systems, large ships, infrastructure items such as dams and road systems, sewage treatment plants, passenger aircraft, helicopters, integrated mail processing systems, missile systems and telecommunication exchanges – to name a few identified by Hobday and Rush. These authors go to explain that the development of CoPS often involves a complex network of actors located in different organizations and societal sectors, including the customer, end user, regulators, suppliers and other stakeholders. Often a specific firm plays the role of systems integrator and coordinates activity among all these actors. The actors that come together for a particular CoPS project must collaborate even as they may also compete for future work opportunities. While CoPS are elaborate systems that are expensive to produce, it is often hard to estimate the value they bring to the economy because their contributions do not align with traditional accounting methods. Hobday and Rush also point out that the traditional model of a project innovation lifecycle may not apply to CoPS because innovation at the product level happens before and during the long-term design and deployment of CoPS. Figure 3-3 shows a summary of how management challenges may occur in the production of CoPS that are less likely for mass produced goods.[clxxvi] Elsewhere, Rush summarizes the three key challenges of executed a CoPS project as defining requirements, coordinating information among the networked team and with the customer, and developing effective processes that balance risk.[clxxvii] The challenges shown here will be considered as the case studies of learning in collaborative satellite projects are further explored.

Contrasting Management Challenges of Complex Product Systems with those of Mass Produced Commodity Goods		
Challenges	***Mass produced goods***	***Complex Product Systems***
Management Objectives	• Well defined, consistent goals • Focused and clear objectives	• Ill defined or competing goals • Unclear and multiple objectives
Production Task	• Manufacturing intensive • Mass assembly driven • Codified information • Routine Production	• Design intensive • Systems integration driven • Uncodified, tacit information • Non-routine production
Organization	• Functionally-based • Hierarchical	• Project-based • Consensus based/team based
Learning	• Learning in functional departments • Learning is routine, systematic • Knowledge is explicit, codified	• Learning in projects • Learning is sporadic, fragmented • Knowledge is implicit, tacit
Innovation Processes	• Manufacturing intensive • Supplier driven • Single-firm centered • Market mediated	• Design intensive • Customer driven • Collaborative, network driven • Negotiated
Management Tools	• Off the shelf, proven tools • Well established Information Technology tools • Consistent with practice	• Few, mostly unproven tools • Information Technology tools not well established • Inconsistent with practice
Nature of Risk	• Controllable • Predictable • Short term, stable	• Hard to control, hidden • Unpredictable, emergent • Long term, unstable
Decision Making	• Certain environment • Complete information • Goal oriented	• Uncertain environment • Incomplete information • Learning oriented
Customer/Market	• Arms length market transaction • Market price • Well defined market • Requirements pre-defined	• Involved, professional customer • Negotiated price • Multiple stakeholder interests • Requirements negotiated
Success/Failure Factors	• Efficiency, cost led • Single success criteria • Easily defined, measured • Departmental efficiency	• Flexibility, effectiveness led • Multiple success criteria • Hard to define, measure • Team performance, effectiveness

Figure 3-3: Summary of contrast between mass produced commodities and Complex Product Systems (Howard and Rush 1999)[clxxviii]

Moody and Dodgson provide a useful example by using the CoPS definition to study the development of a small satellite program in Australia. Although Australia is a highly developed country in many aspects, they do not have a strong local capability in satellite design and manufacturing. The study explored their learning process and found that the project exhibited many aspects of a CoPS system, although it was a relatively simple satellite.[clxxix]

The next section discusses how the literature on Technology Transfer can be applied to the case studies of collaborative satellite projects. For this study, the concept of technology transfer is seen as one step in the overall process of technological learning. The technology transfer literature takes a variety of perspectives, however, which makes the term difficult to use with precision. For this research, the transfer process focuses on the interaction between a learning organization and a technology source to move knowledge and physical elements of technology into the control of the learning organization. This interaction is a small part of the effort that the learning organization must exert to achieve capability. As Dahlman and Westphal point out, the long term goal of capability building is technological mastery, which is "operational command over technological knowledge, manifested in the ability to use this knowledge effectively." They go on to say that "although knowledge can be transferred, the ability to make effective use of it cannot be. This ability can only be acquired through indigenous technological effort..."[clxxx] The concept of technological learning emphasizes this indigenous effort while technology transfer emphasizes the partnership with a foreign technology source.

3.2 Technology Transfer

There is a broad and active literature about the concept of Technology Transfer. This literature has useful input regarding collaborative satellite projects that are used to build technological capability. The input must be considered with care, however, to account for the various assumptions, definitions and contexts that exist with the technology transfer literature. The term "technology transfer" is used loosely in scholarly literature to describe several types of activity. In almost all cases, the activity involves two organizational units interacting in order to make a technology controlled by one unit available to the second unit. The overall relationship between the organizational units and the purpose for the transfer varies within the literature. Scholars of technology transfer study the movement of technology from research to commercial organizations within the same country; the movement of technology between units within a large firm; and the movement of technology from a commercial organization in one country to a separate commercial organization in another country. As an example of the breadth of the literature, consider the *Journal of Technology Transfer,* which publishes articles that take a management and strategy perspective on the topic. The journal recently featured articles about the transfer of scientific results and technical inventions from universities to existing commercial actors;[clxxxi] about new commercial firms that spin out of universities;[clxxxii] about collaboration on research and development between firms;[clxxxiii] about technical knowledge moving between firms based on worker mobility;[clxxxiv] about the role of government in supporting firms that develop and commercialize new technology;[clxxxv] and about the impact of intellectual property rights on technology transfer.[clxxxvi] Clearly technology transfer literature has an extensive purview.

Some authors that use the phrase Technology Transfer as a key term in their work focus on issues that are broader than those described above. The mainstream technology transfer literature emphasizes either the perspective of multinational firms or their interaction with recipient firms that receive their technology. Some authors go beyond this bilateral relationship to consider the broad scope of policies and activities that recipient countries need to put in place in order to advance their level of technological capability. These scholars write about technology transfer but they are not just concerned with the adoption of a specific technology. They are concerned with the complex process through which a country starts a process to "generate technical change continuously" in order to become internationally competitive.[clxxxvii] For the purpose of this study, such literature considers the wider issue of Technological Learning as discussed above, not technology transfer.

Within the technology transfer literature, the sub-topic of International Technology Transfer holds particular relevance to the collaborative satellites under study. This smaller set of literature assumes that technology is moving across national borders and therefore considers the unique management, policy, cultural, language and development issues that ensue. Much of the International Technology Transfer literature builds on this classic scenario: a multinational firm is headquartered in a more developed country and seeks opportunities to sell its product or service in a less developed country via technology transfer. The firm may be motivated to harness the foreign market for several reasons. For example, if the rate of technological progress is high in their industry, they may sell more advanced variants of their product in domestic markets and less advanced variants abroad. The competition or market size may also be advantageous in a foreign market.[clxxxviii] Once a firm chooses to operate in a foreign market, it faces the decision of how to enter the market. The firm can set up its own operations in the foreign market or partner with existing firms that already operate in that market. Firms often choose to partner with existing firms in order to benefit from their knowledge of the new market and to avoid the cost of initiating a new organization. Regardless of whether the operator in the new market is part of the original firm or an external partner, the original technology holder needs to transfer the technology required to produce the product or service to a new setting. The relationships between the original technology holder and the new operator may be of several types; these types are sometimes divided based on the extent of control that the original technology holder has over the operator in the new market. Approaches that bring a high degree of control include the following: establishing a fully owned foreign branch of the firm; buying an existing firm and converting it into a foreign branch; setting up a subsidiary; and creating an affiliation with an existing firm. Approaches with a medium degree of control include outsourcing a subset of the production or services; buying a minority stake in a firm from the new market; or setting up a joint venture for a specific project. Approaches with a low degree of control include partnering with a firm to co-market independent products; selling a license that allows a firm to produce and sell the product or service; or selling a turnkey facility that allows a firm to produce and sell.[clxxxix, cxc] Gross provides another broad list of possible partnership arrangements including: Foreign direct investment, licensing, technical assistance, training, turnkey contract, representation, exporting, franchising, management contract, research and development contract, co-production agreement and subcontracting.[cxci] Variations and combinations of these approaches are possible. The International Technology Transfer literature often focuses on the decisions made by the multinational firm as it considers how and when to extend market access through these mechanisms. The literature also considers the potential benefits to less developed countries that may accrue when a multinational firm injects new technology into their marketplace. Ideally, this injection of new technology benefits the less developed country; such benefit is not guaranteed however.[cxcii]

The primary perspective of the International Technology Transfer literature focuses on the challenges facing a multinational firm as it seeks to profit by extending operations to an international market. Some authors also focus on the recipient firms. These perspectives are different from the collaborative satellite projects examined here in several important ways. First, in the collaborative satellite projects, the activity is initiated by the national space organizations in the customer countries who buy satellites. The national space organizations choose to buy these satellites via close relationships with suppliers who provide extensive training. This is unlike the scenarios in International Technology Transfer literature in which firms from more developed countries initiate a relationship with a less advanced firm in order to extend their market access. It is true that the satellite supplier firms are seeking to extend their sales into new markets like their counterparts in the literature. Unlike the firms in the International Technology Transfer literature, however, these satellite suppliers are not moving toward a broad distribution of their satellites via a foreign partnership. They are selling to an individual customer without a commitment to long term interaction. Second, the collaborative satellite projects are part of a long term strategy by the national space organizations to build their local technological capability. The impetus for bringing the technology into the customer countries is internal to the less developed country. In the International Technology Transfer literature, the impetus is often external to the less developed country. Third, the firms that originally hold the technology in the International Technology Transfer literature are generally assumed to be large enterprises. In the collaborative satellite projects, two of the three supplier firms are small or medium sized. This affects some of the firm's organizational dynamics. There are also some similarities between the collaborative satellite projects and the archetypal scenario from the International Technology Transfer literature. During the collaborative satellite projects, two or more organizations come together to execute a technical activity. One of the organizations has the knowledge, procedures, capabilities and intellectual property rights required to execute the activity and the other organization does not. Furthermore, the organizations come from different countries that potentially have different cultures, trade policies, intellectual property policies and project management approaches. All of this also true in the International Technology Transfer literature. This community of scholars has proposed some useful definitions, concepts and models to inform such situations.

Contractor and Sagafi-Najed[cxciii] as well as Reddy and Zhao[cxciv] provided reviews of the International Technology Transfer literature in 1981 and 1989 respectively. Both reviews assume the multinational firm is the primary source and agent of technology transfer; also both reviews explicitly consider the opportunities that technology transfer may provide for less developed countries to enhance their technological base. Although International Technology Transfer transactions are initiated due to a desire by multinational firms to extend their market access, they have the potential to help firms in less developed countries harness new technology. Both reviews discuss this issue and consider policy options for less developed countries to promote local technology adoption. Contractor and Sagafi-Najed take an issue-based approach to organizing their review. They begin by establishing that technology is a key ingredient for economic development, but note that factors such as the nature of the technology transfer process influence how technology contributes. They go on to explore how the technology transfer process includes the sharing of a "bundle of information, rights and services" from a supplier firm to a recipient during a long term relationship.[cxcv] Often the recipient is seeking to maximize their opportunity for technical growth at a reasonable cost while the supplier is seeking to balance the possibility for control with the opportunity to earn profit. The market for international technology transfer was driven, as of the 1981 review, by an extreme concentration of technology among a small number of firms and countries. Also, in this time period, technology supplier firms tended to prefer technology transfer approaches with high degrees of control such as moving technology to foreign affiliates. The issue of cost arises in this review, with a particular focus on the concerns of less developed countries about the price they may pay to access foreign technology. Contractor and Sagafi-Najed cite the concern that recipient firms from less developed countries have low bargaining power and may be overcharged for technology, but they also note that it is difficult to confirm this empirically. This review broadly addresses the concept that technology transferred to a new country should be appropriate in terms of issues such as the capital to labor ratio, the need for employment creation, and the need for some regional distribution of technology in the recipient country. The final sections of the review consider policy options for recipient governments, supplier firms and supplier governments that seek to address the challenges above with varying success. In the 1970s, for example, developing countries such as Japan, Mexico and India established instruments such as laws and review boards that sought to monitor and manage the process of foreign technology transfer. The goal of such instruments was to ensure that the technology transfers bring local benefit.

In contrast to Contractor and Sagafi-Najed, Reddy and Zhao take a structural approach to organizing their review by building around the actors and activities of a technology transfer scenario.[cxcvi] This review address 1) issues for the supplier country and firms, 2) issues for the recipient country and firms; and 3) issues related to the technology transfer transaction itself. For the supplier country, researchers question whether exposing technology in international partnerships is helpful or hurtful to a nation's global competitiveness. Reddy and Zhao concluded that benefits from economic returns and technical exchange outweighed risks of revealing technical information. A similar debate is captured about the benefit to recipient countries. The potential benefits include the opportunity to export new products while generating foreign currency, creating employment and enhancing local skills. The concerns echo the concepts mentioned by Contractor and Sagafi-Najed. The benefits to less developed countries may be lost if the technology is inappropriate, too advanced, obsolete or tightly controlled. Almost a decade after Contractor and Sagafi-Najed's review, Reddy and Zhao also note the high concentration of technology among a small number of countries and firms. In discussing the nature of the technology transfer transaction, this review explains that the goals of the supplier and recipient may not be aligned and this creates a potential for conflict. The conflicts are likely to arise over issues of pricing, ownership of the technology and the opportunities for recipients to pursue their own technical development.

The collaborative satellite projects do interact with some of the issues highlighted in these reviews. This is especially true for the issues at the level of the recipient and supplier organizations. The supplier organizations do need to determine the appropriateness of the technology for their context and an appropriate cost to pursue the technology. The supplier firm needs to consider the costs and benefits of sharing their technologies with customers; they weigh the opportunity for business with loss of exclusive control over their intellectual property. Both supplier and recipient need to consider what mode of transfer will fit their needs. The national level issues introduced by the reviews touch these case studies indirectly. The case studies observe the recipient countries during a small segment of a long term attempt to boost national technological capability and they capture the impact of trade policies by the supplier government.

Most work in the International Technology Transfer Literature focuses on the manufacturing sector. Consider for example, the book by Seurat that gives detailed advice on how to train a team in a new organization to use new technical skills.[cxcvii] The level of detail is valuable for the present study because Seurat considers practical steps that can be taken in daily training. Seurat, however, assumes that the technology in developing countries is high volume manufacturing. The manufacturing sector is not the strongest model for this study on collaborative satellite projects because satellites are a craft product in which design, testing and operations share importance with manufacturing. Also, much of the mainstream manufacturing sector focuses on large scale production of similar products, whereas most satellites are built in small batches of one or two. In addition, the collaborative satellite projects under study include the purchase of both satellites as well as long term training for teams of engineers. The intended outcome of the projects is to allow the customer to operate a satellite, produce information about their environment and advance the skills of their personnel. These outcomes can be considered as a combination of products and services. Even though the customers are purchasing physical products, the suppliers are also giving training and advisory services. For these aspects of the collaborative satellite projects, the literature on International Technology Transfer in the service and infrastructure industries is relevant. Grosse provides an introduction to the issues of technology transfer in the service industries, such as banking, consulting, hospitality, marketing, telecommunications, insurance and software. Grosse defines a service as an "intangible item that depends to some extent on interaction between the buyer and seller for its provision." [cxcviii] This is in contrast with a product that can be accessed without direct interaction. Grosse interviewed representatives of multinational firms in service industries that had operations in Latin America. He found that the important enabling technologies in the services included knowledge, experience, service methods and management skills. The technology suppliers in this study tended to transfer technology to affiliates in Latin America via training, documentation, and sending experts or employees from the home office for temporary or long term visits. Grosse's work highlights the importance of intangible technologies that relate to tacit knowledge held by people and built up over time in service industries.

Like the satellite industry, the construction industry offers a mix of services and products. While the output of a construction project is a tangible building, construction industry professionals provide many services to their clients along the way to producing the building. Ofori[cxcix] describes several features of the construction industry that impact technology transfer. Some of the features are similar for the satellite industry. In both industries, the government is an important client, especially for the initial investment in infrastructure. The demand is inconsistent in both industries and business is structured around projects to produce one item at a time normally. Suppliers compete for work through proposals in both industries and there may not be continuity in suppliers or the technology they use over time. The price is a key driver for customers when they are selecting among competing proposals. In both industries the government of the customer country plays a strong role in regulating the way the activity is pursued. The construction industry is not like the satellite industry in some ways. Generally, the construction industry is much larger than the satellite industry in terms of people and financial impact on the economy. The cost of construction is driven by location to a larger extent than in satellites. Also, the technology used by the construction industry is generally more mature and unprotected than for satellites. While there are advanced technical approaches, suppliers in the construction industry often have the option of choosing a less advanced approach that is affordable and familiar. Even so, Ofori notes that the demand for advanced construction approaches is increasing in less developed countries. The techniques include both the practical steps to implement the building and the management approaches. Ofori found that less developed countries depend on external inputs in their construction projects. The technology is transferred via joint ventures, training as part of equipment purchases and observation of foreign firms. Ofori found several barriers to technology transfer in the construction industry: 1) The foreign firms with advanced technology are hesitant to provide assistance that would make local firms more competitive against them in the future; 2) Incorporating technology transfer into a project bring the risk of increased cost, schedule delay and complexity; and 3) Each construction project is unique and learners may not be able to apply knowledge across projects. Each of these barriers may be relevant to the satellite industry to some extent. Waroonkun and Stewart[cc] performed a study in which they surveyed 162 Thai construction professionals to learn their experiences and opinions about technology transfer. The survey respondents included project managers, site engineers, consulting engineers, construction managers and architects. These professionals share some characteristics with roles in a satellite project. They are concerned with the high level design, management and functioning of a project, not the detailed implementation. This is similar for satellite engineers and project managers. A majority of the respondents had experience with two or more projects in which technology was transferred from a foreign firm to their Thai firm. In most cases, the relationship between the Thai firm and foreign firms were via joint venture, turnkey contracts and management contracting. The Thai construction professionals reported their opinions that it was helpful to work with supplier firms with "experience working with foreigners, a strong knowledge base and [who] are willing to transfer their knowledge."[cci]

Within the International Technology Transfer literature, there is a sub-topic that focuses on the impact of cultural differences in the transfer process. Several authors within the International Technology Transfer literature contend that differences in national culture should be explored as a potentially important factor. Kedia and Bhagat[ccii] in 1988 as well as Bhagat et al[cciii] in 2002 build on Hofstede's[cciv] cultural dimensions to propose relationships between culture and technology transfer. Hofstede conducted a foundational study published in the early 1980s; the study identifies four dimensions of national culture that are exhibited in the workplace. Hofstede's team surveyed employees from one company with subsidiaries in about 67 countries. The results showed that half the variance in employee responses could be explained by four cultural dimensions: "power distance, uncertainty avoidance, individualism vs. collectivism, and masculinity vs. femininity."[ccv] In later revisions of the framework, the dimensions of long term versus short term orientation[ccvi] and indulgence versus restraint[ccvii] were added. These later dimensions are not used here. The power distance dimension measures "the extent to which members of a society accept that power in institutions and organizations is distributed unevenly." The uncertainty avoidance dimension "is the degree to which the members of a society feel uncomfortable with uncertainty and ambiguity." The individualism versus collectivism dimension describes the "degree of interdependence a society maintains among individuals." More masculine cultural traits include "achievement, heroism, assertiveness and material success," whereas feminine cultural traits emphasize "relationships, modesty, caring for the weak and the quality of life."[ccviii] Kedia and Bhagat's[ccix] 1988 work defines eight propositions based on Hofstede's original four dimensions and Hall and Johnson's[ccx] definition of technology as embodied in either products, persons or processes. Among the propositions are expectations that cultural differences are more important for transferring process and person-embodied technology than product-embodied technology. Also, organizations with similar approaches to uncertainty may make more effective transfer partners, and technologies that shift the power distribution are unlikely to be transferred effectively. Masculine cultures are said to be better absorbers of technology than feminine. Bhagat et al,[ccxi] qualifies some of these statements by considering the nature of technology as defined by Garud and Nayyar, which describes technology along the three dimensions of "simple vs complex; explicit vs tacit and independent vs systemic."[ccxii] Bhagat et al combine power distance with the individual/collective dimension and considers "vertical individualism, horizontal individualism, vertical collectivism, and horizontal collectivism."[ccxiii] Based on these definitions, individualistic culture is better preparation for transferring or absorbing explicit and independent technology. Collectivistic cultures should be stronger than individualists with absorbing tacit and systemic knowledge. If two organizations differ in terms of both power distance and the individual/collective dimensions, their partnership for technology transfer is expected to be less effective than the partnership of organizations with similar orientations. The work by Bhagat et al and by Kedia and Bhagat was theoretical; they proposed hypotheses to be tested by other researchers. As one example, Lin and Berg[ccxiv] performed an empirical study tested some of these ideas. They surveyed senior engineers in large Taiwanese manufacturing firms. They used a model that considered the nature of technology, the level of international experience of the transferee and transferor of technology, cultural differences and effectiveness of the transfer. Effectiveness in this case is based on learning by the recipient firm and technical performance of the project. The study did not find a strong direct influence of cultural difference on technology transfer effectiveness, whereas the maturity and codification level of the technology did increase with effectiveness. The culture difference variable did seem to interact with the technology characteristics, however; this warrants more research. This study found, as they hypothesized, that supplier firms with more international experience have more bargaining power and they are more savvy with protecting technology. Meanwhile, recipient firms with more international experience are more effective in learning and technical communication. Shore and Venkatachalam[ccxv] studied the relationship between technology transfer and culture specifically for information technology. This is relevant to the collaborative satellite project case studies because satellites systems are a type of information technology. Satellites deliver data that is harnessed by geographic information systems in order to produce useful information. Shore and Venkatachalam also build on the definitions and propositions of Hofstede[ccxvi] as well as Kedia and Bhagat;[ccxvii] the study uses power distance and uncertainty avoidance to define cultural differences. Shore and Venkatachalam develop a framework that considers national cultures; the competitive environment and task congruency. The latter factor defines the similarity or difference between the methods of the recipient organization before and after transfer. Shore and Venkatachalam assume that task congruency and the competitive environment combine to influence whether differences in national culture create conflicts during technology transfer. For example, they expect that when both task congruency and the competitive environment are high, there is little impact from cultural differences. On the other hand, when both task congruency and the competitive environment are low, differences in national culture are amplified during technology transfer. Shore and Venkatachalam tentatively support these claims with three qualitative case studies about technology transfer experiences of European firms. They conclude that research on information technology transfer should consider their variables along with other potentially important variables such as resistance to change by individuals.

Chiou et al[ccxviii] researched the characteristics of technology transfer recipients using 303 surveys distributed during a conference on mining that was held in China in 1990. The survey sought information about technology transfer experiences of the respondents. The questions explored issues such as the nature of the transfer project, the size of the recipient firm, the amount of experience of the individual and the firm, cultural affinity and the benefit the recipient received from the technology. This study builds on definitions from Hall and Johnson[ccxix] as well as Kedia and Bhagat.[ccxx] They hypothesize that organizations pursuing product and process embodied technology (rather than person embodied) "are more likely to be in larger organizations and have stayed longer with the organization than know-how technology pursuers."[ccxxi] Chiou et al also expected that individuals and organizations that pursued person embodied technology or know-how would have more experience with the technology than those pursuing product and process technology. The level of cultural affinity should be higher for person embodied technology. Also, product and process embodied technology is more valuable for addressing short term needs whereas person embodied technology is related to a long term objective to make better quality products. These hypotheses were largely confirmed by the empirical results.

Finally, Fredland[ccxxii] provides a high level reminder in his writing on public sector technology transfer. He outlines three historical phases; each is defined by a specific philosophy of technology transfer held by the more advanced countries. Before World War II, technology transfer to developing countries was "inadvertent, incidental, uncoordinated, nonpolitical", but it did assume a posture of encouraging dependency of developing countries on more developed countries. From 1945 to 1989, Fredland claims that technology transfer became an instrument of Cold War politics. Advanced countries gave low technology to developing countries but tied their activities to political alliances. Starting around 1989, Fredland finds a third era in which there is intentional transfer that is less politically driven and more related to the integration of a global economy in which production occurs around the world. In all three phase, Fredland accuses the high technology countries of seeking to create dependency by lower technology countries. Fredland reminds readers that the development process and the technology that supports it are laden with values defined by countries with more power and financial success. Fredland encourages less developed countries to consider whether they agree with the values defined by these countries before blinding adopting new technology. Suppliers of technology sometimes pursue transfer in order to obtain political and economic influence in foreign states. According to Fredland recipients may comply with the expectations of technology suppliers in the short term but they will likely build resentment over time.

3.3 Project Delivery

The third perspective from literature is the project management perspective. The collaborative satellite projects under study can be viewed as episodes of infrastructure procurement by a government from a foreign firm. The literature on project management points out that there are a number of contractual models through which these governments can hire such firms. Traditional models are named Prime Contractor, Multiple Primes, Turnkey, Build-Operate-Transfer, etc. Authors argue that the chosen model has a key impact on project outcomes. They further argue that most governments would benefit from thinking more strategically about which model to choose. This literature uses the phrase "Project Delivery Method" to describe the nature of the partnership agreement that connects the organizations involved.[ccxxiii] The choice of project delivery method overlaps to some extent with the discussion about different modes of technology transfer. The project delivery literature, however, provides a more complete discussion of the project management aspects of procuring a major infrastructure system.

Gordon proposes an approach to selecting a project delivery method for major infrastructure projects that aligns concerns from the market, the customer and the supplier. The course is taught with a focus on real estate and civil construction, but the principles are relevant to many types of infrastructure and CoPS projects. The project delivery method includes the approach to select and evaluate suppliers, choose a contract type with the primary supplier and choose an organizational relationship with the supplier that implies mutual responsibility and risk. For many projects, there is a question of whether the role of financing, designing and implementing the project are delegated to one organization or to several. Different project delivery methods vary in areas such as the level of involvement required by the customer, the level of technical sophistication the customer needs and the sharing of risk between the customer and primary suppliers. Gordon specifically addresses six types of project delivery methods, namely, General Contractor, Construction Manager, Multiple Primes, Design-Build, Turnkey and Build-Operate-Transfer. These approaches can be used with various combinations of contract types (such as lump sum, fixed price, cost plus) and aware processes (such as negotiation or bidding with selection based on quality, schedule or price). Gordon proposes a six step process to evaluate the project and choose an appropriate method. The first step considers characteristics of the project such as time constraints and the need for flexibility. The second step considers characteristics of the owner such as technical knowledge, risk aversion, and regulatory restrictions. The third step considers the characteristics of the market regarding availability of project inputs and the financial situation. In the fourth-sixth steps, the analyst combines these three factors and considers whether the project is more like a commodity or complex product laden with service aspects. Based on this synthesis, the ultimate decision is based on reasoned judgment. In most cases, some project delivery methods are clearly inappropriate, but several may be appropriate.[ccxxiv] The project delivery concepts offered a structured and a strategic approach to the types of decisions facing any organization that procures a major infrastructure or CoPS system. The goal is to manage risk by effectively designing the relationship between customer and suppliers.

3.4 Systems Architecture

The literature discussed above comes out of communities that traditionally address issues facing developing countries. The literature on technological learning, technology transfer and project delivery uses concepts from economics, management and policy to describe challenges and prescribe approaches to meet them. Engineering is not a major tool for these scholars. These areas of literature have generally not addressed space activity to a great extent, although there are a few examples of case studies about space technology. The literature reviewed above is generally written by scholars who are not specialists in space technology or any type of engineering. The high level goal of this study is to understand the nature of collaborative satellite projects as an opportunity for learning and problem solving. With that understanding, the next step is to move toward developing prescriptive theory targeted to the decision makers in the emerging space countries and to the supplier firms that partner with them.

Each of the three areas of literature reviewed above provides useful perspective and advice to these audiences. Each area of literature also has some important gaps when viewed individually. The technological learning literature provides insight into the long term growth process at a national level. Prescription from the technological learning literature is written for national policy makers as well as firm managers. The theoretical discussions in the technological learning literature provide complete conceptual guidelines for how to move an organization forward in technological capability. The concern is how to convert these concepts into practical approaches. The literature tends to address this by recording case studies of successful firms in developing countries who have achieved a new capability. The case studies are somewhat revealing, however, they often gloss over key details that are necessary to understand the success. For example, a case study may state that a firm used educational scholarships, consultants, crisis construction and reverse engineering over several years to initiate a new technical activity. Within each of these approaches there are many implementation issues that are often not covered in case studies. For example, how does a firm select participants for a scholarship program and retain them after studies are completed? What type of contractual relationship is effective when engaging consultants? How can firm leadership balance crisis construction with overwhelming employees? How much time and resource should be expended on reverse engineering for various types of technology? What are the relationships between these various approaches? The technology transfer literature has an obvious gap in that it focuses on the interaction between a technology supplier and recipient despite the fact that many key issues relate to the independent effort of the recipient. The project delivery literature is intentionally narrow; it only addresses the formal project management issues related to procurement and managing suppliers. It does not address issues of learning or capability building. In addition to these blind spots, none of these three areas of literature explicitly links the process of technological learning with the process of applying technology to meet national needs by designing and implementing a satellite program. The national space organizations pursue collaborative satellite projects with two high level goals. They seek to procure a satellite that will provide value through specific services while contributing to a long term development of technological capability. The approaches and concepts from the technological learning, technology transfer and project delivery literatures are not appropriate to combine these issues in a unified analysis.

The author proposes that a tool from the engineering community may help address this issue and bring new insights about the collaborative satellite projects as vehicle for technological learning and problem solving. The tool is Systems Architecture. This section presents the theoretical and methodological concepts that will guide the use of Systems Architecture as a tool for data collection and analysis. The aim is to achieve finely detailed case studies about the collaborative satellite projects that integrate technical, management and policy aspects. Using systems architecture, this study can retain the useful concepts from the technological learning, technology transfer and project delivery literatures while seeking new insights. The new insights may come from the conceptual approach that treats the collaborative satellite projects as systems that have architecture which can be observed and analyzed. There has been very little academic study of the series of collaborative satellite projects used by emerging space nations in Africa, Asia and Latin America to initiate satellite projects. Thus, this work is new in terms of content. However, many of the ideas from the literature discussed above certainly apply to these satellite projects. The more important novelty is the attempt to integrate the issues of technology learning with the issues of space engineering using systems architecture.

The term Systems Architecture is used here in a specific way as defined by scholars at the Massachusetts Institute of Technology and within the Engineering Systems Division,[ccxxv,ccxxvi] as well as the text by Maier and Rechtin.[ccxxvii] A system is a related set of elements that together generate a function or outcome which the elements do not generate individually.[ccxxviii,ccxxix] A system is complex if it is made of a large number of elements related with many interfaces.[ccxxx] The architecture of a system describes its function, the structural relationships of its elements, the technical rules government system performance and the operational approach over time.[ccxxxi] Architecting is the process of defining the architecture of a system. Architecting is distinct from engineering and design. Maier and Rechtin classify engineering as a deductive process that uses analytical tools to achieve quantifiable system characteristics. Architecting is inductive and relies on non-quantifiable guidelines learned by experience.[ccxxxii] Engineering applies scientific principles to decide characteristics of a system to meet technical performance requirements. Architecting on the other hand comes earlier in the lifecycle of a system and seeks to assign form to function in order to bring value to a stakeholder. Form refers to elements of a system; forms can include physical and informational items. Forms execute the functions that a system performs; they are also the objects on which functions act. Ideally, a system executes functions such that it brings value to a stakeholder. A stakeholder may be any person or organization that is impacted by or affects a system, but generally there is a primary set of stakeholders that define the purpose of a system. Value is defined by the primary stakeholder and refers to benefit at a certain cost the stakeholder is willing to invest.

The architecting process often begins with a Stakeholder Analysis. Stakeholder Analysis is desirable as part of the process of understanding the identities, interests and relationships of a system. Stakeholder analysis "is an approach, a tool or set of tools for generating knowledge about actors – individuals and organization – so as to understand their behavior, intentions, interrelations and interests.[ccxxxiii]" Simply put, Stakeholder Analysis answers three questions: 1) Who is involved with an issue? 2) What is their relationship to the issue? and 3) What is their relationship to each other? Stakeholder Analysis has been used with different methods and for many purposes in the fields of management, policy analysis and project evaluation. It is commonly applied in topic areas such as natural resource management, health, and community development. In the management tradition, Stakeholder Analysis has a particular focus on how managers of firms respond to concerns from the many people that can affect or are affected by the firm's activities. Stakeholder Analysis for firms may be "normative," and provide a guide to managers about the stakeholders they should consider for ethical or legal reasons. Normative work may be used to encourage firm managers to consider criteria such as environmental preservation in decision making – criteria that go beyond profit maximization. Alternatively, Stakeholder Analysis can be "instrumental," meaning that it strives to enable managers of firms to manipulate stakeholders in order to reach objectives[ccxxxiv]. In the policy analysis or project evaluation traditions, Stakeholder Analysis can be used before, during or after the implementation of an initiative. It is a tool to extend participation in decision making and to find areas of conflicting interests. It can potentially increase the effectiveness of an initiative by forming new coalitions and leveraging opportunities for compromise. In all of these traditions, Stakeholder Analysis can be an opportunity to give voice to stakeholders that may otherwise go unrecognized, such as future generations, the natural environment, the poor and minorities[ccxxxv]. For a system architect, stakeholder analysis is an approach to indentify the interaction between the system of interest and related actors.

This work focuses on the functional aspects of system architecture, using a definition that an architectural concept assigns function to a particular form. Given these concepts, the ideal process to define the architecture of a proposed system is as follows: 1) Identify stakeholders and determine their needs; 2) Determine the primary function that a system must execute to meet the stakeholder needs as well as supporting functions; 3) Analyze the function by decomposing it into progressively narrower functions that can be executed by individual system elements; 4) Identify various options for the items of form that can execute the functions; 5) Choose specific elements of form to each function and assign interrelationships among the forms. [ccxxxvi] The choice of specific elements of form should be based on the needs of the stakeholder. It is this choice that must be made based partly on unquantifiable concepts and heuristics.

The process defined above is effective when a system is being conceived but does not yet exist. In these case studies of collaborative satellite projects, the process is used in reverse to identify system functions and forms. This will be discussed more later. In practice, not all system architectures are explicitly designed based on criteria driven by well defined stakeholder needs. As stated by Crawley et al "architectures may arise in the process of deliberate *de novo* design of a system; by evolution from previous designs with strong legacy constraints; by obeying regulations, standards, and protocols; by accretion of smaller systems with their own architectures; or by exploration of form and behavioral requirements via dialogue between users and architects, to name a few known mechanisms."[ccxxxvii] When system architectures evolve from past approaches or under the influence of multiple, decentralized decision makers, the functions and characteristics of the system may not provide value to stakeholders consistently. Over time, systems also exhibit lifecycle characteristics sometimes termed "ilities." These are aspects of the system that are difficult to predict but are highly important to stakeholder concerns, such as safety, reliability, flexibility, affordability, etc.[ccxxxviii]

It is not certain *a priori* what can be gained by defining the architecture of the collaborative satellite projects. The aim is to elucidate features of the projects that are not captured by traditional economic and management approaches, identify further detail then previous CoPS case studies and link the technical and social elements of the projects. The technical elements refer to the use of the satellite as an information system; the social elements revolve around the technological learning process. Based on these aims, research questions are proposed in the next section on research design.

[cxxxix] Amsden, A., "Escape from Empire: The Developing World's Journey through Heaven and Hell," MIT Press, Cambridge, Massachusetts, 2007, pp. 163.
[cxl] Amsden, Alice. *Rise of the Rest: Challenges to the West from Late-Industrializing Economies.* Oxford; New York; Oxford University Press, 2001.
[cxli] Figueiredo, Paulo. "Does Technological Learning Pay Off? Inter-Firm Differences in Technological Capability-Accumulation paths and Operational Performance Improvement." *Research Policy.* Vol 31, pp 73-94, 2002.
[cxlii] Lall, S., "Technological Capabilities and Industrialization," *World Development,* Vol. 20, No. 2, 1992, pp. 165-186.
[cxliii] Kim, Linsu. *Imitation to Innovation: The Dynamics of Korea's Technological Learning.* Boston: Harvard Business School Press, 1997.
[cxliv] Dosi, G., Marengo, L., Fagiolo, G., "Learning in Evolutionary Environments." Working Paper WP-96-124, International Institute for Applied Systems Analysis. 1996.
http://eprints.biblio.unitn.it/archive/00000031/01/CEEL96_05.pdf Accessed December 29, 2011
[cxlv] Dahlman, C., Ross-Larson, B., Westphal, L., "Managing Technological Development: Lessons from the Newly Industrialized Countries." *World Development.* Vol. 15, No. 6, 1987, p. 759-775.
[cxlvi] Dahlman, C., and Westphal, L., "The Meaning of Technological Mastery in Relation to Transfer of Technology." *Annals of the American Academy of Political and Social Science.* Vol. 458, Technology Transfer: New Issues, New Analysis, November 1981, p. 12-26.
[cxlvii] Schumpeter, Joseph A., *The theory of economic development.* Trans. Redvers Opie. 2nd Ed. Cambridge, Massachusetts: Harvard University Press, 1936.
[cxlviii] Nelson, R., S. Winter. *An evolutionary theory of economic change.* London: Belknap Press, 1982.
[cxlix] Polanyi, M., "The Logic of Tacit Inference." *Philosophy,* Vol. 41, No.155,1966, p.1-18.
[cl] Schumpeter, Joseph. The Theory of Economic Development. Trans. Redvers Opie. 2nd ed. Cambridge, Massachusetts: Harvard University Press, 1936.
[cli] Nelson, Richard. "Economic Development from the Perspective of Evolutionary Economic Theory." Oxford Development Studies 36.1 (2008): 9-21.
[clii] Nelson, Richard. National Innovation Systems: A Comparative Analysis. New York: Oxford University Press, 1993.
[cliii] Amsden, Alice. The Rise of "the Rest:" Challenges to the West from Late-Industrializing Economies. New York: Oxford University Press, 2001.
[cliv] Figueiredo, Paulo. "Does Technological Learning Pay Off? Inter-Firm Differences in Technological Capability-Accumulation Paths and Operational Performance Improvement." Research Policy 31 (2002): 73-94.

[clv] Hobday, Michael. "Technological Learning in Singapore: A Test Case of Leapfrogging." The Journal of Development Studies, 30.3 (1994): 831-858.
[clvi] Kim, Linsu. Imitation to Innovation: The Dynamics of Korea's Technological Learning. Boston, Massachusetts: Harvard Business School Press, 1997.
[clvii] Ahmed, Zafar, and John Humphreys. "A Conceptual Framework for Developing Country Transnationals: PROTON Malaysia." *Thunderbird International Business Review,* p. 45.
[clviii] Bozeman, B., "Technology Transfer and Public Policy: a Review of Research and Theory," *Research Policy,* Vol 29, 2000, pp. 627-655.
[clix] Kim, Linsu. *Imitation to Innovation: The Dynamics of Korea's Technological Learning.* Boston: Harvard Business School Press, 1997
[clx] Grieve, R., "Appropriate Technology in a Globalizing World." *International Journal of Technology Management and Sustainable Development,* 3(3), pp 173-187, 2004.
[clxi] Amsden and Chu. *Beyond Late Development: Taiwan's Upgrading Policies.* Cambridge: MIT Press, 2003.
[clxii] Hobday, Michael, *Innovation in East Asia: the Challenge to Japan.* Edward Elgar Publishing, 1995.
[clxiii] Kim, Linsu. *Imitation to Innovation: The Dynamics of Korea's Technological Learning.* Boston: Harvard Business School Press, 1997.
[clxiv] Utterback, James, *Mastering the Dynamics of Innovation,* Harvard Business School Press, Cambridge, 1994.
[clxv] Cohen, W. And Levinthal, D., "Absorptive Capacity: A New Perspective on Learning and Innovation," *Administrative Science Quarterly,* Vol. 35, No. 1, Special Issue: Technology, Organizations, and Innovation. (Mar., 1990), pp. 128-152.
[clxvi] Kim, Linsu. "Building Technological Capabilities for Industrialization: Analytical Frameworks and Korea's Experience." *Industrial and Corporate Change.* Vol 8, No 1, 1999.
[clxvii] Kim, Linsu. "Building Technological Capabilities for Industrialization: Analytical Frameworks and Korea's Experience." *Industrial and Corporate Change.* Vol 8, No 1, 1999.
[clxviii] Kim, Linsu. "Building Technological Capabilities for Industrialization: Analytical Frameworks and Korea's Experience." *Industrial and Corporate Change.* Vol 8, No 1, 1999.
[clxix] Polanyi, M., "The Logic of Tacit Inference," *Philosophy,* Vol. 41, No. 155, 1966, pp. 1-18.
[clxx] Nelson, R. and S. Winter. *An evolutionary theory of economic change.* London: Belknap Press, 1982.
[clxxi] Edmonson, A., Winslow, A., Bohmer, R., "Learning How and Learning What: Effects of Tacit and Codified Knowledge on Performance Improvement Following Technology Adoption," *Decision Sciences,* Vol. 34, No. 2, 2003, pp. 197.
[clxxii] Nonaka, I., "A dynamic theory of organizational knowledge creation." *Organization Science,* Vol. 5, No. 1, February 1994, p. 14-37.
[clxxiii] Kim, Linsu. "Building Technological Capabilities for Industrialization: Analytical Frameworks and Korea's Experience." *Industrial and Corporate Change.* Vol 8, No 1, 1999.
[clxxiv] Lall, S., "Technological Capabilities and Industrialization," *World Development,* Vol. 20, No. 2, 1992, pp. 165-186.
[clxxv] Hobday, M., Rush, H., "Technology Management in complex product systems (CoPS) – ten questions answered." *International Journal of Technology Management.* Vol. 17, No. 6, 1999.
[clxxvi] Hobday, M., Rush, H., "Technology Management in complex product systems (CoPS) – ten questions answered." *International Journal of Technology Management.* Vol. 17, No. 6, 1999.
[clxxvii] Rush, H., "Managing Innovation in Complex Product Systems (CoPS)." *The Institution of Electrical Engineers,* London, 1997.
[clxxviii] Hobday, M., Rush, H., "Technology Management in complex product systems (CoPS) – ten questions answered." *International Journal of Technology Management.* Vol. 17, No. 6, 1999.
[clxxix] Moody, J., Dodgson, M., "Managing Complex Collaborative Projects: Lessons from the development of a new satellite." *Journal of Technology Transfer.* Vol. 31, 2006, p. 567-588.
[clxxx] Dahlman, C., and Westphal, L., "The Meaning of Technological Mastery in Relation to Transfer of Technology." *Annals of the American Academy of Political and Social Science.* Vol. 458, Technology Transfer: New Issues, New Analysis, November 1981, p. 12-26.
[clxxxi] Clark, B., "Influences and conflicts of federal policies in academic-industrial scientific collaboration," *The Journal of Technology Transfer,* Vol. 36, No. 5, 2011, p. 514-545.
[clxxxii] Salvador, E., "Are science parks and incubators good "brand names" for spinoffs? The case study of Turin." *The Journal of Technology Transfer,* Vol. 36, No. 2, 2011, p. 203-232.

[clxxxiii] Huang, K., Yu, C., "The effect of competitive and non-competitive R&D collaboration on firm innovation," *The Journal of Technology Transfer,* Vol. 36, No. 4, 2011, p. 383-403.
[clxxxiv] Lenzi, C., "Workers' mobility and patterns of knowledge diffusion: evidence from Italian data." *The Journal of Technology Transfer,* Vol. 35, No. 6, 2010, p. 651-670.
[clxxxv] Upadhyay, V., Sikka, P., Abrol, D., "Technology dissemination programmes and extramural R&D support in India," *The Journal of Technology Transfer,* Vol. 35, No. 6, 2010, p. 680-690.
[clxxxvi] Wakasugi, R., Ito, B., "The effects of stronger intellectual property rights on technology transfer: evidence from Japanese firm-level data." *The Journal of Technology Transfer,* Vol. 34, No. 2, 2009, p. 145-158.
[clxxxvii] Wei, L., "International Technology Transfer and Development of Technological Capabilities: A Theoretical Framework." *Technology in Society,* Vol. 17, No. 1, 1995, p. 103-120.
[clxxxviii] Wei, L., "International Technology Transfer and Development of Technological Capabilities: A Theoretical Framework." *Technology in Society,* Vol. 17, No. 1, 1995, p. 103-120.
[clxxxix] Chen, S., "Extending Internalization Theory: A New Perspective on International Technology Transfer and its Generalization." *Journal of International Business Studies,* Vol. 36, No. 2, March 2005, p. 231-245.
[cxc] Contractor, F., Sagafi-Nejad, T., "International Technology Transfer: Major Issues and Policy Responses," *Journal of International Business Studies,* Vol. 12, No. 2, Autumn 1981, p. 113-135.
[cxci] Grosse, R., "International Technology Transfer in Services," *Journal of International Business Studies,* Vol. 27, No. 4, 1996, p. 781-800.
[cxcii] Wei, L., "International Technology Transfer and Development of Technological Capabilities: A Theoretical Framework." *Technology in Society,* Vol. 17, No. 1, 1995, p. 103-120.
[cxciii] Contractor, F., Sagafi-Nejad, T., "International Technology Transfer: Major Issues and Policy Responses," *Journal of International Business Studies,* Vol. 12, No. 2, Autumn 1981, p. 113-135.
[cxciv] Reddy, N., Zhao, L., "International Technology Transfer: A review." *Research Policy,* Vol. 19, 1990, p. 285-207.
[cxcv] Contractor, F., Sagafi-Nejad, T., "International Technology Transfer: Major Issues and Policy Responses," *Journal of International Business Studies,* Vol. 12, No. 2, Autumn 1981, p. 113-135.
[cxcvi] Reddy, N., Zhao, L., "International Technology Transfer: A review." *Research Policy,* Vol. 19, 1990, p. 285-207.
[cxcvii] Seurat, Silvere. *Technology Transfer: A realistic approach.* Paris, France. 1979.
[cxcviii] Grosse, R., "International Technology Transfer in Services," *Journal of International Business Studies,* Vol. 27, No. 4, 1996, p. 781-800.
[cxcix] Ofori, G., "Construction Industry Development: role of technology transfer," *Construction Management and Economics,* Vol. 12, 1994, p. 379-392.
[cc] Waroonkun, T., and Stewart, R., "Modeling the international technology transfer process in construction projects: evidence from Thailand," *Journal of Technology Transfer,* Vol. 33, 2008, p, 667-687.
[cci] Waroonkun, T., and Stewart, R., "Modeling the international technology transfer process in construction projects: evidence from Thailand," *Journal of Technology Transfer,* Vol. 33, 2008, p, 667-687.
[ccii] Kedia, B., Bhagat, R., "Cultural Constraints on Transfer of Technology across Nations: Implications for Research in International and Comparative Management," *The Academy of Management Review,* Vol. 13, No. 4, October 1988, p. 559-571.
[cciii] Bhagat, R., Kedia, B., Harveston, P., Triandis, H., "Cultural Variations in the Cross-Border Transfer of Organizational Knowledge: An Integrative Framework." *The Academy of Management Review,* Vol. 27, No. 2, April 2002, p. 204-221.
[cciv] Hofstede, G., "National cultures in four dimensions: A research-based theory of cultural differences among nations." *International Studies of Management and Organizations,* Vol. 13, No. 1-2, 1983, p. 46-74.
[ccv] Hofstede, G., "National cultures in four dimensions: A research-based theory of cultural differences among nations." *International Studies of Management and Organizations,* Vol. 13, No. 1-2, 1983, p. 46-74.
[ccvi] Hofstede, G., Minkov, M., "Long- versus short-term orientation: new perspectives." *Asia Pacific Business Review,* Vol. 16, No. 4, p. 493-504.
[ccvii] Hofstede, G., Hofstede, G. J., Minkov, M., *Cultures and Organizations: Software for the Mind.* 3rd Ed. McGraw-Hill, 2010.
[ccviii] Hofstede, G., "Cultural Dimensions in Management and Planning." *Asia Pacific Journal of Management,* January 1984, p. 81.

[ccix] Kedia, B., Bhagat, R., "Cultural Constraints on Transfer of Technology across Nations: Implications for Research in International and Comparative Management," *The Academy of Management Review,* Vol. 13, No. 4, October 1988, p. 559-571.
[ccx] Hall, G., and Johnson, R., "Transfer of United States aerospace technology to Japan."In R. Vernon (Ed.), *The technology factor in international trade,* New York: Columbia, p. 305-358.
[ccxi] Bhagat, R., Kedia, B., Harveston, P., Triandis, H., "Cultural Variations in the Cross-Border Transfer of Organizational Knowledge: An Integrative Framework." *The Academy of Management Review,* Vol. 27, No. 2, April 2002, p. 204-221.
[ccxii] Garud, R., Nayyar, P., "Transformative capacity: continual structuring by intertemporal technology transfer." *Strategic Management Journal.* Vol. 15, 1994, p. 365-385.
[ccxiii] Bhagat, R., Kedia, B., Harveston, P., Triandis, H., "Cultural Variations in the Cross-Border Transfer of Organizational Knowledge: An Integrative Framework." *The Academy of Management Review,* Vol. 27, No. 2, April 2002, p. 204-221.
[ccxiv] Lin, B., Berg, D., "Effects of cultural difference on technology transfer projects: an empirical study of Taiwanese manufacturing companies." *International Journal of Project Management.* Vol. 19, 2001, p. 287-293.
[ccxv] Shore, B., Venkatachalam, A., "Role of national culture in the transfer of information technology." *Journal of Strategic Information Systems,* Vol. 5, 1996, p. 19-35.
[ccxvi] Hofstede, G., "National cultures in four dimensions: A research-based theory of cultural differences among nations." *International Studies of Management and Organizations,* Vol. 13, No. 1-2, 1983, p. 46-74.
[ccxvii] Kedia, B., Bhagat, R., "Cultural Constraints on Transfer of Technology across Nations: Implications for Research in International and Comparative Management," *The Academy of Management Review,* Vol. 13, No. 4, October 1988, p. 559-571.
[ccxviii] Chiou, J., Lee, M., Calantone, R., "International Technology Transfer from the recipient's perspective: the differences between hard technology pursuers and know-how technology pursuers." *Journal of Global Marketing,* Vol. 9, No. 3, 1996, p. 5.
[ccxix] Hall, G., and Johnson, R., "Transfer of United States aerospace technology to Japan."In R. Vernon (Ed.), *The technology factor in international trade,* New York: Columbia, p. 305-358.
[ccxx] Kedia, B., Bhagat, R., "Cultural Constraints on Transfer of Technology across Nations: Implications for Research in International and Comparative Management," *The Academy of Management Review,* Vol. 13, No. 4, October 1988, p. 559-571.
[ccxxi] Chiou, J., Lee, M., Calantone, R., "International Technology Transfer from the recipient's perspective: the differences between hard technology pursuers and know-how technology pursuers." *Journal of Global Marketing,* Vol. 9, No. 3, 1996, p. 5.
[ccxxii] Fredland, R., "Technology Transfer to the Public Sector in Developing States: Three Phases," *Journal of Technology Transfer,* Vol. 25, No. 3, Oct 2000, p. 265.
[ccxxiii] Miller, John B. "Engineering Systems Integration for Civil Infrastructure Projects." *Journal of Management in Engineering.* September/October, p. 61, 1997.
[ccxxiv] Gordon, C., "Choosing appropriate construction contracting method," *Journal of Construction Engineering and Management,* Vol. 120, March 1994, p. 196.
[ccxxv] Crawley, E., de Weck, O., Eppinger S., Magee, C., et al, "The Influence of Architecture in Engineering Systems," *Engineering Systems Monograph,* MIT Engineering Systems Division MIT, 2004. http://esd.mit.edu/symposium/monograph/default.htm Accessed December 29, 2011
[ccxxvi] Crawley, E., "Course lecture Notes: System Architecture," Massachusetts Institute of Technology, 2007 http://ocw.mit.edu/courses/engineering-systems-division/esd-34-system-architecture-january-iap-2007/, Accessed December 29, 2011.
[ccxxvii] Maier, M., Rechtin, E., *The Art of Systems Architecting, 2nd ed.* CRC Press: Boca Raton, 2002.
[ccxxviii] Crawley, E., "Course lecture Notes: System Architecture," Massachusetts Institute of Technology, 2007 http://ocw.mit.edu/courses/engineering-systems-division/esd-34-system-architecture-january-iap-2007/, Accessed December 29, 2011.
[ccxxix] Maier, M., Rechtin, E., *The Art of Systems Architecting, 2nd ed.* CRC Press: Boca Raton, 2002.
[ccxxx] Maier, M., Rechtin, E., *The Art of Systems Architecting, 2nd ed.* CRC Press: Boca Raton, 2002.
[ccxxxi] Levis, A., "System Architectures." *Handbook of Systems Engineering and Management*, edited by A. P. Sage and W. B. Rouse. New York: John Wiley & Sons, 1999, p. 427-454.
[ccxxxii] Maier, M., Rechtin, E., *The Art of Systems Architecting, 2nd ed.* CRC Press: Boca Raton, 2002.

[ccxxxiii] Varvasovszky, Z. and Brugha, R., "How to do (or not to do)…A Stakeholder Analysis." *Health Policy and Planning.* Vol. 15, No. 3, p.338, September 2000.
[ccxxxiv] Reed, M., Graves, A., Dandy, N., et al. "Who's in and Why? A Typology of Stakeholder Analysis Methods for Natural Resource Management," *Journal of Environmental Management.* Vol. 90, pp. 1933-1949, 2009.
[ccxxxv] Varvasovszky, Z., and Brugha, R., "Stakeholder Analysis: A Review," *Health Policy and Planning.* Vol. 15, No. 3, pp. 239-246, 2000.
[ccxxxvi] Crawley, E., "Course lecture Notes: System Architecture," Massachusetts Institute of Technology, 2007 http://ocw.mit.edu/courses/engineering-systems-division/esd-34-system-architecture-january-iap-2007/, Accessed December 29, 2011.
[ccxxxvii] Crawley, E., de Weck, O., Eppinger S., Magee, C., et al, "The Influence of Architecture in Engineering Systems," *Engineering Systems Monograph,* MIT Engineering Systems Division MIT, 2004.
[ccxxxviii] Crawley, E., de Weck, O., Eppinger S., Magee, C., et al, "The Influence of Architecture in Engineering Systems," *Engineering Systems Monograph,* MIT Engineering Systems Division MIT, 2004.

4 Research Design and Methods

This dissertation seeks to lay a foundation on which to inductively build theory about a poorly understood phenomenon: collaborative satellite projects with learning and problem solving goals. This is done through exploratory work that examines the nature of these collaborative satellite projects. The research design is grounded in social science approaches to theory building, although the use of systems architecture integrates a technical approach from system design. The study uses qualitative, process data organized into case studies via in-situ field work. Social science literature provides guidance about how to execute such research. The ideas presented here are drawn heavily from the academic management community, especially from those that study organizational dynamics. This research tradition is highly relevant to the proposed thesis because it seeks to understand the dynamics of a technology project in a unique organizational context. Some methodological guidance is the subject of debate; on other issues social scientists generally agree. There is general agreement that theory building is an essential goal of social science pursuit. Building theory means creating explanations for phenomena in the social world that reveal how and why they occur. In some contexts, there is a desire to use such explanations to enable prediction or manipulation of social systems. Applied social sciences such as management work in this vein. More universally, however, social scientists seek understanding of social life.[ccxxxix] In the context of research on Complex Product Systems, such an understanding of social life can be used to improve the design, implementation and operation of socio-technical systems. Secondly, most researchers accept that theory can be built deductively or inductively. A deductive process begins with reflection on past work, personal experience and logical reasoning. Deductively built theories are refined by testing them against empirical findings. An inductive process may also begin by considering past work, but it is given full form via empirical observation. For this reason, field work is a useful tool to develop theory inductively. Thirdly, authors tend to accept general statements for what distinguishes a strong theory. Such a theory includes a clear statement of *what* is involved – the variables or concepts of interest. It next describes *how* these variables or concepts are related or how they behave. Ideally, the theory will go on to explain *why* the variables or concepts behave as observed.[ccxl] In the end, the theory is most useful if it is accurate, parsimonious and general.[ccxli]

Social science researchers differ on some key points with regard to theory building. First, there is debate about what it means to explain phenomena and seek general theory. On one hand, explanation can be conceived as the search for the mean causal effect of one variable on another in a social system. This perspective uses a stochastic view of the world. It proposes that empirical observations of the relationships between variables are a combination of a systematic causal component and a random component. Here the goal of theory building is causal inference; it seeks to approximate the systematic affect of one variable or a set of variables on an outcome. This type of work aims to build highly general theories, sometimes called covering laws.[ccxlii] On the other hand, some researchers do not aim for such broad generality. A process and mechanisms approach begins by establishing the causal links in a specific empirical episode. The goal is to establish the series of actions or activities that lead from a cause to an effect. Individual actions or activities are named mechanisms; while the series of mechanisms are called processes. One episode is explained when a logical chain of mechanisms can describe the process of moving from cause to effect or from state A to state B. Generality can be sought by defining the specific mechanisms of that episode as part of more generic classes of mechanisms or by finding commonly occurring processes. Such an analysis does not assume that the same process always moves from cause to effect or from state A to state B. Thus, this perspective does not seek to build a covering law about what causes the effect. Rather, a process theorist seeks to understand why common processes or combinations of mechanisms occur and how they impact the system of interest.[ccxliii] In this dissertation, a process and mechanisms approach is employed whenever relationships are explored. This approach is more tenable than traditional causal inference for the qualitative, theory building work. The process tracing perspective is at the center of another distinction made within social science research. This issue centers on the difference between qualitative research based on variables and research based on processes. Mohr wrote the seminal work that distinguishes between a variable-based approach and a process-based approach to organizational research[ccxliv] Mohr argues for the separation of theories based on variables from those based on theories. A process approach can be especially helpful for case studies because of the importance of time as an organizing factor for the data. Yin's commonly cited textbook on case study methods, generally assumes a variable-based approach. Yin, however, includes process-based methods as part of the arsenal of analysis tools that can be applied to case study data.[ccxlv] Meanwhile, Langley writes specifically about how to build theory from data collected under a process approach. Langley encourages the use of both variables and process-based data, but also provides guidance about the strengths and weaknesses of each approach.[ccxlvi] A third area of debate in the literature is about how a researcher should use past literature when beginning the process of inductive theory building. At one extreme are Glaser and Strauss, whose method of grounded theory emphasizes that one should begin theory building with a blank mind and only consider the empirical data.[ccxlvii] Farther along the spectrum is Eisenhardt with a 1989 paper about the process of building theory from case studies. Eisenhardt advises that researchers use past research to define problems and define initial constructs that may need to be measured in the field. When it comes to theory building, however, Eisenhardt advises minimal use of previous literature. The line is drawn around defining specific relationships between variables; this should be based on empirical data only.[ccxlviii] Even farther from grounded theory is Parkhe's approach, which advocates using all available theory in the literature, while doing inductive case studies. Parkhe suggests a constant iteration between theory and observation.[ccxlix] At the end of the spectrum opposite Glaser and Strauss is Yin's case study guidance. Yin's work writes from the perspective that most work is deductive and suggests developing theory before data collection.[ccl] This dissertation most closely follows Parkhe's approach.

Eisenhardt summarizes the process of building theory from case studies as follows: 1) define research question; 2) selection cases through theoretical sampling; 3) craft data collection instruments; 4) overlap data collection and analysis in the field; 5) analyze data within and across cases; 6) shape initial hypotheses; 7) compare outcomes to existing literature; 8) reach closure based on theoretical saturation.[ccli] Langley's work gives examples of how to do step 5 of Eisenhardt's plan. Langley suggests seven strategies for making sense of process-based data. One method is called alternative templates. This can be applied by using different theories or frameworks to explain the empirical observations. The goal is to see where each theory has a weakness and look for ways to synthesize their contributions. For this work, ideas from technology transfer, project management and technological learning theories are applied to the data, both within and across cases. A second analysis method is called visual mapping. This uses graphics to summarize information, show time sequences of events or draw relationships among the data. This dissertation will make use of graphics and tables to summarize information about time and architectural approaches. Finally, Langley describes a synthetic strategy that blends variable and process work. This path looks at processes as if they were variables and describes them with characteristics. The goal is then to understand what factors influence the processes. As advised by Langley, multiple strategies will be used to analyze the data, especially visual mapping and viewing processes as variables.[cclii] Weick and Eisenhardt provide examples of some of the results that are relevant to the exploratory nature of this work. There are the intermediate products of the theory building process. Weick notes several items that he calls "approximations" to theories. Assuming a variable-based approach, they include lists of variables, which show what is important to an explanation; definitions of variables and concepts; and potential relationships between concepts.[ccliii] Analogous concepts may be applied to the process approach. Eisenhardt performed an inductive project with Bourgeois in which the results were initial theoretical propositions and their corresponding testable hypotheses. At the end of this qualitative project, Eisenhardt had defined hypotheses that could be operationalized and tested with quantitative research.[ccliv]

4.1 Research Questions

A five part research question guides the analysis and synthesis of the dissertation.

Research Question 1 (RQ1): What are the Architectures of Collaborative Satellite Projects?
The answer to this question describes the collaborative satellite projects using an architectural approach that captures both social and technical system aspects. This description identifies specific practical decisions facing decision makers who lead collaborative satellite projects. It further identifies the set of options from which decision makers can choose.

Research Question 2 (RQ2): How are the Architectures of Collaborative Projects Similar and Different?
The answer to this question uses an architectural approach to do a structured comparison of the collaborative satellite projects by identifying which elements of form are assigned to common

project functions. This analysis contrasts the implementation approaches of the four emerging space nations as they executed early satellite projects.

Research Question RQ3: What Capability Building Opportunities do Individuals Have?
The answer to this question uses definitions from the technological learning literature to define capability building in the context of the collaborative satellite projects at the individual level. Capability Building profiles are developed and analyzed for individual engineers.

Research Question RQ4: What Capability Building Achievements do Organizations Have?
The answer to this question uses definitions from the technological learning literature to define capability building in the context of the collaborative satellite projects at the organizational level. Capability Building profiles are developed and analyzed for national space organizations and their partners. This analysis enables a comparison of the capability building achievements of the four emerging space nations.

Research Question RQ5: What are potential relationships between architecture and capability building?
As an exploratory step, this question inductively considers whether there are links between the implementation approaches used by the four emerging space nations and the capability building outcomes they achieve.

4.2 Research Methods

This research addresses the five research questions using a case study approach in order to study recent and contemporary events over which the research has little control. The case study is an effective tool because the phenomena of interest within the collaborative satellite projects are likely to be highly driven by context. Yin provides all of these as appropriate reasons for pursuing a case study approach. A case study is "an empirical inquiry that investigates a contemporary phenomenon in depth within its real-life context…."[cclv] The research questions for this study are given above. There are not specific propositions or hypotheses for the questions because the research is exploratory. The implicit proposition underlying all of the questions is that the use of architecture as an organizing factor in data collection and analysis will provide new insights into the detailed implementation issues for the collaborative satellite projects. The unit of analysis for each case study is a specific satellite project, during which one or more satellites is procured by a national space organization from a foreign firm.

The research design uses a multi-case study approach. This creates the potential to find future research directions based on similarities and differences in projects. Based on the foundational analysis summarized in the introduction about national satellite programs, there may be about twenty to thirty examples of collaborative satellite projects of the type studied here. Six projects are chosen that have several key factors in common. Each is a collaborative satellite project executed by a national space organization and a foreign firm. Each project explicitly includes the development of a satellite and training as objectives. For each project, engineers from the customer country spend months or years working at the facility of the foreign firm while the firm designs and builds a satellite for the national space organization. The firms explicitly offer a training program as part of the contract to sell the satellite. Also the satellites from six projects are similar in that they all carry optical, earth observation payloads as their primary purpose. Another reason for selecting the six case study projects was the ability and willingness of the national space organizations to host the research. This required an investment of time and resources on the part of the host to make people and documentation available.

Three key factors are varied across the six case study projects; these factors are expected to lead to observable differences in architecture and capability building. The first factor is the combination of supplier and customer. The six satellite projects involve four nations and three suppliers. One nation works with a single supplier for two projects; one nation works with two different suppliers. Two suppliers work with two different nations in the case studies. The second factor that varies across the projects is the technical approach of the suppliers. Two of the suppliers use the emerging small satellite engineering philosophy, while one uses a traditional technical approach. Third, the technical performance of the satellites varies between medium and high resolution imagery. These variations may lead to patterns in the observed architecture and capability building outcomes.

Table 4-1: Summary of Key Aspects of Case Study Projects; Names of nations and firms are coded for anonymity

Satellite Projects	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Country	Nation Alpha		Nation Beta		Nation Gamma	Nation Delta
Satellite Type	Remote Sensing					
Satellite Imagery Performance	Medium Resolution	High Resolution	Medium Resolution	High and Medium Resolution	High Resolution	High Resolution
Supplier	Supplier Omega1	Supplier Tau1	Supplier Omega1		Supplier Tau1	Supplier Sigma1
Technical Approach	Small Satellite Philosophy					Traditional Technical Approach

This section explains methods for data collection and the early analysis steps. The specific steps used to answer each research question are further explained in a later section.

4.2.1 Data Collection

Data is primarily collected via field research within the countries that executed the collaborative satellite projects as well as at the site of the supplier firms. Field research is necessary because the facts about the satellite projects are generally not documented or available to the public. The primary data collection methods include interviews, observation, and review of primary documents. The author performed extensive interviews among stakeholders from the customer countries and supplier firms. During these visits, the author interviewed engineers, managers and policy makers that were involved in the projects of interest. Table 4-2 summarizes the data collection via interviews and site visits. Four nations (Nation Alpha, Nation Beta, Nation Gamma and Nation Delta) were visited because they executed collaborative satellite projects. Nations Omega, Tau and Sigma were locations of supplier firms. Note that the interviews with the representatives of Nation Sigma were done outside the country at a conference. The lengths of the visits were determined by the ability of the organizations to host the researchers. During each visit, data was collected via formal, hour long interviews; through informal meetings; through observation and tours of the facilities and activities; and through documentation provided by the customers and suppliers. All the interviews were recorded and transcribed. Upon completion of the field work, the data from the interviews, research notes and stakeholder documentation was catalogued.

Table 4-2: Summary of Field Data Collection

Country	Type	# Sites Visited	# of People Interviewed	Types of Organizations Visited
Nation Alpha	Customer	3	11-20	• Industry • National Government
Nation Beta	Customer	1	21-30	• National Government
Nation Gamma	Customer	1	6-10	• National Government
Nation Delta	Customer	2	6-10	• National Government
Nation Omega	Supplier	2	21-30	• Industry • University
Nation Tau	Supplier	3	11-20	• Industry • University • National Government
Nation Sigma	Supplier	0	1-5	• Industry

The interview approach seeks to balance the types of personnel interviewed in each context. At national space organizations, the goal is to interview engineers from a variety of subsystem teams and technical specialties. In addition, interviews include managers and policy makers when possible. At supplier firms, the goal is to also interview people from a variety of technical backgrounds and leadership levels who made direct contributions to the case study projects. At each host organization a representative coordinated the interview schedule – mediating between the researchers and the employees.

The interview questions are defined using inspiration from Systems Architecture as defined by Crawley[cclvi] and Enterprise Architecture as defined by Nightingale and Rhodes.[cclvii] Both topics define the purview of a system architect broadly to include issues of policy, organizational processes and structure, market factors, and knowledge management. The interview includes questions on the following topics: the interviewee's professional position, duties, career path and educational background; experience and role in the case study satellite projects; organizational, management and training aspects of the case study projects; technical and operational approaches for the projects; strategic project issues relating to partner selection and motivations; and capability building achievements during the projects. One version of the interview instrument is used suppliers and one for customers. These versions are adapted during each interview based on the individual's position and experiences. Information about the individual's position and career path, indicate which questions they are able to answer. When possible the interviewees received a preview of the interview questions in advance. Appendix B: Interview Material contains generic examples of interview questions for supplier firms and customers organizations.

4.2.2 Data Analysis

The data analysis process uses four steps to answer the research questions. At the end of the data collection activities, the evidence included hundreds of interview transcripts, photographs from site visits, research notes and documents provided by case study participants. The first step organized the information from all the data sources into a consistent framework and created a case study database that saved the evidence in a traceable manner. Using evidence from one case study project, a series of project attributes were inductively defined to categorize the information from the interviews. The list of attributes was refined as evidence from each case study was coded. Evidence was sought from interviews as well as other sources to produce comparable data about each case study. The final list of project attributes is summarized in outline form here. The facts about each aspect of the project were recorded in Excel along with a note stating the source of the fact. For each project attribute, multiple sources were available to confirm the information or to indicate conflicting evidence.

Table 4-3: Project Attributes

Attributes that Describe the Collaborative Satellite Projects

1. Contextual & Background Information on Satellite Space Program
2. Summary of Key Events (Timeline)
3. Motivations and Objectives for the Satellite Project
4. Initiation and Approval of Satellite Project
5. The Project Team
    5.1. Relationship of Satellite Customer to Other Organizations
    5.2. List of Team Members
    5.3. Team Size
    5.4. Selection of Engineers for Satellite Project
        5.4.1. Selection Process
        5.4.2. Previous Affiliation
        5.4.3. Available Pool of Talent and Experience Level of Hired Engineers
        5.4.4. Perspective and Personality of Engineers
    5.5. Selection of Foreign Contractors/Suppliers
        5.5.1. Selection of Satellite Supplier and Trainer
        5.5.2. Selection of Launch Provider
    5.6. Team Location
    5.7. Team Roles
6. Project Facilities
7. Training
    7.1. Objectives & Expectations for Training
    7.2. Preparation for Training
    7.3. Transition to Training Location
    7.4. Training Approaches & Relationship with Mentors
    7.5. Examples of Training Projects
    7.6. Technical Contributions of Trainees
8. Contracts and Agreements
9. Technical Product and Approach
    9.1. Product
    9.2. Approach
10. Management Approach
    10.1. Review Process
    10.2. Project Milestones
    10.3. Management Priorities
11. Policy Issues
12. Cultural, Social and Regional Issues

After the facts about each case study project in the twelve dimensions listed above were captured in a series of spreadsheets, the second step created narrative summaries of each case study. These narratives combined the data from many sources to create consolidated stories of each case study with high levels of detail. The narratives were sent to project participants to be reviewed for accuracy. The third step was to convert the narratives about each case study into an architectural analysis. This step provides the answers to Research Question 1 and 2. The approach is explained more in the section that answers these research questions. The mechanics of this step involve building another Excel spreadsheet. In the first set of spreadsheets, the facts about each case study are collected separately and multiple sources of evidence are used to explore each fact. In this step, one spreadsheet is used to collect standardized facts about all the case study satellite projects using the dimensions listed above. This creates a single document that facilitates comparison of the architecture of each satellite project. The fourth analysis step was to observe capability building for individuals and organizations. For individuals, this step used data from the interviews with customer countries. Interviewees explained their educational experiences, career path and roles during the satellite projects. The mechanics use an Excel spreadsheet to record capability building experiences in a standardized template and color code them to show a progression over time. For organizations, another set of tables were created to track capability building achievements based on evidence from interviews and documents. The sections that answer these research questions provide further explain the theoretical approach and methods to observing capability building for individuals and organizations.

Finally, Yin advises on how to maintain validity and reliability during case study research. Construct validity refers to the quality of operational approaches used to measure a concept. In this work, the concepts that are measured or observed include architecture, individual capability building experiences and organizational capability achievements. Validity is improved for this study by using multiple sources of evidence (interviews, observation and documents), keeping clear links between evidence and results (in the Excel databases and narratives), as well as by having representatives from each case study review the case study narratives. With regard to internal validity, this is most important for Research Question 5. The first four research questions are descriptive; question 5 begins to explore potential causal links between architectural approaches and capability building outcomes. Following Yin's advice, the approach looks for patterns and rival explanations. External validity asks whether findings can be generalized. Yin explains that each case study is like one of a series of experiments, not one of a statistical sample. The generalization is at the level of theory, which may be replicated or updated in future theories. Finally, this research uses several steps to maintain reliability that minimizes bias. Producing and analyzing case study data via field research does require many decisions based on researcher judgment, but the steps are clearly documented to maintain reliability.[cclviii]

[ccxxxix] Van de Ven, Andrew. "Nothing is Quite so Practical as a Good Theory." *Academy of Management Review.* Vol. 14, No. 4, 1989, p. 486-489.

[ccxl] Wheeten, David, "What Constitutes a Theoretical Contribution?" *Academy of Management Review.* Vol 14, No 4, 1989, p. 490-495.

[ccxli] Langley, Ann, "Strategies for Theorizing from Process Data," *Academy of Management Review.* Vol 24, No 4, 1999, p 691-710.

[ccxlii] King, G., Keohane, R., and Verba, S., *Designing Social Inquiry: Scientific Inference in Qualitative Research.* Princeton University Press, Princeton, 1994.

[ccxliii] Tilly, Charles, "Mechanisms in Political Processes," *Annual Review of Political Science.* Vol 4, 2001, p 21-41.

[ccxliv] Mohr, L. B., *Explaining Organizational Behavior.* Jossey-Bass, San Francisco, 1982.

[ccxlv] Yin, R., *Case Study Research: Design and Methods.* Sage Publications, Thousand Oaks, 2009.
[ccxlvi] Langley, Ann, "Strategies for Theorizing from Process Data," *Academy of Management Review.* Vol 24, No 4, 1999, p 691-710.
[ccxlvii] Glaser and Strauss, *The discovery of grounded theory.* Aldine, Chicago, 1967.
[ccxlviii] Eisenhard, Kathleen, "Building Theories from Case Study Research," *Academy of Management Review.* Vol. 14, No 4, 1989, pp 532-550.
[ccxlix] Parkhe, Arvind, " 'Messy' Research, Methodological Predispositions, and Theory Development in International Joint Ventures," *Academy of Management Review.* Vol 18, No 2, 1992, 227-268.
[ccl] Yin, R., *Case Study Research: Design and Methods.* Sage Publications, Thousand Oaks, 2009.
[ccli] Eisenhard, Kathleen, "Building Theories from Case Study Research," *Academy of Management Review.* Vol 14, No 4, 1989, pp 532-550.
[cclii] Langley, Ann, "Strategies for Theorizing from Process Data," *Academy of Management Review.* Vol 24, No 4, 1999, p 691-710.
[ccliii] Weick, Karl, "What Theory is Not, Theorizing Is," *Administrative Science Quarterly,* Vol 40, No 3, 1995, p 385-390.
[ccliv] Bourgeois, L. and Eisenhardt, K., "Strategic Decision Making in High Velocity Environments: Four Cases in Microcomputer Industry." *Management Science.,* Vol 34, No 7, 1988, p 816-835.
[cclv] Yin, R., *Case Study Research: Design and Methods.* Sage Publications, Thousand Oaks, 2009.
[cclvi] Crawley, E., "Course lecture Notes: System Architecture," Massachusetts Institute of Technology, 2007 http://ocw.mit.edu/courses/engineering-systems-division/esd-34-system-architecture-january-iap-2007/, Accessed December 29, 2011.
[cclvii] Nightingale, D., Rhodes, D., "Enterprise Systems Architecting: Emerging Art and Science within Engineering Systems," MIT Engineering Systems Symposium, March 2004.
[cclviii] Yin, R., *Case Study Research: Design and Methods.* Sage Publications, Thousand Oaks, 2009.

5 Case Studies of Collaborative Satellite Projects

This chapter provides summaries of the collaborative satellite project case studies. The chapter opens by introducing the nomenclature used to describe the cases. Four countries are featured in the case studies. For each country, the chapter provides background information, a timeline of their satellite projects and a brief summary of project events. Longer project summaries are provided in Appendix A: Detailed Summaries of Case Study Projects. The detailed summaries are written as Analytical Narratives that present information about each satellite project using an organization scheme based on Architectural Dimensions that were inductively defined during data analysis. The same set of Architectural Dimensions provides the foundation to answer Research Questions 1 and 2.

Codes are used to describe the actors, locations and satellites for each project. Within each nation that participates in the projects there may be various types of organizations – Suppliers, Implementers, Overseers and Universities. Suppliers sell satellites and training services on a commercial basis. Implementers are executing satellite projects and they seek services from the suppliers. Overseers are from the same nation as the Implementers. They provide some combination of funding, government policy guidance and oversight. Universities are academic institutions engaged in teaching and research. Within each organization, there may be various types of personnel – Engineers, Managers, Political Leaders and Professors. Engineers are directly engaged in technical activities of satellite projects. Managers are supervisors of engineers and they are engaged in other activities that may include, project management, quality assurance, administrative activity, business development, compliance with regulatory guidelines and interaction between organizations. Political Leaders are working at high levels of government and defining policy strategy. The Professors category includes personnel in academic positions in universities with duties of teaching and research. These categories are summarized in Table 5-1.

Table 5-1: Guide to Dissertation Naming Convention

Generic Objects in Case Studies	
Geographic Reference	Nation
Organizations	Supplier
	Implementer
	Overseer
	University
Personnel	Engineer
	Manager
	Political Leader
	Professor
Satellites	Remote Sensing

	Communication

In order to protect the identity of the participants in the case studies, codes are used to describe the nations, organizations, personnel and satellites. Table 5-2 introduces the foundational codes that are used for each of these elements. Each Nation is identified by a Greek Letter, such as Alpha, Beta, Gamma, etc. The Organizations, Personnel and Satellites are associated with specific countries and indexed with numbers. The italicized letters in Table 5-2 represent the numerical indices. For example, the first Nation is Nation Alpha. The first Implementer from Nation Alpha is Implementer Alpha1. The first engineer from Nation Alpha is Engineer Alpha1; and the first remote sensing satellite from Nation Alpha is AlphaSat-R1.

Table 5-2: Guide to Dissertation Naming Convention

Code for Specific Objects from Nation Alpha	
Specific Organizations	
Supplier Alpha,*i*	Supplier,*i* from Nation Alpha
Implementer Alpha,*k*	Implementer,*k* from Nation Alpha
Overseer Alpha,*m*	Overseer,*m* from Nation Alpha
University Alpha,*n*	University,*n* from Nation Alpha
Specific Personnel	
Engineer Alpha,*p*	Engineer,*p* from Nation Alpha
Manager Alpha,*q*	Manager,*q* from Nation Alpha
Leader Alpha,*r*	Political Leader,*r* from Nation Alpha
Professor Alpha,*s*	Professor,*s* from Nation Alpha
Specific Satellites	
AlphaSat-R,*t*	Remote Sensing Satellite,*t* from Nation Alpha
AlphaSat-C,*u*	Communication Satellite,*u* from Nation Alpha

Table 5-3 summarizes the six case study satellite projects in which seven satellites were procured by the four case study countries. The table describes their technology and the supplier that sold them.

Table 5-3: Summary of Key Aspects of Case Study Projects

Note: Names of nations and organizations are coded for anonymity						
Satellite Projects	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Country	Nation Alpha		Nation Beta		Nation Gamma	Nation Delta
Supplier	Supplier Omega1	Supplier Tau1	Supplier Omega1		Supplier Tau1	Supplier Sigma1
Technical Approach	Small Satellite Philosophy					Traditional Technical Approach

5.1 Nation Alpha

The first Nation (known hereafter as Nation Alpha) pursued two collaborative projects with remote sensing missions. The first satellite project (AlphaSat-R1) occurred during the decade of the 1990s and involved a partnership with a Supplier Omega1. The second project (AlphaSat-R2) occurred during the 2000s; here Nation Beta partnered with a Supplier from Nation Tau (Supplier Tau1). The sections below summarize key events of the AlphaSat-R1 and AlphaSat-R2 projects.

The AlphaSat-R1 project was initiated because a communication services company from Nation Alpha was procuring the AlphaSat-C1 and AlphaSat-C2 satellites. These would be the first domestically owned communication satellites for Nation Alpha. The communication company entered negotiations with a foreign launch provider. As part of the negotiations, the launch provider offered the free launch of a small satellite (weighing a few hundred kilograms) for Nation Alpha. The small satellite was intended to ride to orbit on the same rocket as the larger communication satellites. In response, the government space research office of Nation Alpha formed a committee to discuss how to respond to the free launch offer. The committee proposed a plan to the government of Nation Alpha for implementing a small satellite project. This plan was approved and supported by government leadership and the project was gradually initiated over several years. The government space research office that established the initial committee took on leadership of the project as the direct Overseer organization (Overseer Alpha1). In order to implement the project, the space research office established a company (Implementer Alpha1) that would serve as the Implementing organization on behalf of the government. The space research office (Overseer Alpha1) decided to develop the small satellite by procuring it from a foreign firm. They sought a firm that would sell the satellite and provide training for engineers from Nation Alpha as part of the project. The government space office chose Supplier Omega1 to supply the satellite and training for a team of engineers from Nation Alpha. Implementer Alpha1 and Supplier Omega1 signed an agreement to implement the AlphaSat-R1 project in the facilities of Supplier Omega1 with a team that included engineers from both organizations. That same year a team of engineers from Nation Alpha traveled to Nation Omega and started a training program in the context of the AlphaSat-R1 project. The core team of 7 engineers from Nation Alpha stayed at Supplier Omega1 for about one year. Meanwhile, back in Nation Alpha, the Implementer Alpha1 grew in personnel as new engineers were hired to focus on AlphaSat-R1 operations and on future missions. AlphaSat-R1 was proposed as a small satellite to be launched with the larger communication satellites (AlphaSat-C1 and AlphaSat-C2). The AlphaSat-R1 team missed the opportunity to launch with the AlphaSat-C1 and AlphaSat-C2 satellites. The project continued, however, and aimed for a new launch date. There were delays in securing a new launch opportunity. The first launch attempt finally came about two years after the manufacturing of AlphaSat-R1 was completed. During the first launch attempt, there was an engine malfunction and the launch was rescheduled. The AlphaSat-R1 was finally launched a few months later. A team of engineers from Nation Alpha learned how to operate the satellite using a ground station installed by Supplier Omega1. The ground station was located in a major city within Nation Alpha.

AlphaSat-R2 was the second small satellite project in which Nation Alpha partnered with a foreign company for both training and joint execution. Under the oversight of the government space research office (Overseer Alpha1), Implementer Alpha1 partnered with Supplier Tau1 to build the satellite and payload. The collaboration between Implementer Alpha1 and Supplier Tau1 actively started a few months before the launch of the first remote sensing satellite, AlphaSat-R1. During a four year period, a set of engineers from Implementer Alpha1 lived and worked in Nation Tau under the mentorship of the Supplier Tau1 team. The initial work was on the payload system for AlphaSat-R2. Several Implementer Alpha1 engineers were sent to Nation Tau to work on the satellite's development. After about one year, Implementer Alpha1 and Supplier Tau1 extended their agreement from the payload project to include a satellite bus to carry the payload. Implementer Alpha1 also developed new facilities in Nation Alpha during the AlphaSat-R2 project. About 5 years into the project, Implementer Alpha1 completed an Assembly, Integration and Test facility at their location; there they integrated the flight model of AlphaSat-R2. For the following four years, AlphaSat-R2 was in Nation Alpha where it was further tested and calibrated. Other important space events took place in during the AlphaSat-R2 project. The government space research office (Overseer Alpha1) transition to become a full government space agency around the second year of the project (the agency is coded as Overseer Alpha2). Also the first astronaut program for Nation Alpha began around the third year of the AlphaSat-R2 project. AlphaSat-R2 was launched about 9 years after the project was initiated.

5.1.1 Project Background

This section explains the context, technical requirements and capability building objectives for Nation Alpha.

5.1.1.1 Context

When the AlphaSat-R1 and AlphaSat-R2 projects took place in Nation Alpha, the country was coming out of a forty year process of major social and economic transition. In the 1950s Nation Alpha gained independence from a former colonial power. During the following decade Nation Alpha gradually defined its borders and pursued political stability. In the thirty years from 1970 to 2000, Nation Alpha sought and achieved social and economic transformation in many ways. The primary economic activity was gradually converted from agriculture to manufacturing. Prior to this a few cash crops dominated the exports from Nation Alpha. Eventually manufacturing in both lower technology areas such as textiles and higher technology areas such as electronics dominated the export sales from Nation Alpha. The government was an active catalyst to this transition. A government initiative for economic growth in the 1970s and 1980s emphasized poverty alleviation and sought to lessen economic inequality. The government continued such planning with a new initiative starting in the 1990s that focused on balanced national development. The government set forth an aggressive national vision for achieving grand strides toward national development in the twenty-first century. As part of this process the government set up state owned enterprises in key sectors of the economy where they sought strategic activity– such as the energy and automotive industries. These enterprises blazed new trails and created new national capabilities. The government encouraged interaction between national firms and foreign or multinational firms. This was seen as an opportunity to absorb new technology into the country. The government made large scale national investments in areas such as architecture, energy and information technology. This included defining special zones to encourage high technology industry. A series of new architectural landmarks displayed both national prestige and technical achievement. These investments were also designed to invite international participation in the emerging high technology community within Nation Alpha.

From a social perspective, Nation Alpha balanced a complex web of factors. The ethnic demographics of the population were diverse, and there were traditional economic disparities along ethnic lines. The development efforts of the government sought to redress such disparities, especially for the traditionally disadvantaged majority. The concerns of minority communities – especially indigenous people – were not always met, and this led to social and political tension. These tensions gradually eased somewhat between 1970 and 2000. As part of the ethnic divisions, there was competition within the country among various languages. Several dominant international languages threatened the relevance of the local language in education and business. The government pursued an evolving approach to both maintain the local language while acknowledging the usefulness of international languages for business and education. Also during this period, there was a transition for the role of woman in society. Many women entered the workforce – in both the manufacturing sector and the civil service. Strong economic growth in certain periods attracted foreign immigrants to job opportunities, adding to the already diverse demographics. The country also sought to find balance in the area of religion. The government both supported an official national religion while maintaining the right of other religions to co-exist. Finally, society was affected by the dramatic environmental changes that were part of the rapid economic transitions of the period. Traditional environmental practices and resources were threatened by the economic growth, but the short term benefits were positive for many members of the population, so environmental concern was inconsistent. Much of these social and economic dynamics were driven by a key government leader who persisted in office through a long tenure. This key government leader (Leader Alpha1) lent personal vision and support to many of the development projects and landmark architectural icons of the period. In the context of these social and economic factors, the satellite projects and other space activity were a consistent with the drive to harness information and communication technology, develop local technical skills and foster national prestige.

Prior to the AlphaSat-R1 project, Nation Alpha had long been aware of the benefits of satellite services. The first satellite communication receiving stations were installed in Nation Alpha during the 1960s and a national remote sensing center was established in the 1980s to harness earth observation data. Meanwhile, the government of Nation Alpha took broad interest in space in the late twentieth century. They appointed a government office to support national space research (Overseer Alpha1). It was based out of the central government. Part of the office's role was to promote public awareness and outreach about space. The new office established a national planetarium as a tool for space science education and research. A communication firm (Implementer Alpha 2) took the lead with regard to owning and operating satellites in Nation Alpha. Their business model was to own and operate communication satellites, but they did not focus on satellite manufacturing. Implementer Alpha2 bought the first satellites owned by Nation Alpha from a foreign satellite manufacturer. The procurement was a pair of small communication satellites – AlphaSat-C1 and AlphaSat-C2. As part of the contract with the supplier firm, a team of fourteen engineers from Nation Alpha went to the supplier firm's location for a 6 month training experience. The AlphaSat-C1 and AlphaSat-C2 projects precipitated the inspiration for Nation Alpha's first small satellite project. Implementer Alpha2 approached a foreign launch provider to launch AlphaSat-C1 and AlphaSat-C2. As part of the negotiations for this launch, the provider offered to launch a small satellite for free as a secondary payload on the same rocket with the communication satellites. This offer catalyzed the first satellite project with major national participation.

A Manager (Manager Alpha1) was leading Implementer firm Implementer Alpha1 and managing the day to day aspects of the AlphaSat-R1 project. At the time when Implementer Alpha1 was formed, it was designed to be a temporary organization with the sole purpose of providing institutional infrastructure for the engineers hired to implement the small satellite project. Manager Alpha1 challenged this assumption when the core team of engineers returned from training at Supplier Omega1. He saw that Nation Alpha had made progress in learning to use satellite technology. He promoted a vision to the government leaders that Nation Alpha could also work toward becoming a producer of space technology. A key government leader (Leader Alpha1) who had given great political support to AlphaSat-R1 also championed the idea of continuing Implementer Alpha1 as a government-linked, space technology company. While Implementer Alpha1 did not receive regular government funding for operations, it would be the government's primary contractor for satellite development projects.

The government space research office (Overseer Alpha1) gradually evolved. Government Leader Alpha2 played a key role in helping Nation Alpha define their approach during the AlphaSat-R1 project. She left Nation Alpha, however, for several years between the AlphaSat-R1 and AlphaSat-R2 projects to pursue a different type of international leadership role. She returned for a few years and oversaw the conversion of the government space office (Overseer Alpha1) into Nation Alpha's national space agency (Overseer Alpha2). The space agency became the new government organization that served as Overseer to Implementer Alpha1 for satellite projects.

The seeds of the AlphaSat-R2 project were planted during the AlphaSat-R1 project when Leader Alpha2 met Professor Tau1 during an international conference. Professor Tau1 had done pioneering work in Nation Tau to establish a satellite workforce using a series of small satellite projects. During the conference, Professor Tau1 gave a presentation that described a vision for how developing countries can begin work on space technology. Leader Alpha2 took note of the presentation and began a long term dialog with Professor Tau1 about the possibility of Nations Alpha and Tau partnering on a joint satellite development project. As the AlphaSat-R1 project was nearing a close, Implementer Alpha1 transitioned to a long term organization and formulated a proposal for a follow on satellite mission. Eventually, Implementer Alpha1 and Overseer Alpha1 came together to make a proposal for a second small satellite that they could present to the Nation Alpha government. The relevant government ministry (Overseer Alpha3) coordinated with Implementer Alpha1 and Overseer Alpha1 to seek government approval and funding for AlphaSat-R2. Once money was allocated, Implementer Alpha1 was contracted to build the new satellite.

5.1.1.2 Technical Requirements

As Nation Alpha pursued the AlphaSat-R1 project they targeted a small spacecraft that could potentially provide useful data related to fisheries, forestry, river pollution, oil exploration, mapping and meteorology. Overall, however, the technical performance of the satellite was a secondary objective compared to the desire to build capability in engineers from Nation Alpha. The technical performance was largely driven by the capabilities and experience of Supplier Omega1. The system was designed to provide optical imagery of medium and low resolution. The satellite also carried a non-real time communication payload for the amateur radio community.

The technical requirements for AlphaSat-R1 stand in contrast with AlphaSat-R2. The primary goal during the AlphaSat-R1 project was for engineers from Nation Alpha to learn about satellite technology; it was not pivotal that the satellite provide consistent, operational data to specific end users. During the second project (AlphaSat-R2), this gradually changed. Over the life of the project, the team made several decisions that showed a commitment to producing more useful, operational data. The leadership of Overseer Alpha1, especially Leader Alpha2, actively defined that they wanted this second remote sensing satellite to provide operationally useful data. To ensure that the data was useful, they insisted that the system be optically calibrated. The Nation Alpha team emphasized the performance of the imager instrument when making decisions about training, partnership, local facilities and procurement. Nation Alpha chose to partner with a company that agreed to jointly develop a new earth observation imager. They selected specific engineers to focus on learning and executing the imager technology. They also set up local facilities to calibrate the imager payload before it was flown in space. All of these actions were pursued as part of the motivation to make the second satellite project more operational and useful. In addition to a high performance payload, Nation Alpha wanted to design the mission to meet the specific needs of their country, by using an orbit that suited their geographic location. This decision was non-traditional, innovative and risky. Because the orbit was rare, this design choice would give Nation Alpha both benefits through notoriety and costs due to technical and logistical challenges. For this second mission, the Nation Alpha team (Overseer Alpha1 and Implementer Alpha1) drove the requirements definition rather than the satellite supplier. AlphaSat-R2 was designed to carry a high resolution imager with high performance. Nation Alpha sought to achieve a mission that would stand out internationally by making a technical contribution to the global repertoire of satellite experience.

5.1.1.3 Capability Building Objectives

The long term objective of the AlphaSat-R1 project was to establish the capability for Nation Alpha to domestically produce satellites. The Nation Alpha leadership recognized that in the short term, these skills may not be acquired through a single project. As short term objectives, Manager Alpha1 hoped that his engineers would have the opportunity participate in building, testing and operate a satellite. This would enable them in the future to buy sophisticated satellite technology and gradually build up expertise about satellites.

The Nation Alpha team continued to seek capability building for Implementer Alpha1 engineers during the AlphaSat-R2 project. The trainee engineers were a new group that did not participate in AlphaSat-R1 or attend the training with Supplier Omega1. For this second project, the Nation Alpha team sought the opportunity for engineers to participate in more phases of the satellite design. During the AlphaSat-R1 project, the Nation Alpha engineers were present at Supplier Omega1 only for the late stages of the development process – integration and test. For AlphaSat-R2, one goal was for Nation Alpha engineers to experience the entire satellite development lifecycle, starting with design. Another aspect of this was a goal for the Nation Alpha engineers to experience the design of a new spacecraft rather than a spacecraft based on a previously used design. These were seen as valuable steps toward reaching the long term goal of developing satellites locally.

5.1.2 Project Timeline

Table 5-4 and Table 5-5 show the timelines for the AlphaSat-R1 and AlphaSat-R2 projects. The time is shown in Project Years instead of calendar years in order to protect identity. The comments use labels generic to all the projects to categorize each event into one of five categories: Facilitating Event, Project Initiation, Engineers at Supplier Location, System and Facility Development, Satellite Launch. The timelines emphasize the development period of the satellites up until launch. After that milestone the operational phase begins, which is important for delivering products to the system end users. The operational phase is not the focus of this analysis, however.

Table 5-4: Timeline for AlphaSat-R1 Project

Project	***AlphaSat-R1 Project***	***Comment***

Year		
1	Free launch offered with AlphaSat-C1 and AlphaSat-C2 Project	Facilitating Event
	Overseer Alpha1 forms committee to plan satellite project	Project Initiation
2	Formal ceremony initiates project	Project Initiation
3		
4	Implementer Alpha1 established	Project Initiation
	Contract signed between Implementer Alpha1 and Supplier Omega1	Project Initiation
	Nation Alpha Engineers arrive at Supplier Omega1	Nation Alpha Engineers at Supplier Location
	AlphaSat-R1 development	System and Facility Development
5	AlphaSat-R1 development	System and Facility Development
	Nation Alpha Engineers depart Supplier Omega1	Nation Alpha Engineers at Supplier Location
6		
7	AlphaSat-R1 Launch	Satellite Launch

The AlphaSat-R1 project occurred over a seven year period from facilitating event to launch.

Table 5-5: Timeline for AlphaSat-R2 Project

Project Year	***AlphaSat-R2 Project***	***Comment***
1	Leader Alpha2 met Professor Tau1	Facilitating Event
2		
3		
4	Project Initiation	Project Initiation
	First set of Nation Alpha Engineers arrive in Nation Tau	Nation Alpha Engineers at Supplier Location
	Payload development started	System and Facility Development
5	Nation Alpha Engineers at Supplier Tau1 Satellite development	Nation Alpha Engineers at Supplier Location System and Facility Development
6		
7		
8		
9	Satellite assembled in Implementer Alpha1	System and Facility Development
10	Satellite tested and calibrated in Nation Alpha	System and Facility Development
11	Satellite tested and calibrated in Nation Alpha	System and Facility Development
12	Satellite tested and calibrated in Nation Alpha	System and Facility Development
13	AlphaSat-R2 Launched	Satellite Launch

The AlphaSat-R2 project occurred over a nine year period from initiation to launch. Table 5-6 shows the relationship between the timelines of the two projects.

Table 5-6: Joint Timeline for AlphaSat-R1 and AlphaSat-R2 Projects

<table>
<tr><th>Project Year – AlphaSat-R1</th><th>AlphaSat-R1 Project</th><th>Project Year – AlphaSat-R2</th><th>AlphaSat-R2 Project</th></tr>
<tr><td rowspan="4">4</td><td>Project Initiation</td><td rowspan="4">1</td><td rowspan="4">Facilitating Event</td></tr>
<tr><td>Project Initiation</td></tr>
<tr><td>Nation Alpha Engineers at Supplier Location</td></tr>
<tr><td>System and Facility Development</td></tr>
<tr><td rowspan="2">5</td><td>System and Facility Development</td><td rowspan="2">2</td><td rowspan="2"></td></tr>
<tr><td>Nation Alpha Engineers at Supplier Location</td></tr>
<tr><td>6</td><td></td><td>3</td><td></td></tr>
<tr><td rowspan="3">7</td><td rowspan="3">Satellite Launch</td><td rowspan="3">4</td><td>Project Initiation</td></tr>
<tr><td>Nation Alpha Engineers at Supplier Location</td></tr>
<tr><td>System and Facility Development</td></tr>
</table>

5.1.3 Observations

Several observations about Nation Alpha's satellite projects stand out.

- Nation Alpha started their first national satellite project based on an external stimulus, but the timing aligned well with national priorities to invest in science and technology.
- Nation Alpha had a clear priority definition in each project of how the objectives of capability building and technical performance were balanced.
- The Implementer in Nation Alpha was a quasi-commercial, government linked company. This model is unique to Nation Alpha among the case study countries. The Implementer Alpha1 also worked in non-space technology fields in parallel with their satellite projects.
- The leadership in Nation Alpha carefully pursued their relationship with their suppliers for both satellites and launch services. In these two satellite projects, Nation Alpha worked with newly established suppliers and sought to find mutual benefit with them.
- Between the AlphaSat-R1 and AlphaSat-R2 projects, Implementer Alpha1 changed their hiring strategy. For the first project the core group of trainees was primarily experienced professionals hired temporarily. For the second project, Implementer Alpha1 hired young professionals for long term training.

5.2 Nation Beta

Nation Beta pursued two remote sensing satellite projects during which they procured three satellites. During the first project, Implementer Beta bought BetaSat-R1 from Supplier Omega1. During the second project, Implementer Beta bought BetaSat-R2 and BetaSat-R3 from Supplier Omega1. BetaSat-R2 was bought as the primary product to provide high quality data for Nation Beta. BetaSat-R3 was a training project that allowed engineers from Nation Beta to work more autonomously on the satellite development. Both BetaSat-R2 and BetaSat-R3 were launched.

The BetaSat-R1 project was the initiation of Nation Beta's national satellite program. Nation Beta's space agency was created in the late 1990s; the agency began a process of establishing six specialized centers to pursue various aspects of research and operations in space technology and it applications. The Nation Beta central government formally approved the space agency a few months after it opened. Implementer Beta served as the implementing organization for the BetaSat-R1 project. The formation of Implementer Beta was a facilitating event that marked Project Year 1 for the BetaSat-R1 project. Implementer Beta chose to pursue a small satellite project for their first national procurement of a spacecraft. Overseer Beta was the ministry in Nation Beta that provided oversight to Implementer Beta. In Project Year 2 Overseer Beta signed an agreement with Supplier Omega1 to provide a remote sensing satellite and to train a team of Nation Beta engineers. The Nation Beta government placed the satellite project into a larger national program by approving a national space policy document in Project Year 3. Fifteen young men from all over Nation Beta were chosen to participate in the training under Supplier Omega1. The engineers that were trained at Supplier Omega1 left Nation Beta in Project Year 3 to move to Nation Omega. These trainees remained in Nation Omega until the middle of Project Year 5. They joined the Supplier Omega1 team for the development of the BetaSat-R1 spacecraft. While in Nation Omega, the trainees were assigned roles within the Supplier Omega1 engineering team. They worked with subsystem groups including imaging, Attitude Determination and Control, Propulsion, Structures, Ground Station Operations, Power, On-Board Data Handling and Communication. The purpose of the training was to prepare Nation Beta to one day build satellites independent of foreign assistance. In Project Year 5, after a new presidential administration was formed in Nation Beta, the central government approved the launch of BetaSat-R1, the installation of the BetaSat-R1 ground control station, and the long term establishment of a permanent location for Implementer Beta with improved facilities. Starting in early Project Year 5, the ground control station for BetaSat-R1 was built and commissioned in Nation Beta's capital city. It was completed just in time for the launch of BetaSat-R1 in Project Year 5.

For Nation Beta's second remote sensing satellite project, they again partnered with Supplier Omega1. Two spacecraft were procured: BetaSat-R2 was a high performance satellite designed to produce excellent imagery; BetaSat-R3 was a training satellite for the Nation Beta engineers to learn from. The project was implemented by Nation Beta's national space agency

(Implementer Beta) under a relevant ministry (Overseer Beta). The satellite project was initiated as Nation Beta was in preparing an agreement with several other countries in the region to create a collaborative satellite constellation. This constellation agreement was signed in Project Year 1. In Project Year 2, Overseer Beta signed a contract with Supplier Omega1 for the BetaSat-R2 & R3 project on behalf of Nation Beta. The national leader of Nation Beta approved the contract soon after. A few months before the contract was formally signed the first of two cohorts of Nation Beta engineers traveled to Nation Omega to work with Supplier Omega1. The training continued through Project Year 5. Both Supplier Omega1 and Implementer Beta celebrated new facilities during this project. Supplier Omega1 opened it's a new corporate headquarters in Project Year 2. Implementer Beta commissioned a new campus in Project Year 3, moving into a permanent, dedicated facility for the first time. Between Project Year 3 and Project Year 5, the two spacecraft – BetaSat-R2 & R3 – went through all the major project milestones. In the midst of this progress, Implementer Beta transitioned to a new leader in Project Year 4. In Project Year 5, Implementer Beta held a special event to commemorate a major anniversary. Supplier Omega1 expected the BetaSat-R2 & R3 satellites to launch in Project Year 6, but launch delays plagued the project. The satellites were both launched in Project Year 7.

5.2.1 Project Background

This section explains the context, technical requirements and capability building requirements for Nation Beta.

5.2.1.1 Context

The BetaSat-R1 project, and the initiation of Nation Beta's national space program, came as the culmination of internal and external processes that shaped the pioneering space activities. Prior to the founding of a national space agency and the first satellite project, there were several strains of space-related activity in Nation Beta. These included academic research in astronomy and space science, participation in international initiatives related to space services, a series of policy proposals promoting space activity in the country and a gradual process by the government to establish science policy infrastructure. Universities in Nation Beta were involved in astronomy and space science research for decades before the BetaSat-R1 project. Several universities had science departments or research centers dedicated to space. Some of these universities formed international partnerships with foreign universities. There early attempts to set up scientific equipment such as telescopes, although these projects were often not sustained. Nation Beta took steps to participate in the international space community, starting in the 1970s and 1980s through fora such as the United Nations and INMARSAT. Nation Beta also sought partnerships with governments that operated satellites to access environmental remote sensing data.

Over several decades, a number of proposals were written by academic and government representatives that called for a national space program in Nation Beta. Some of these proposals had support and input from multilateral agencies. The reports varied in scope. Some proposed general space activity; some wrote specifically about national needs for remote sensing data; and others proposed space investment as part of a larger effort in science and technology. One of these proposals led to the formation of a national remote sensing agency. This series of reports coincided with a gradual build up in science policy infrastructure within the national government. Through the 1970s and 1980s, Nation Beta slowly defined the organizations and mechanisms by which they would manage national science and technology investment. There were several precursor organizations before a formal ministry was established to specifically address science and technology. Once established, the ministry went through a series of transitions in leadership and focus that paralleled the transitions in national leadership. Eventually, two key ministers of science and technology were able to formulate and execute visions for increasing national investment in science and technology, including space. An incubating agency was formed to strengthen the national infrastructure for science and technology research. This incubator birthed several new specialty agencies, including the national space agency. The new agencies started off as units within the incubator. Later, some of the personnel from the larger agency split off to form the new agency with a specialized mission. This was the process for forming Nation Beta's national space agency.

In Project Year 1 for BetaSat-R1, Implementer Beta was formed as the national space agency and Nation Beta committed itself to the local design and development of satellites. A national space policy document was officially approved; it formally documented the motivation to use space technology for development. In terms of external influences, Nation Beta's aspirations coincided with Supplier Omega1's idea to coordinate a group of countries for collaboration in a satellite constellation. The first leader of Implementer Beta, met representatives from Supplier Omega1 at a conference and learned about their offerings and methods.

Nation Beta's motivation to pursue the BetaSat-R2 project can be described from four perspectives – national development, national pride, personnel training and continuity with the BetaSat-R1 project. The first two areas are discussed here. The capability building and technical motivations are discussed later. Both the official documents and the words of government leaders expressed the idea that Nation Beta viewed the satellite program as part of the national development process. The National Space Policy and Programmes document attributed a direct link between national space activity and national development saying, "No nation [can] call itself developed in the 21st century that does not have indigenous critical mass of trained space scientists and engineers who contribute actively to the solution of the nation's problems." The policy also argued that Nation Beta's national development process will be enhanced by pursuing space activity and local expertise in the topic. The space policy mentions specific areas in which Nation Beta can apply space to development challenges, including agriculture, forestry, communication, transportation, tourism, education, health care, energy, safety and security. Publications from Implementer Beta, the national space agency, followed the same theme. Implementer Beta stated that Nation Beta is investing in satellite technology in order to apply space services to social needs as part of the national development process. During a ceremony to commemorate the opening of Implementer Beta's permanent facility, the president of Nation Beta made a speech. He talked about how national development motivated Nation Beta's space activity. He said that space would help Nation Beta achieve the Millennium Development Goals and a national development strategy. The key areas of need that he highlighted were poverty, food security, infrastructure, energy, health, housing and disasters. The Nation Beta President saw the potential for benefit from space assets that would provide guaranteed access to data and lead to geospatial information. This idea that satellites would contribute to development also had regional implications. Nation Beta made an agreement with several other countries in their region to pursue a collaborative satellite constellation. BetaSat-R2 was the country's contribution to this constellation of satellites that would collect and share environmental data about the region.

Along with a belief that satellites projects contribute to development, Nation Beta leaders expressed a sense that the space activity contributed to national pride and prestige. After the BetaSat-R2 contract was signed but before major project milestones had been reached, both the Nation Beta president and the leader of Implementer Beta spoke in a language evoking national pride about the projects. The president highlighted the pioneering achievements of Nation Beta in owning an earth observation satellite and establishing a space agency with a research center. The leader of Implementer Beta spoke of the political benefits for the nation through the space program, saying that Implementer Beta's work had "transformed Nation Beta into the position of key player in the global space industry" allowing Nation Beta to "join the league" of space players. He expected their progress in space technology to lead to geopolitical changes: "When you have these types of technology with you, you are respected." He stated that the launch of BetaSat-R1 was important because it countered the "myth some people have...that Nation Beta cannot do high tech."

5.2.1.2 Technical Requirements

For BetaSat-R1, the supplier had great influence in defining the technical specifications because the project was done in the context of a multi-country, collaborative constellation. Supplier Omega1 developed the concept for the constellation and proposed it to potential customers – inviting them to become collaborators. As the supplier envisioned, each constellation collaborator would purchase and operate a satellite as part of a fleet. Each of the satellites in the fleet would be identical and use compatible ground control stations. By participating in the collaborative constellation, the Nation Beta team accepted the technical specifications proposed for the satellite fleet. As a group, the constellation pursued medium resolution imagery in the optical spectrum; the imagery would provide wide views with mid-level detail. The constellation also sought to produce images of high enough quality to sell commercially. They planned a fleet of satellites weighing 100kg or less that could be launched together and operated in a coordinated constellation. The capability building goals were determined within the context of the training and technology approaches of the constellation.

The political motivations for BetaSat-R2 are discussed above. From a technical standpoint, the purpose included providing continuity after the BetaSat-R1 project and procuring a satellite with increased technical performance. The Nation Beta team took more initiative in defining the specifications for BetaSat-R2 than they did with BetaSat-R1. BetaSat-R1 was designed for medium spatial resolution, and its technology was based on a previous satellite from Supplier Omega1. BetaSat-R2 was a new product designed to achieve high resolution performance and produce detailed images. In order to reach the goal of improving technical performance while continuing the data stream of BetaSat-R1, BetaSat-R2 carried multiple imaging systems. The satellite included one imager system with similar performance to BetaSat-R1 as well as a second imager with high quality, detailed images. BetaSat-R2 was also planned to produce images of commercial quality. As part of the same project, Implementer Beta purchased BetaSat-R3. This was a secondary, training project on which Implementer Beta engineers did the majority of the hands on work. The technical performance of BetaSat-R3 was similar to that of BetaSat-R1. Just after the BetaSat-R2 & R3 contract was signed, Implementer Beta documented specific objectives for how they would use the new satellites. For operations, a new Mission Control Center was to be established at the planned permanent location for Implementer Beta in Abuja. BetaSat-R2 was to produce optical data that could support information products such as digital maps, topographic databases, administrative boundaries, cadastral databases, transportation databases, hydrographic databases, land use databases, geological data and demographics data. The high resolution data from BetaSat-R2 would be useful for urban mapping, detection of oil spills and security monitoring. Other proposed applications included hydrology, crop mapping, forest monitoring, structure mapping, development of roads, rails and pipelines, and detection of illegal mining or fires. Implementer Beta also had the objective of building on their geospatial infrastructure to organize the BetaSat-R2 data using information management systems and to define a data sharing policy. The capability building objectives for the BetaSat-R2 project were balanced with the technical objectives, as described below.

5.2.1.3 Capability Building Objectives

Implementer Beta pursued the long term goal of achieving local capability to design and manufacture satellites. As one Implementer Beta official interprets, "[The] main thrust of the National Space Policy is to acquire competency and capability in space technology development through appropriate human resources development and capacity building." The same official spoke to the Nation Beta trainee engineers before they left for Supplier Omega1 and said that the goal of the training was to achieve "indigenization of this technology" because Nation Beta would not always rely on foreign partners. The training experiences for Implementer Beta engineers during the BetaSat-R1 and BetaSat-R2 projects contributed to this long term goal. In the short term, Implementer Beta hoped that the experience with BetaSat-R1 would enable the Nation Beta engineers to build satellites "with only minimal supervision." Implementer Beta saw BetaSat-R2 as a continuation of their training activities. The specific training approach for the

BetaSat-R2 project was to send twenty-five engineers and scientists to Supplier Omega1 for about 30 months. They would work on building a training satellite model that was based on flight standards. This training satellite became BetaSat-R3. A portion of the twenty-five would also pursue graduate degrees related to space technology and earn Master of Science degrees. For all three satellites – BetaSat-R1, BetaSat-R2 and BetaSat-R3 – the training focused primarily on satellite engineering rather than on operations or payload development. Only a small subset of the Nation Beta engineers focused on operations or payloads.

5.2.2 Project Timeline

Table 5-7 and Table 5-8 show the project timelines for the BetaSat-R1 and BetaSat-R2 & R3 projects. The time is shown in Project Years instead of calendar years in order to protect identity. The comments use labels generic to all the projects to categorize each event into one of five categories: Facilitating Event, Project Initiation, Engineers at Supplier Location, System and Facility Development, Satellite Launch. The timelines emphasize the development period of the satellites up until launch. After that milestone the operational phase begins, which is important for delivering products to the system end users. The operational phase is not the focus of this analysis, however.

Table 5-7: Timeline for the BetaSat-R1 Project

Project Year	***BetaSat-R1 Project***	***Comment***
(1)	Implementer Beta established	Facilitating Event
	BetaSat-R1 project approved	Project Initiation
(2)	Contract signed with Supplier Omega1	Project Initiation
(3)	Nation Beta national space policy approved	Facilitating Event
	Nation Beta trainees arrive in Supplier Omega1	Trainees at Supplier Location
	BetaSat-R1 development	System and Facility Development
(4)	Nation Beta trainees in Supplier Omega1	Trainees at Supplier Location
	BetaSat-R1 development	System and Facility Development
(5)	New president re-approves BetaSat-R1 project	Project Initiation
	Nation Beta trainees depart Supplier Omega1	Trainees at Supplier Location
	BetaSat-R1 development	System and Facility Development
	BetaSat-R1 launch	Satellite Launch

Table 5-8: Timeline for the BetaSat-R2 and BetaSat-R3 Projects

Project Year	*BetaSat-R2 and BetaSat-R3 Projects*	*Comment*
(1)	Regional collaboration agreement signed	Facilitating Event
(2)	Contract with Supplier Omega1 signed	Project Initiation
	Nation Beta president approved project	Project Initiation
	Cohort 1 trainees arrive at Supplier Omega1	Trainees at Supplier Location
	Supplier Omega1 Opens New Facility	System and Facility Development
(3)	Cohort 1 trainees at Supplier Omega1	Trainees at Supplier Location
	BetaSat-R2 & R3 satellite development	System and Facility Development
	Implementer Beta opens new campus	System and Facility Development
(4)	Cohort 1 trainees at Supplier Omega1	Trainees at Supplier Location
	Cohort 2 trainees arrive at Supplier Omega1	Trainees at Supplier Location
	BetaSat-R2 & R3 satellite development	System and Facility Development
(5)	Cohort 1 and Cohort 2 Trainees depart Supplier Omega1	Trainees at Supplier Location
	BetaSat-R2 & R3 satellite development completed	System and Facility Development
(6)	Launch Delay	Launch
	Implementer Beta Operations Team receives one month training at Supplier Omega1	Trainees at Supplier Location
(7)	BetaSat-R2 & R3 Satellites Launch	Launch

5.2.3 Observations

Several observations about Nation Beta's satellite projects stand out.

- Nation Beta transitioned from a first project with little training structure on a medium performance satellite to a second project with highly structured training and two satellites. They explicitly pursued a high performance satellite and a "high autonomy" satellite.
- The time gap between the BetaSat-R1 and BetaSat-R2 & R3 programs caused some challenges. Some of the BetaSat-R1 engineers did not stay as Implementer Beta employees or continue working on the next generation program. The majority of the BetaSat-R2 & R3 engineers were new hires. Thus, it may be that the organization benefitted more than the individuals from the series of projects. The organization was

able to pursue a more advanced project during the second generation even though the many of the individuals were inexperienced.

- There was little coordination or overlap between the training in on BetaSat-C1 and the remote sensing series of projects. One specific engineer was drawn from the communication program and sent to train at Supplier Omega1. He saw benefit from the BetaSat-C1 training as he worked on BetaSat-R1. He felt he gained a strong theoretical foundation during the communication program and he had more opportunities for hands on work during the remote sensing program.
- A few key individuals helped design and initiate the space program in Nation Beta. Leaders at the level of president, minister and their close advisors played important roles.
- The space program was created as part of a larger policy to enhance the infrastructure for government funded science and engineering organizations.
- Supplier Omega1 became more formal in several dimensions during the sequence of projects described here. They first worked with Nation Alpha on AlphaSat-R1. Later they worked with Nation Beta for two satellite programs. During this series of project, Supplier Omega1 grew in terms of personnel, facilities, and formality of processes. They formalized their system engineering and project management approaches. They also formalized their training structure and the role of the training manager.

5.3 Nation Gamma

Implementer Gamma1 was formed as a new research center in Nation Gamma in the 2000s. Implementer Gamma1 was formed by a small team of young engineers working under a director. The purpose of Implementer Gamma1 was to equip young professionals of Nation Gamma with advanced skills in science and technology. One of the early priority areas for Implementer Gamma1 was space technology. The newly formed organization decided to procure a small remote sensing satellite to facilitate environmental monitoring of their region. Implementer Gamma1 considered multiple suppliers for this mission, and ultimately selected Supplier Tau1 based in Nation Tau. Soon after the founding of Implementer Gamma1, they started working with Supplier Tau1 on the GammaSat-R1 project. A team of engineers from Implementer Gamma1 went to Nation Tau to live and work alongside the Supplier Tau1 engineers. They learned about satellite engineering and contributed to the GammaSat-R1 project. The satellite was delivered by Supplier Tau1 to Implementer Gamma1 two years later, as scheduled. The aim was to launch later that year. There were delays in executing the launch, however. The satellite was not launched until the following year. Before GammaSat-R1 was launched, Implementer Gamma1 had already begun work with Supplier Tau1 on a second remote sensing satellite for Nation Gamma (GammaSat-R2). More young engineers from Nation Gamma were hired and sent to Nation Tau for training.

5.3.1 Project Background

This section explains the context, technical requirements and capability building objectives for Nation Gamma.

5.3.1.1 Context

In the 2000s, several young engineers from Nation Gamma were hired to join a burgeoning project. They were among the first employees of a new research organization, Implementer Gamma1. Some of the engineers were hired before the formal opening of Implementer Gamma1. For months before the institute was officially established, the small team "worked together to form the vision for the organization." They addressed questions such as the name, logo and administrative procedures of the new institute. They also considered what they could learn from foreign models of similar research organizations. The initial leadership of Implementer Gamma1 determined that the institute would be multidisciplinary and seek activity in a variety of fields such as environment, energy and astronomy. They also decided to begin their work with a project related to space technology. The young engineers, who did not have training in space technology, started doing independent study on the topic. "We spent about 8 months reading books. Sitting in the office and reading about space." A later step was to learn about the companies that could sell Implementer Gamma1 an appropriate satellite. The Implementer Gamma1 team wanted to buy both a satellite and pay for training for their engineers. After the months of preparation and background study, the small Implementer Gamma1 team made a proposal to Nation Gamma government for their initial activities. They received funding and formal status as a government department in Project Year 2. GammaSat-R1 was the first earth observation satellite project on behalf of Nation Gamma, and it was Implementer Gamma1's first major initiative. GammaSat-R1 was part of Implementer Gamma1's goal of "inspiring scientific innovation and fostering technological advancement in Nation Gamma." Later, Implementer Gamma1 also began activities in areas such as alternative energy sources and the energy applications of nanotechnology. Implementer Gamma1 sought to develop an organization that produced practical research, rather than being primarily theoretical. One element that helped them pursue this was the design of their human resource policies. Implementer Gamma1 created a promotion scheme to reward performance by giving awards for activities such as presentations or achievements. They also created a management and technical track so that people could be promoted along either path. Before Implementer Gamma1 pursued the GammaSat-R1 project, there was a user base in Nation Gamma for geo-referenced information – such as that produced by satellites. Users were generally more familiar with the benefits of high resolution, visible data than the other parts of the spectrum. They were also not specifically aware of the capabilities of satellite data. The new Implementer Gamma1 team worked to promote the use of satellite data. Implementer Gamma1 worked toward building a relationship with the government and demonstrating that they could provide useful satellite-based tools. They worked to build awareness by doing project with specific ministries. They also tried to raise awareness within universities by having students do projects using satellite data. The universities benefitted from working with Implementer Gamma1 and receiving additional data. Implementer Gamma1 chose the firm Supplier Tau1 as their partner to provide GammaSat-R1 and a training program in satellite engineering. Supplier Tau1 was a medium sized firm of about 100 employees. They marketed internationally, especially to customers in the Middle East, Asia and Europe.

5.3.1.2 Technical Requirements

The Implementer Gamma1 team sought a first satellite project that balanced both capability building opportunities and technical performance. They procured a satellite with high resolution optical imagery; this offered high performance for the size and cost of the spacecraft. Some of the applications they proposed to use the satellite for included infrastructure planning, environmental monitoring, land degradation, agricultural mapping, land use monitoring and water quality.

5.3.1.3 Capability Building Objectives

In the area of capability building through the GammaSat-R1 project, Implementer Gamma1 sought to build organizational capability in satellite technology and contribute to national development in the long term. Implementer Gamma1 explicitly valued the technology training aspects of GammaSat-R1 because they saw technical advancement as key to the country's development process. "They wanted to work in a field that would grow Nation Gamma national skills and grow scientists....Space became a way to go into a field we had not been in and we wanted to take young engineers to develop them through technology transfer." Previously, industries such as construction, aviation and tourism were growing quickly, "but foreigners were doing the work." Implementer Gamma1 chose to work closely with a foreign satellite company because they saw it was a way to build local knowledge and help uplift their national capabilities. At the organizational level, Implementer Gamma1 defined long term objectives for capability in satellite technology. They sought to develop a long term satellite program with continuity. Implementer Gamma1 signed the contract to do a second remote sensing satellite with Supplier Tau1 before the GammaSat-R1 was finished. Thus Implementer Gamma1 valued the first project for the learning opportunity, not only for the data results. They sought to reach a dual goal of demonstrating local capability (with one satellite) and generating revenue with a highly capable instrument on a second satellite. Implementer Gamma1 pursued the GammaSat-R1 project with the long term goal of developing organizational capability to design and manufacture satellites. They set goals for a progression of technical capability over a series of projects. The progressing capability was defined by the level of involvement Implementer Gamma1 engineers could have in the project. They hoped to learn enough during GammaSat-R1 that they would be capable of contributing to a second satellite at a level of 50%.

5.3.2 Project Timeline

Table 5-9 shows the project timeline for the GammaSat-R1 project. Project Years are used as the unit of time instead of calendar years in order to maintain anonymity of the organizations.

Table 5-9: Timeline for the GammaSat-R1 Project

Project Year	*GAMMASAT-R1*	*Comment*
(1)	Implementer Gamma1 team forms to plan	Facilitating Event
(2)	Implementer Gamma1 officially established	Facilitating Event
	GammaSat-R1 project initiated	Project Initiation and Approval
	Implementer Gamma1 engineers in Nation Tau	Trainees in Supplier Location
	GammaSat-R1 development	System and Facility Development
(3) (4)	Implementer Gamma1 engineers in Nation Tau GammaSat-R1 development	Trainees in Supplier Location System and Facility Development
(5)	Implementer Gamma1 engineers in Nation Tau; GammaSat-R1 launch	Trainees in Supplier Location Launch

5.3.3 Observations

Several observations about Nation Gamma's satellite project stand out.

- Nation Gamma pursued the GammaSat-R1 project, not just to participate in space, but to build their national technological capability in many areas. The space project was to be a catalyst for overall growth. Implementer Gamma1 was not formed as a space agency, but a general research organization.
- The GammaSat-R1 project was highly impacted by the AlphaSat-R2 project. Nation Gamma worked with the same supplier – Supplier Tau1 – and they built a similar satellite.
- The Nation Gamma team invited a group of young engineers to play a key role in the national technology institution when they founded Implementer Gamma1. The young professionals were given both the resources and authority to pioneer a new area for the country.

5.4 Nation Delta

Nation Delta bought its first national, remote sensing satellite from Supplier Sigma1 of Nation Sigma. This project, DeltaSat-R2, was actually the second remote sensing satellite for the country following another university project, DeltaSat-R1. The implementing organization was Implementer Delta1, the national remote sensing agency. Implementer Delta1 and Supplier Sigma1 signed an agreement to pursue the satellite project in the mid-2000s. The agreement appointed Supplier Sigma1 as the prime contractor in the DeltaSat-R2 project. In this role, Supplier Sigma1 was responsible for providing the spacecraft, ground control segment, launch services and training of Nation Delta engineers. A team of twenty engineers from Nation Delta went to Nation Sigma for a two year training program. When the Nation Delta trainees arrived in Nation Sigma, the DeltaSat-R2 project was in the preliminary design phase. The first phase of training was an academic curriculum in which the Nation Delta engineers received about nine months of basic and advanced courses on satellite engineering and space project management. After the course work, the trainee engineers worked on a group satellite design project to apply the knowledge from the classes. The next stage of training focused on tasked-based practice in specific disciplinary areas. Each trainee was assigned to a mentor on a specific disciplinary team; they worked with that mentor to learn skills related to satellite engineering. The final phase of training in Nation Sigma focused on operations. Before the Nation Delta engineers returned home, work began in Nation Delta to establish the ground-based infrastructure for control and data reception for DeltaSat-R2. About one year passed between the return of the Nation Delta trainees from Nation Sigma and the launch. During this time, the trainees assumed new roles as the operations team focused on both routine operation (sending commands and mission plans) and operation support (monitoring satellite status and addressing anomalies). The original timeline called for a three year lifecycle to achieve satellite design, development and launch. Early on, the launch was scheduled for Project Year 4, but some complications led to a change of launcher. The satellite was finally launched in Project Year 5. The Supplier Sigma1 team had worked closely with the Implementer Delta1 operation team in Nation Delta starting in early Project Year 4 to lead pre-launch activities. These activities included installation of the ground control equipment, qualification of the system and certification of the operation team. For the first few months after launch, the Supplier Sigma1 team worked closely with the Nation Delta satellite operators to support them through Early Operations and In-Orbit Tests. By the end of Project Year 4, the Nation Delta team was able to take over primary operational responsibility for DeltaSat-R2 and the system was handed over to Nation Delta.

5.4.1 Project Background

This section explains the context, technical requirements and capability building objectives for Nation Delta.

5.4.1.1 Context

Nation Delta entered the DeltaSat-R2 project after decades of utilizing satellite earth observation data produced by other countries. Several key partnerships in the 1970s and 1980s helped establish their national infrastructure for earth observation. Early in this period, Nation Delta worked with several foreign partners to set up a ground receiving station and learn how to apply the data. At the time of the DeltaSat-R2 project, Nation Delta was receiving earth observation data from many foreign sources. Nation Delta has traditionally produced many agricultural exports. The government recognized satellite imagery as helpful to support the management and monitoring of these crops. Government agencies have been the major users of satellite data in Nation Delta. Nation Delta was also an early adopter of satellite communication technology in the 1960s. Later a local Nation Delta company began to operate communication satellites for the regional market.

The implementing organization for the DeltaSat-R2 project was Implementer Delta1, the Nation Delta national remote sensing agency. Going into the DeltaSat-R2 project, Implementer Delta1 was divided into four main organizations that contributed to different parts of the satellite data value chain. The DeltaSat-R2 project was concerned with upstream procurement of a spacecraft and ground control system as well as human resource development for satellite operators. A second section operated satellite receiving stations to capture satellite data from both domestic and foreign satellites. The data was passed on to a third section for early processing of the satellite data into a useful format. A fourth section did the final processing to create satellite data products with analysis and interpretation. During the period of the DeltaSat-R2 project, Implementer Delta1 was transitioning from an organization that produced satellite data or imagery to an organization that produced information and analysis based on satellite data.

DeltaSat-R2 was the second remote sensing satellite project, but the first at the national level. The university from Nation Delta partnered with a foreign university to build and operate a small satellite that carried a camera and a communication payload. This small satellite was launched in the late 1990s. In another satellite hardware project, a Nation Delta ministry collaborated with a foreign country on a communications project by providing a payload. The DeltaSat-R2 project was not directly affiliated with the previous satellite projects, nor was there deliberate transfer of knowledge or personnel between the projects. DeltaSat-R2 was the first satellite project for Implementer Delta1.

5.4.1.2 Technical Requirements

Even though Nation Delta had operational access to satellite earth observation data from many foreign sources, leadership in Implementer Delta1 saw a need for control over a national satellite to ensure access to specific data. The capability would support natural resource monitoring and management, which were high priorities. Implementer Delta1 had found that the data they required was not always available with the timing or characteristics they needed. DeltaSat-R2 was to improve the situation by producing data from any part of Nation Delta with days. Implementer Delta1 sought the capability of controlling their own satellite and repeating measurements if necessary to answer questions of national importance. Other applications that motivated the project include creating elevation maps using stereo images; establishing a mosaic map of the whole country; and monitoring potential drought conditions. Implementer Delta1 had three operational objectives with the DeltaSat-R2 mission. One was to apply the data produced by DeltaSat-R2 to national needs as described above; the second was to generate revenue by charging a fee to supply data to users outside of Nation Delta. Users could request data or work with Implementer Delta1 to set up a compatible ground station to receive DeltaSat-R2 data directly. Implementer Delta1 did not expect to recoup the cost of the entire project in data revenue, but they did hope to see some return. Third, Implementer Delta1 sought to become one of the main satellite data providers in their region. Based on these needs and objectives, Implementer Delta1 procured a satellite that had high performance in terms of image quality and operational flexibility. The satellite featured high and medium resolution imagers. The satellite was based on designs used previously by Supplier Sigma1. This meant that the project used low-risk, proven technology, and produced data with quality similar to other commercial and government satellite operators. Nation Delta's strategy emphasized technical performance of the satellite in the short term and they sought capability building for the engineers in the long term.

5.4.1.3 Capability Building Objectives

Nation Delta leadership acted out of a long term vision to develop a workforce capable of designing and manufacturing satellites when they planned the DeltaSat-R2 project. In the short term, however, the training and facilities they invested in did not focus on that goal. The Nation Delta trainee engineers moved into full time operations roles after returning from Nation Sigma; and Nation Delta leadership did not build local satellite fabrication facilities. There are no immediate plans to build satellites locally because the infrastructure required for assembly, integration and testing were very expensive. Engineers from Implementer Delta1 were the only people qualified to do operations, but this fact also prevented them from focusing on satellite engineering. The training experience was also shaped by the fact that the trainee engineers represented their government and reviewed the work of Supplier Sigma1 before milestones were accepted.

5.4.2 Project Timeline

Table 5-10 summarizes the project timeline for the DeltaSat-R2 project.

Table 5-10: Timeline for the DeltaSat-R2 Project

Project Year	*DeltaSat-R2 Project*	*Comment*
(1)	Implementer Delta1 signs contract with Supplier Sigma1	Project Initiation
(2)	Nation Delta Trainees arrive at Supplier Sigma1	Trainees at Supplier Location
	DeltaSat-R2 development	System and Facility Development
(3)	Nation Delta Trainees at Supplier Sigma1	Trainees at Supplier Location
	DeltaSat-R2 development	System and Facility Development
(4)	Nation Delta Trainees depart Supplier Sigma1	Trainees at Supplier Location
	DeltaSat-R2 development	System and Facility Development

	Two Ground Stations Set up at Implementer Delta1	System and Facility Development
(5)	DeltaSat-R2 launch	Satellite Launch

5.4.3 Observations

Several observations about Nation Delta's satellite project stand out.

- Nation Delta stands out among these satellite projects because their satellite was procured from a more traditional supplier than those of the other nations. It was larger and more expensive than the other satellites.
- The training approach of Supplier Sigma1 with the Implementer Delta1 team was very structured. The training program provided explicit guidance to the Nation Delta engineers about what to do or expect in each phase. They had courses, a team project, OJT, operations training at Supplier Sigma1, operations training in Nation Delta and then they started doing full time operations work. The structure did not require much initiative from individuals, although some individuals took initiative and found extra activities within the structure. Also, a few leaders had to solve challenges when there were unexpected issues, such as the launch vehicle delays.
- The Nation Delta experience points out that having multiple projects does not guarantee progressive learning. The Implementer Delta1 team did not directly benefit from the DeltaSat-R1 project at University Delta1, based on available data.
- The Nation Delta training emphasized design and analysis aspects more than assembly, integration and testing for the overall group. A few individuals did get to participate in the AIT. The courses, design project and many of the OJT projects were more related to design and analysis.
- Implementer Delta1 is unique for making some of their engineers responsible as technical monitors of the supplier. This was a potentially useful way to engage the trainee engineers in an active way with the technical material produced by the supplier. Even if the Nation Delta engineers did not do much of the design, they had to ask themselves whether the design met their expectations and requirements. Thus, the Nation Delta engineers did not present at reviews (except during the team design project), but they worked at each review to respond to the material produced by Supplier Sigma1.
- Language is an issue for the Implementer Delta1 partnership with Supplier Sigma1, as it was for Nation Tau working with Nation Alpha and Nation Gamma.
- Implementer Delta1 sought to buy a satellite that would produce data that was high quality enough to sell commercially. This objective is different from the other three countries.

6 Addressing the Research Questions

The previous chapter told the stories of the collaborative satellite projects. This chapter analyzes these stories by defining the architecture of the projects and measuring capability building of individuals and organizations. With this foundation, the chapter also takes initial steps to seek connections between architecture and capability building. This discussion is guided by the five part research question below:

- Research Question 1: What are the Architectures of Collaborative Satellite Projects?
- Research Question 2: How are the Architectures of Collaborative Projects Similar and Different?
- Research Question 3: What Capability Building Opportunities do Individuals Have?
- Research Question 4: What Capability Building Achievements do Organizations Have?
- Research Question 5: What are potential relationships between architecture and capability building?

6.1 Observations in Project Architecture

This section addresses Research Questions 1 and 2, which focus on the architecture of the collaborative satellite projects. These questions build on the analysis approach of defining the projects as social and technical systems made of components which are related by specific structure and functional assignments. Describing the architecture of a system answers the key questions required to understand that system. These are questions such as who is involved, what does the system accomplish, why is the system created, when do major milestones occur, where are the system components, how is the system objective achieved and how many resources does the system consume and produce?

The architecture of an existing system can be defined via the following steps. First, identify the primary stakeholders for which the system is designed to produce value. Second, identify the constraints/opportunities, requirements and objectives of the stakeholders. Third, define the set of functions that are executed to achieve the objectives and requirements while staying within the constraints. Fourth, identify the generic objects of form that execute the functions. Fifth, identify the set of alternatives for specific forms that could potentially be used to execute the functions. The combination of a function, generic forms and specific alternative forms is called a dimension. Each dimension represents a potential decision point for stakeholders. The sixth step is to group the dimensions into categories that represent stakeholder views of the system. The seventh step is to outline how the system changed over time using a timeline of major events. The information required to complete each of these steps is drawn from the narratives of each satellite project that were summarized above. This section uses a structured approach to handling the same data in order to draw out comparisons.

The first steps are to identify the primary stakeholders and their constraints, requirements and objectives. The primary stakeholders for each collaborative satellite project are the Implementing Organizations, Overseer Organizations and Suppliers. The objectives, requirements and constraints are defined by considering these organizations and the context in which they operate. The model in Figure 6-1 highlights the approach to understand each of these areas.

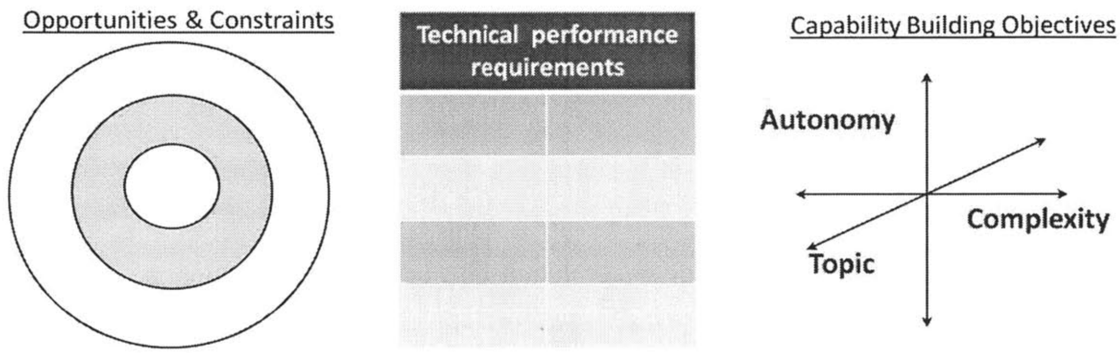


Figure 6-1: Contextual Opportunities and Constraints, Technical Performance Requirements and Capability Building Objectives are all important contextual factors

The constraints and opportunities faced by a system are defined by its context. In Figure 6-1, the Contextual Constraints and Opportunities are represented by a target-shaped diagram showing concentric circles. This represents the reality that context is nested. The satellite project takes place within a particular organization, nation and set of international relationships. There are contextual factors at these and other levels such as individual, small team, large team, organizational network, societal sector, disciplinary sectors, nation, region and world. The factors at the various levels influence each other. Contextual constraints at the level of the implementing organization may be in areas such as personnel, budget, technical heritage, facilities and objectives. A broader contextual level may be the national network of organizations that are stakeholders of the satellite project. The network may include government ministries, national research organizations, firms and academic institutions. Such a network of organizations is impacted by organizational inter-dependencies, communication channels, lines of authority and regulatory issues. Constraints at the level of the national organizational network may also shape constraints at the level of the executing organization. At a higher level, there may be constraints related to the international context. Broad national realities related to foreign policy and trade may influence the satellite project. Historical relationships between countries can come into play, for example. Contextual levels may be defined in other ways as well. A contextual level can be defined as the bilateral relationship between the Implementing Organization and Supplier. Contextual levels may also be defined within an organization, perhaps at the level of a disciplinary team or division.

The requirements for the system are defined here in terms of the technical performance sought by the stakeholders from the project system. For this research, all of the customers purchased a technical package that included at least one optical remote sensing satellite, a new or upgraded ground system for satellite control and image processing as well as some amount of support during launch. Ultimately, the satellite and ground support systems are expected to fulfil a function for earth observation with certain specifications. The mission technical specifications are driven by the characteristics of the data such as spatial resolution, temporal frequency, spectral coverage, volume, processing level and storage approach. The technical performance requirements are represented in the model by a table. Tables of this style are often used to summarize the specifications of satellite systems. The technical performance requirements for the project system relate closely to several stakeholder concerns. First, they identify if there are any needs for information based on societal or scientific questions. Second, they establish the relative importance of technical system performance as compared to capability building goals. Some stakeholders define vague or limited technical performance for their satellite project because they view the capability building aspects as more important. Third, the technical performance requirements place the satellite system in relation to the state of the art. Stakeholders may seek performance near the technical frontier or choose a more conservative technical approach. The requirements also determine whether the system will use existing technology or require development of new technology. In some projects, stakeholders prioritize the development and proving of new technology more than overall system performance.

The objectives are defined as the goals for capability building of people, teams and organizations during the satellite project. A set of axes is used to represent the objectives as a reminder that capability building through the process of technological learning happens in multiple dimensions. The topics that trainees learn during satellite projects may vary from highly technical to managerial to social. The progress may be through advances in complexity or advances in autonomy.

After stakeholders are defined and their contextual constraints/opportunities, technical requirements and capability building objectives are identified, the next step in establishing the architecture of a system is to define the set of functions the project system achieves. Each function is executed by an object of form. At a high level, there is a generic or solution neutral object of form. In each specific instance of a project, a different specific object of form may be chosen. Forms may be physical objects, people, organizations, systems or organizational processes. A project dimensions is the combination of a system function paired with generic and specific forms. The dimensions are categorized into architectural views that that represent key stakeholder concerns. Examples of architectural views include training approaches, timing of the project, technical approaches, facilities and personnel assignments. Within each view there is a series of related dimensions (function-form pairs) of the project. For each dimension, a decision maker selects a particular instance of form from among a broad set of options. These options may be discrete or continuous.

The next sections apply these steps and definitions to answering Research Questions 1 by describing the overall architecture of the collaborative satellite projects under study. The answer to RQ1 shows which architectural views, dimensions, functions and options for form are common to all projects. Research Question 2 considers specific architectural views and compares the approaches that nations used to assign form to function.

6.1.1 Research Question 1: What are the Architectures of Collaborative Satellite Projects?

The first research question asks, "What are the architectures of the collaborative satellite projects?" The approach to answering this question applies the seven steps described above to the group of satellite projects in order to find a common definition of architecture that applies to all of them. This section demonstrates what it means to apply the seven steps to a generic satellite project by applying constraints, requirements, objectives, architectural views and project dimensions to the entire group of projects. The next section answers Research Question 2 by examining examples of the similarities and differences between the project architectures as seen in their contextual factors and architectural dimensions.

6.1.1.1 Architectural Definition Steps One and Two

As discussed above, context is a nested reality that is experienced at multiple levels. Table 6-1 gives examples of constraints and opportunities that impact some or all of the collaborative satellite projects in this study. This set of contextual constraints and opportunities focus on the national level of analysis. In the table, the set of contextual factors are shown that emerged from the case studies. For each factor, three levels of impact are defined, ranging from low to high. The wording for the extent of impact of that factor is modified to fit each factor. The table here shows the generic definition of the constraints and opportunities. They will be applied to the case studies in a later section.

Table 6-1: Examples of Contextual Constraints and Opportunities

Contextual Constraints and Opportunities			
Prior use of remote sensing services on national level	never	sometimes	often
Prior use of communication satellite service by national organizations	never	sometimes	often
National Space Office (during time of project)	no	partial	yes
Past domestic satellite projects	none	few	many
Major space event: Partnership opportunity	no	partial	yes
Major space event: Policy or facility established	no	partial	yes
Key Leader: Overseer Organization	no	partial	yes
Key Leader: Implementing Organization	no	partial	yes
National Vision: Space as part of development process	no	partial	yes

National Vision: Accomplishment in space tech	no	partial	yes
Level of Political Support	low	medium	high
National Space Policy Infrastructure	weak	growing	strong

The first contextual factors address the extent to which satellite services of remote sensing and communication were used in the nation before the collaborative satellite project began. This factor is included because it gives an indication of the nation's experience and capability with harnessing the products of a satellite system. The use of satellite services might mean that the nation accessed remote sensing data from foreign satellites, operated domestic communication satellites or regulated the offering of communication service by foreign firms. In order to effectively apply satellite remote sensing data, the nation needs to access a relevant data source, analyze the data to convert it to useful information, combine the satellite-based information with other types of information, present the results in a manner relevant to a decision maker and distribute the information effectively. If these activities are established in a country before they procure a remote sensing satellite, the same infrastructure and knowledge can be applied to harness the data from the new satellite. If the infrastructure and knowledge to harness satellite data are weak, that will impact the process of applying data from the new satellite. At the same time, the technical expertise required to design, manufacture and launch satellites is distinct from that required to harness and apply satellite services. The people and organizations that have experience with satellite services may understand the capabilities of satellites, but not have the technical knowledge to build them. For the first two contextual factors, a range of never, sometimes and often is used to distinguish between levels of prior use of satellite services.

The next factor considers whether a country has established a national space office during the time of the collaborative satellite project. The term "space office" is purposely chosen to be generic. It refers to any national level, government office that plays a coordinating role related to space research or projects. The office may be a research funding unit, a formal space agency or a committee. The key characteristic of a national space office is that it is established with a focus on the nation's national space policy and programs. Table 6-1 considers three levels of achievement: No, Partial and Yes. Partial implies that the office is forming during the time of the collaborative satellite project.

The contextual analysis captures experience with past domestic satellite projects. This factor tracks whether countries have procured or built satellites domestically. This includes both government and commercial projects, and it is indicated by levels of none, few or many. Also relevant are the occurrence of major events that catalyze space activity. Examples include an invitation from a foreign firm or nation to partner on a space project. Collaborative satellite projects are sometimes initiated in response to such invitations. Another type of catalyzing space event is the establishment of a government policy related to space or the opening of a new facility. Table 6-1 highlights whether such facilitating events occurred before the collaborative satellite project. The national space context is also influenced by the presence of key leaders in both Overseer and Implementer Organizations. Such leaders often play a key role in defining and motivating collaborative satellite projects. A well defined national vision can also influence satellite projects. Leaders within both space organizations and the national government can cast vision that places the space activity as part of larger national progress. A National Vision may also define a goal for the technical accomplishment the country seeks in the area of space technology. Articulating how the space program contributes to a positive national vision is part of the pursuit of political support that is required secure funding for space projects. The level of political support is another key contextual factor that influences satellite projects. Because satellite remote sensing projects require high upfront investment and bring an uncertain return, the level of political support is key to initiated and sustaining satellite programs. Satellite projects can also be high visible to the public, especially during the launch phase of the project. A success or failure in the operations phase can receive intense media coverage and scrutiny from public officials and citizens.

The final contextual factor is the National Space Policy Infrastructure. The policy infrastructure refers to the set of legal, policy or regulatory documents that govern space activity in the nation. The policy infrastructure should specify the responsibility of various government organizations to handle legal and regulatory issues that emerge from space activity. The infrastructure also designates the channels for proposing, approving and funding a satellite project. Potentially relevant documents include the following: 1) a national space policy; 2) a document instituting the national space office; 3) documentation that outlines the respective responsibilities of various government organizations with respect to space activities; 4) national legislation that adopts international space treaties; 5) regulation specifying the responsibilities of the government and private parties with respect to government activity. It is difficult for a nation to operate a satellite without minimal space policy infrastructure. As part of the operation process, a particular government organization needs to be designated as the nation's representative within the International Telecommunication Union in order to process the frequency filing for the satellite. This is true whether the satellite is implemented by the government or a private entity. As part of the launch process, there are liabilities that must be considered and accounted for. The United Nations has drafted several treaties that propose legal approaches to handling liability due to the launch, operation and disposal of satellites. If a nation has ratified these treaties, they have a stronger policy infrastructure to respond to potential liabilities. At times, during a nation's first satellite project, the policies and documents are not in place to specify many of these processes and legal relationships. In such a case many of these issues need to be determined as part of the project. These include issues such as designating the government agency responsible for ensuring compliance with international coordination issues. In this framework of contextual factors, the national space policy infrastructure is shown as weak, growing or strong.

In addition to Contextual Constraints and Opportunities, another defining factor for collaborative satellite projects is the set of technical requirements that the stakeholders (Implementers, Overseers and Suppliers) hope to achieve. Several potential technical requirements that emerged in the case studies are shown in Table 6-2.

Table 6-2: Technical Requirements for Satellite Projects

Technical Requirements			
Timing Objective:			
Fast-paced project	no	partial	yes
Maintain data continuity	no	partial	yes
Technical Performance objectives:			
Medium resolution optical imagery	no	partial	yes
high resolution optical imagery	no	partial	yes
operational imagery	no	partial	yes
commercially viable imagery	no	partial	yes

In some cases, the technical requirements are driven by a timing objective. For reasons driven by context, there may be a benefit to have a face-paced project that is operated quickly. There may be political and training benefits from a short development cycle for a satellite. Designing, building and launching a small remote sensing satellite typically takes one or several years. The timing of the project is heavily driven by the technical approach used. If the satellite design is based on previously used components, the time can be decreased. If the design of the satellite or the payload is new, the time increases. If the Implementing or Overseeing Organizations prioritize a fast-paced project, they are likely to pursue a satellite design based on previously used technology. Even if the Supplier pursues a fast-paced project based on the Implementer's desire, there are factors beyond the control of the Implementer and Supplier that can delay the project. The main factor is the timing of the launch. For any launch, the technical process is complex and there are many potential problems that can cause delays. Launches can also be delayed due to regulatory or legal concerns. Launching is dangerous and has a liability of damage to third parties. If there is doubt about the approach to addressing such liability, the launch can be delayed. Small remote sensing satellites are often launched along with other satellites. They may be launched in a group of small satellites in which every satellite has equal priority. They may also be launched in as a secondary payload with a primary satellite. In the latter case, the primary satellite has clear priority. Depending on the agreement the launch provider has with each satellite owner on a shared launch, there may be interdependencies between the satellites. If a primary satellite has a delay, this can cause delays for all the secondary satellites. If a fast-paced project may be a goal of the primary stakeholders, it has many technical implications. There are also many technical factors that can negate the goal.

Timing may also be important due to a requirement to maintain data continuity. This is especially relevant if a country has operated one satellite in the past or received data from a particular source. Satellites are designed for a certain lifetime. Many satellites exceed their design life, but their performance gradually degrades due to the harsh space environment. The Implementer and Overseer Organizations report to customers that rely on a particular stream of remote sensing data for regular observation of a phenomenon. The initiation or schedule for a project may be driven by the need to maintain the continuity of a data set.

For individual remote sensing satellites, the technical performance is often summarized by a primary figure of merit – the spatial resolution of the images that the satellite can capture. Spatial resolution measures the level of detail that the satellite image provides. It literally refers to the size of the object that can be distinguished from another object. The smaller the size of an object, the better the spatial resolution of the satellite imagery is. Thus, high spatial resolution is captured in small numbers. During the past five decades of space activity, the spatial resolution of civilian optical remote sensing satellite images has gradually improved from measures on the order of kilometers to tens of meters to less than one meter. The spatial resolution of satellite imagery is driven by the type and size of imager the satellite carries and the orbital altitude of the satellite. The spatial resolution of small remote sensing satellites that weighed less than 500 kilograms has gradually improved. In the 1990s it was impressive to achieve "medium" resolution imagery on the order of tens of kilometers. In the 2000s, the resolution has improved to the range of a few meters. There are other technical measures that describe the satellites performance. One is pointing accuracy – measuring the degree to which the satellite can maintain a desired angle with respect to the earth. The pointing accuracy of the satellite is determined by the design of the attitude control system (ACS). The ACS is a set of sensors, actuators and processors that estimate and correct the angle of the satellite with respect to the earth. This is a challenging problem to solve on small satellites because they are highly mass constrained. There is a fundamental tradeoff between including the most effective sensors and actuators and maintaining low cost and mass of the satellite. The pointing accuracy performance is closely related to geolocation capability, which describes how accurately the satellite can define the location on earth to which it points. This capability is valuable when the information is later geographically referenced as part of a geographic information system. Finally, the performance of a satellite for an end user is strongly influenced by the amount of data it can store and transmit to earth. Table 6-2 highlights the requirements to achieve medium resolution imagery (on the order of tens of meters) or high resolution imagery (on the order of meters).

Another aspect of the technical requirements refers to the intended audience. The end user of data from a small remote sensing satellite may be the Implementing Organization, academic researchers, government ministries, firms, individuals or others. Often satellites are designed with a primary end user in mind. If an Implementing Organization plans to be the primary user of data, they may have different standards for the data quality than if they plan to make the data widely available. Two potential scenarios are to seek operational or commercially viable data. Operational data in this case means that the data will be consistent in its technical specifications such that it can be used for routine tasks. This requirement is more attainable if the pointing accuracy, geolocation and resolution are well known and consistently attained. In such a case, the Implementer can supply data to resource managers such as Ministries for Agriculture, Forests, Water Management, Transportation and Urban Planning. The Implementer can guarantee a certain quality of the data and the resource managers can confidently apply the data in their models and maps. Because of their low cost and mass limitations, small satellites are not always designed to provide operational data. Another requirement is to produce commercially viable data that is both high quality and marketable to a wide variety of users. To be commercially viable, data must be produced with high quality and time consistency. The satellite should also take imagery of locations that are in high demand. The technical performance of a satellite may be driven by a desire for particular performance in terms of resolution or a particular target consumer. In some cases, however the technical requirement of a satellite are focused more on the performance of the satellite itself than the payload. Satellites are sometimes flown to demonstrate the performance of a component or provide the engineers with the opportunity to experience the satellite lifecycle. One of the factors that influenced the collaborative satellites in these case studies was the relative importance of the satellite's technical performance versus the capability building objectives. Issues relating to capability building are discussed next.

Table 6-3: Capability Building Objectives are driven by Context

Capability Building Objectives			
Key long term objectives:			
Establish national capability to design and manufacture satellites independently	low	medium	high
Create local high technology work opportunities for the country	low	medium	high
Key short term objectives:			
Learn to procure satellite system	low	medium	high
Engineers participate in building, testing operating mission	low	medium	high
Engineers experience lifecycle from design to operations	low	medium	high
Train engineers enough so they can build satellites with support in future	low	medium	high
Train engineers to effectively operate satellite	low	medium	high
Training Focus Area:			
Satellite Engineering focused	low	medium	high
Operations focused	low	medium	high
Payload Engineering focused	low	medium	high
Focus on academic training via university degrees	low	medium	high

Table 6-3 addresses several capability building objectives that could shape collaborative satellite projects. These examples emerged from the case studies. The objectives are divided into three categories – long term, short term and training focus areas. The long term objectives describe a nation's ultimate goal for their satellite program, with the understanding that it may not be achieved through one satellite project. It is the capability or activity they seek over a series of satellite projects. The short term objectives describe the outcomes they seek for a specific satellite project. The training focus area refers to the type of activity that Implementer, Overseer or Supplier organizations desire to assign to the engineers from the Implementer during the project in pursuit of long and short term objectives. Ideally, the short term objectives and training focus are driven by the long term objectives. The table shows three level of priority that might be placed on particular objectives or focus areas. The priority levels range from low to high.

The long term objectives put forth by nations in this study included establishing national capability to design and manufacture satellites and creating opportunities for local companies to work in high technology areas. These objectives potentially impact both the space community and a broader innovation system. The long term goal to have capability to design and manufacture satellites independently implies several layers of achievement, including training individuals, achieving new organizational capability and establishing physical infrastructure to support the activity. Highly specific infrastructure is required to manufacture and test satellites. The process also requires a diverse team that includes diverse roles and skills. The team includes several disciplines of engineering such as optical, electronic, mechanical, thermal, electronic and software. It also requires managers and technicians with specialized knowledge. The countries explored in the case studies began their journeys with few or no organizations that had experience in satellite design and manufacture. The long term objective to establish satellite design and manufacture capability was thus a significant undertaking. The concept of creating opportunities for local companies to work in high technology areas covers several potential long term strategies. In one scenario, a government organization could serve as the Overseer and contract with a commercial firm as the Implementer. That provides business in satellite engineering for the commercial sector. There is also the opportunity for local firms to serve as suppliers to the satellite activity. Several barriers potentially challenge such a goal. The electronic and structural components used for satellites are often made in small, specialized batches. The required quality level is high and the space environment dictates special approaches. In a country with a small level of satellite manufacturing, it is potentially difficult to establish a flourishing supply chain for local firms to produce electronic or structural components. The small batch levels may discourage suppliers from investing in the specialized techniques. The quality levels may also be outside the normal operating conditions of the manufacturers. A third scenario that could bring opportunities for high technology work in the country is stimulating research in space technology. University researchers may partner with Implementing Organizations or serve as Implementing Organizations. Scientists within universities may be particularly interested in proposing research based on the data collected by satellites or in designing scientific instruments to fly as payloads. Engineers within universities may contribute to research or development on satellite technology. All of these are examples of means to reach the long term goal of creating high technology work activity via a satellite program.

The key short term objectives are outcomes that could be achieved within a single satellite project. The most fundamental objective is to learn the process of procuring a satellite system. Procurement includes defining the technical requirements, selecting a Supplier, defining the contract and accepting the technical product. In a pure procurement, the customer may not do any of the design, development or manufacturing, but they still need to exercise some knowledge of the product and its capability. For a nation that has not operated a satellite previously, there are many challenges in the procurement process. Defining the technical requirements requires an understanding of the capabilities of satellites and the relationship between performance improvements and the needs of the end user. Procurement also involves defining the operational procedures, ground system and launch process with the help of the Supplier. As part of procuring a launch the customer must consider issues such as insurance. The objective of learning how to procure a satellite system that meets national needs is not a trivial achievement. The next two short term objectives focus on the type of training experience the Implementer engineers have while working with the Supplier. These objectives are "Engineers participate in building, testing operating mission" and "Engineers experience lifecycle from design to operations." These are two similar but subtly different objectives. One is for the Implementer Engineers to participate in the late lifecycle stages of building, testing and operating of a satellite. The second is for the engineers to experience the entire satellite lifecycle starting with design. The key difference here is the emphasis on design. The skills required for each phase of the satellite lifecycle – design, manufacture, test and operate – are distinct. In large satellite companies, personnel tend to specialize in one of these areas. A training experience may also be structured to emphasize particular stage in the satellite lifecycle. In the cases under study, these were to stated goals of different Implementer Organizations. Another stated goal was to train engineers to equip them to build satellites in the future with support from a partner. This is an intermediate goal between a full training project and a fully independent project. It could be realized in several ways. An Implementer could partner with a Supplier to build a satellite in the Supplier's facility, or an Implementer could build a satellite in their own facility with technical assistance from the Supplier. The final example of a short term objective that emerged from the case studies was that of training engineers to effectively operate a satellite. This objective could be combined with other objectives as well. The operations team could be a subset of the engineers who are training in other areas or they could be a specialized team that only does operations.

This distinction leads into the last set of potential objectives related to Training Focus Area. Here four potential focus areas observed that could be combined in a variety of ways. The areas include satellite engineering, operation, payload engineering and academic training. A training focused on satellite engineering emphasizes the design, manufacture and test of the satellite bus. Operations focus specializes in the use of the ground system to receive information about the state of the satellite, to receive data from the satellite and to send commands. The operations team requires a basic understanding of how each part of the satellite functions so that they can detect and respond to operational anomalies. Payload engineering focuses on the specialized physics and engineering skills to design, manufacture and test payloads. In this study the primary payloads were optical remote sensing imagers. The payload system included an imager, supporting electronics, supporting mechanical structure and optical assembly. A focus on academic training via university degrees may cover a variety of topics related to satellites, operations and payloads. A satellite training program may emphasize one of these focus areas for the whole team or assign parts of the team to focus in one specific area. That decision may be made by the Implementer or Supplier. The level of priority placed on a particular objective is ranked from low to high.

This section has explored contextual factors that shape the architecture of collaborative satellite projects, including constraints & opportunities, technical requirements and capability building objectives. It has discussed generic definitions and descriptions of these factors. The actual decisions made by nations in this study will be explored in a later section. The next section continues through the steps to define the architecture of a collaborative satellite project by defining the set of functions executed to achieve the objectives and requirements, identifying generic objects of form that execute these functions, identifying alternatives for specific objects of form and combining them with functions to define dimensions, and grouping the dimensions into categories called architectural views.

6.1.1.2 Architectural Definition Steps Three through Six

The discussion above addressed Steps One and Two of defining the architecture of the collaborative satellite projects. The next discussion will show the outcomes of Steps Three through Six. Note that the order of Steps Three through Six is flexible and the process is iterative. In some cases it may be easier or logical to define the stakeholder views before defining the dimensions as sets of functions with relevant forms. Once a set of views is proposed, the dimensions are reviewed to look for additional views that may be relevant. The following discussion shows the outcome of this iterative procedure and explains the rationale and definition of the architectural views, dimensions, functions and forms. Here the dimensions and views are defined inductively by moving from interview data to the structured narratives to tabular summaries that capture consistent information about each project. The set of views is based on the project attributes introduced in the Table 4-3. The original interview questions were defined based on the generic features of systems as described by the Theory of Systems Architecture.

Organizational View

Table 6-4: Dimensions within the Organizational Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Organizational View					
Implementer Organization	*Implementing Satellite Project*	Government-linked Company	National Space Agency	National Remote Sensing Agency	National Research Agency
Overseer Organization	*Overseeing Satellite Project*	Government Ministry	National Space Agency		
Funding Organization	*Funding Satellite Project*	Government Ministry			
Supplier Organization	*Supplying satellite and training program*	Small, university spinoff firm	Medium Firm	Large Firm	
National Space Organization	*Coordinating National Space Activity*	Government Research Office	National Space Agency	National Remote Sensing Agency	National Research Agency
National Space Leader	*Leading National Space office*	Former University Professor	Former Government Bureaucrat		
Implementer Organization Size	*Defining number of people in Implementing Organization*	1 to 50 people	50 to 100 people	> 100 people	
Implementer Visiting Team Size	*Defining number of people that visit Supplier from Implementer*	6 to 10 people	11 to 15 people	16 to 20 people	21 to 30 people
Launch Provider	*Providing Launch Opportunity*	Launch vehicle manufacturer	Launch service provider		
Technical Consultant	*Providing Technical Consultation*	University Professor	Commercial Firm		
Constellation Collaborator	*Contributing to Collaborative Constellation*	Nation	Firm		
Launch Customers	*Sharing launch vehicle*	Nation	Firm	(Primary)	(Secondary)
Ground Station Supplier	*Delivering Ground Support System*	Ground System Firm	System Integrator Firm		
Customer Local Team	*Working on Local Project Aspects*	Primary Operations Team	Satellite Facility Team	Ground Station Facility Team	Management Team

The first view of the project is the Organizational as seen in Table 6-4. This view primarily identifies major functions executed by organizations. It assigns a generic title to the organizations that execute those functions and considers the range of possible organizations that were seen to execute those functions in the case study projects. As defined above, the Implementer Organization performs the function of Implementing the Satellite Project on behalf the nation that commissions it. The generic term Implementer is used through this thesis to describe this role, but several types of organizations play this role in the case studies, including government linked companies, national space agencies, national remote sensing agencies and national research agencies. Each of these specific instances of an Implementer Organization has distinct features. The government linked company stands out as being the only Implementer that operates under a commercial business model. The National Space Agency fills the role described above as the national space office that coordinates national space activity. A space agency may be involved with many types of space activity including research, engineering, outreach and policy development. The National Remote Sensing Agency is concerned specifically with the acquisition and application of earth observation data for the purpose of meeting the data needs of government researchers, universities and potential customers. Remote sensing agencies may not rely on satellite data exclusively. Earth observation data can be collected from satellites, planes and balloons. The stakeholders of a national remote sensing agency are often the government agencies that routinely use geographically referenced maps in their work. A National Research Agency is not necessarily focused exclusively on space activity. The satellite project may be one in a series of research activities that cover a spectrum of projects. Each of these specific instances of an Implementer Organization has a different reason for existing based on their title. Companies exist to generate profit and employment; national space agencies are political organizations that execute government mandates in many areas of space; remote sensing agencies have a specific goal to generate information from data for operational users; research agencies are driven to generate academic or theoretical contributions that may not be driven by profit, policy or operational needs. These contrasts are summarized in Table 6-5.

Table 6-5: Different categories of Implementer Organizations may have different characteristics

Characteristics of Implementer Organizations				
Characteristics	***Government Linked Company***	***National Space Agency***	***National Remote Sensing Agency***	***National Research Agency***
Raison d'être	Generate Profit and Employment	Follow Policy Mandates and Coordinate Government Space Activity	Generate information for data users	Generate academic, theoretical and practical research contributions

The next dimension in Table 6-4 includes the function of Overseeing the Satellite Project. This is done generically by an Overseer Organization. In these case studies, the specific organizations that filled the Overseer role included government ministries and national space agencies. In some cases there was more than one Overseer for a single project. The role of the Overseer Organization varies for each nation. In some cases they serve as the ultimate customer of the satellite, while the Implementer acts on their behalf. In other cases, the Implementer is the customer and the Overseer serves only as the liaison between the Implementer and the national government. In all cases the Overseer plays a role in the funding process of the satellite projects. The role of Funding Organization in these cases was always played by a government ministry. The ministry represented the Implementer in the national funding allocation process and argued for the funding to be awarded for the satellite.

The Supplier Organization executes the function of supplying the satellite and training program to the Implementer Organization. It is significant that in all the case study projects, both the satellite system and the training program were explicitly included in the request of the Implementer to the Supplier. In these collaborative satellite projects, the Suppliers can be divided into three categories: Small university, spinoff firms; Medium Firms; and Large Firms. The categories are significant because they imply several dynamics regarding the size, work environment, technology approach and business models of the firms. In these case studies, the small firms had recently spun out of universities. They were small in terms of personnel, with employees numbering a few hundred or less. When the firms started their work, they shared facilities with the university from which they spun. The firms were begun due to commercialization of the research efforts of space engineering teams. They pursued new approaches to satellite engineering compared to more established firms. They also leveraged their relationship with the universities to hire, pursue joint research and stay involved with recently developed technology. The work culture in the small firms is highly flexible and does not rely heavily on documentation. The small firms tend to work frequently with inexperienced customers and purse high risk projects that are technology experiments. Since the customers are inexperienced, the training components of the contracts are highly important. Later in their evolution, these small spinoff firms became more established medium sized firms. In this stage, the firms have large numbers of employees, numbering several hundred. The work environment gradually grows more structured and documentation is standardized to enable effective communication among the larger team. The projects are a mix of experimental and operational projects that demonstrate both the ingenuity and reliability of the Supplier. The customer base also changes to be more balanced among experienced and inexperienced clients. The training is still important, but its share of the activities diminishes. The medium firms are still connected to university for research and hiring, but they distinguish themselves by establishing their own facilities and activities. In the case studies, there is one large firm that represents the typical aerospace supplier which if commonly found in countries with long histories of space activity. The Large Firm has thousands of employees; managing this large team requires a highly structured environment with highly standardized documentation. The large firm focuses on low risk projects with mature technology for much of its business. They place a medium level of priority on training. Their customer based is a mix of experienced and inexperienced clients. The large firm operates in a series of well established, customized facilities that allow them to take on many projects simultaneously. The characteristics of the three types of Suppliers are summarized in Table 6-6. Note that as the size increases from medium to large, some characteristics such as customer base and training emphasis do not seem to change greatly.

Table 6-6: Differences among Categories Supplier Organizations

Characteristics of Supplier Organizations			
Characteristics	***Small, University Spinoff Firm***	***Medium Firm***	***Large Firm***
Size	~ A few hundred employees or less	A few hundred or more	Thousands of Employees
Work Environment	Flexible, Non-Structured, Loosely Documented	Medium level of structure and increasing documentation	High Structure and Documented
Technology Approach	Experimental and High Risk Projects; Minimal Outsourcing	Mix of experimental and routine projects; Medium Outsourcing	Primarily low risk projects with mature technology; High outsourcing
Customer Based	Inexperienced Customers	Mix of experienced and inexperienced	Mix of experienced and inexperienced
Training Emphasis	High	Medium	Medium
University Relationship	Highly Important	Medium Importance	Low Importance
Facilities	Shared with University or Temporary	Developing	Well established, customized

Returning to Table 6-4 which shows the organizational views, the next few dimensions address potential forms that execute the function of coordinating national space activity and leading the national space office. In some situations, the role of national space organization is played by a national space agency, but in these case studies it is also played by entities that include the government research office, national remote sensing agency and national research agency. The key difference between a government research office and national research agency is scope of activities. The office focuses on funding and coordinating research while the agency executes research in dedicated facilities. Several types of people lead the national space office in these case studies, including former university professors and government bureaucrats who move from another government job to take on this role.

The size of the teams within the Implementers varied over three categories. The entire organization ranged from less than 50 to greater than 100 people. The size of the teams that the Implementers sent as visiting engineers to the Supplier firm fit into ranges from 6 to 30 people. Other key organizations that executed functions in the collaborative satellite project are described in Table 6-4. The Launch provider role was sometimes played by the actual manufacturer of the launch vehicle and in other cases played by a third party launch service provider. In this case, the service provider is the interface between the Supplier and Implementer on one hand and the Launch Vehicle Manufacturer and Operator on the other. In some cases a Technical Consultant provided consultation to the Implementers and Overseers. Both university professors and commercial firms provided this function. In several projects, the Implementer joined additional nations and firms to form a constellation of satellites with common characteristics. In these cases, the role of Constellation Collaborator was relevant. Most of the satellite shared a launch vehicle with other small satellites in order to save money. The other Launch Customers interacted with the Implementers as part of the launch process. In some cases, the Suppliers did not manufacture ground stations and separate firms played the role of Ground Station Supplier. These firms or the Suppliers sent representatives to participate in the installation of the Ground Station in the Implementer's nation. Finally, this analysis emphasizes the role of the Implementer team that works at the site of the Supplier during the satellite development process. There is also a team of Implementer engineers and managers that works primarily at the site of the Implementer. They work on local projects aspects, including preparing for operations and harnessing the satellite data. There are several potential versions of Customer Local teams that focus on operations, facilities or management.

This concludes the discussion of the Organizational View of the collaborative satellite projects. Specific attention was given to the differences in specific forms for the Implementer and Supplier Organizations. These differences will be relevant to later discussion.

Project Initiation View

Table 6-7: Dimensions within Project Initiation Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*					
		Project Initiation and Approval View					
Project Leader	*Appointing Project Leader*	New Leader	Existing Leader				
Organizational Appointment	*Appointing Implementing Organization*	Founding new government organization	Appointing existing government organization	Founding new company	Appointing existing company		

This view explores key functions that facilitated the initiation of the collaborative satellite projects. One function was appointing a leader for the satellite project, who may sit within the Implementer or Overseer Organization. Two modes were found in the case studies – either appointing a new leader or the continued presence of an existing leader. Similarly, the initiation of some projects involved establishing new organizations, either in the government or commercial sectors.

Personnel Management View

Table 6-8: Dimensions within Personnel Management Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*				
		Personnel Management View				
Engineer Selection Organization	*Selecting Engineers for Training*	Implementing Organization	Implementer and Supplier			
Engineer Recruitment Source	*Defining Selection Pool*	Experienced Academics	Military Representatives	Experienced Industry Professionals	Recent Graduates & Young Professionals	National Citizens
Engineer Recruitment Process	*Announcing Training Opportunity*	Network with universities	Coordinate with Military	Advertise with media	Use personal networks	Recruit among expatriate community
Engineer Evaluation Process	*Evaluating Engineers for Training*	Application	Interviews	Tests		
Hiring Time Horizon	*Defining Hiring Time Horizon*	Duration of Project	Project and Long Term	Long Term Employment		
Engineer Role Selector	*Selecting Training Roles for Visiting Engineers*	Implementer	Satellite Supplier			
Role Assignment Philosophy	*Guiding placement of engineers in technical roles*	Assign each person to multiple areas; cover many areas	Assign each person to one specific area	Assign each person to a strategic area; cover few areas		
Post-Training Assignment	*Assigning Engineers to Positions after Supplier Training*	Pre-project organization	Implementer Organization	University in Supplier Country	New Project at Supplier Organization	New position outside Implementer Organization

The Personnel Management View, like the Organizational View, has a large collection of dimensions. These functions determine the policies used by the Implementer to recruit, evaluation, select and hire engineers that were part of the team sent to work at the Supplier location. The first dimension specifies which organization plays the role of Engineer Selection. In some cases the Implementer performs this alone; in other cases the Supplier is also involved. The next dimension defines the target population from which the Selection Organization seeks candidates for the selection process. Potential populations include experienced professionals in the military, academia or industry or recent graduates and young working professionals. There may also be a citizenship requirement for the candidates. The third dimension defines the process by which the training opportunity is announced to potential engineers. This Engineer Recruitment Process took the form of networking with universities, coordinating with the military, advertising with media, using personal networks and recruiting among the expatriate community. Clearly, the choice of target population influences the type of recruitment process. After recruitment comes the function of evaluating the engineers to select the appropriate group for the training experience. The evaluation tools included applications, interviews and tests. The Implementer Organizations hired engineers for different time horizons and with different purposes. One scenario was to only hire for the duration of the project; a second was to hire for the purpose of the project with the assumption that the engineer would continue employment with the Implementer after the project; a third scenario was to hire outside the context of the project and select from among long term employees to find engineers for the training experience. Once the engineers are hired in the Implementer Organization, there is another selection process to define what technical specialty each engineer will focus on during the training. The function of Selecting Training Roles was implemented by some combination of the Implementer and the Satellite Supplier. The role assignment was done according to a Role Assignment Philosophy. One philosophy sought to cover many areas by assigning each person to multiple topics. A second philosophy sought to assign each person to one, focused area; in this case the number of topics was limited by the size of the team. A third philosophy chose a few strategically important topic areas to cover and only assigned people to these areas. In this case, the number of topics covered may be less than the number of people in the team.

The final function of the Personnel Management dimensions is to assign engineers to a role after their training when they return to their home nation. The engineers may not continue in the exact activity they worked on in the Supplier site if the Implementer does not have facilities or projects to support this. If the Hiring Time Horizon is defined as the duration of the project, the engineer may return to the pre-project organization after completing training with the Supplier. If the Hiring Time Horizon is for long term employment with the Implementer, they may return immediately to that site. Other potential post-training assignments include studying at a university in the country of the Supplier, continuing at the Supplier for a new project on behalf of the Implementer or pursuing a position in a new organization. The approach taken by the Implementer to define the Post-Training Assignment of their engineers is critical to the process of long term building organizational capability. Each potential post-training assignment has a different impact on the organizational capability of the Implementer. If the engineer returns to their pre-project organization, they may not directly contribute to the Implementer's work, but they can spread the knowledge they learned in their home organization. This is especially relevant if the home organization has a mechanism to harness the training that the engineer received through relevant projects or academic instruction. If the engineer continues their study at a university and remains part of the Implementer team, they may be able to deepen their individual knowledge in a particular discipline and use that in future projects with the Implementer. If the engineer continues in a new project at the Supplier Organization, the advantage is that they will build immediately on what they learned in the previous project and continue to fine tune their skills. This will ideally lead to an increased level of responsibility and autonomy in the engineer's work. Finally, if an engineer moves to a new position outside the Implementer Organization their skills and training is lost the Implementer. They may be able to contribute to another relevant organization in the same nation, but their impact on organizational capability building is lost in the short term. In the long term, if they return to the Implementer Organization with skills sharpened by other work environments, they could be an even stronger engineer and contribute greatly. The decision makers who define the Personnel Management approaches for the Implementer face challenges in finding appropriate policies and incentives to guide each step of the process. They need to attract appropriate candidates, select the best among the pool and assign people to roles where they can thrive. After training, they need to find incentives for the engineers to remain in the Implementer Organization and build it up. Often, in early projects, the Implementer Organization is not well established and their work portfolio is uncertain. This situation sometimes leads engineers to pursue opportunities outside the Implementer Organization after their training at the Supplier is complete.

Supplier Selection View

Table 6-9: Dimensions within Supplier Selection Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*					
Supplier Selection View							
Supplier Selection Process	*Choosing satellite supplier*	Choose personal acquaintance	Join invitation for collaboration	Call for selective Tendering	Hire Consultant to Review	Open Call for Proposals	Travel to tour international suppliers
Priority Supplier Attributes	*Differentiating among suppliers*	Technical performance and flexibility	Training package	Space heritage	Price	University Relationship	Schedule
Competing Suppliers	*Competing for Supplier Contract*	Government Space Agencies	Small Commercial Firm	Medium Commercial Firm	Large Commercial Firm	State Owned Enterprise	
Launch Provider Selector	*Selecting Launch Provider*	Customer	Satellite Supplier	Consultant			
Competing Launch Providers	*Competing for Launch Contract*	Government Space Agency	Established Commercial Firm	Start up Commercial Firm			
Priority Launcher Attributes	*Differentiating among launch providers*	Technical constraints and	Price	Geography	Multi-satellite Capacity	Implementer Familiarity with	New Launch Supplier

		Performance				Supplier	

The Supplier Selection View includes six dimensions that capture the functions by which the Implementer and Overseer Organizations choose partners from whom to procure the satellite and launch services. The first three dimensions in the Supplier Selection View determine which Supplier is selected to provide the satellite system and the training services. The choice of Supplier depends on the set of Competing Suppliers, the Priority Supplier Attributes and the Supplier Selection Process. Potential approaches that are used in these case studies to select suppliers include choosing a supplier represented by a close personal acquaintance of a leader from the Implementer team; responding to an invitation from the supplier for collaboration on a project; inviting specific suppliers to prepare proposals in a selective tender; holding an open call for proposals; and traveling to tour the facilities of suppliers in many countries. As part of any of these strategies, the Implementer may also hire a consultant to review the potential suppliers and their proposals. Within these options some are highly structured and formalized (call for selective tendering, open call for proposals, international tour of suppliers); others rely more on informal, personal relationships. What might determine the process that is used to select the Supplier? Sometimes there are contextual opportunities or constraints that lead to a particular Supplier Selection Process. The political climate surrounding the satellite project, the experience and perspective of key leaders in the Implementer and Overseer Organizations, the space policy infrastructure and the national vision may all shape the Supplier Selection Process. A formal, structured process might be used in a context characterized by ample space policy infrastructure and a political climate that treats space projects with the same priority level as other national infrastructure projects. In such a scenario, leaders may find it important to hold a selection process that exhibits rigor, lack of personal bias and due diligence. The selection process may also need to follow guidance put forth in space policy documents. Such a formal process is easier to achieve when the Implementer has experience that helps them structure the process or when they work with a consultant that can help structure the process. When an Implementer holds a call for selective tendering or an open call for proposals, they need to generate appropriate Requests for Proposals. This process requires some technical understanding of the requirements and operations concept for the satellite system. An informal Supplier Selection Process – such as choosing based on personal relationships or responding to an invitation for collaboration – may be preferred in other cases. If the political climate is highly supportive, if there is limited guidance from space policy documentation, or if key decision makers have little experience, an informal relationship may be pursued. The political support coupled with the limited policy guidance implies that there are not strict constraints directing leaders to follow a particular Supplier Selection Process. The lack of experience for the decision makers implies that they will need to choose a Supplier that they trust to provide helpful advice and technical support during the satellite procurement and training process.

The function of Differentiating among Suppliers is performed generically by the Priority Supplier Attributes. In addition to choosing a process by which to select the suppliers, decision makers choose reasons for preferring one supplier over another. This preference may be exercised explicitly or implicitly. In a formal selection process based on calls for proposals, it is more likely that decision makers representing the Implementer formally define the attributes they value in a potential supplier. If an informal selection process based on personal relationships or an invitation for collaboration, there may be no documentation or definition of specific supplier attributes that are valued. After the fact, decision makers from the case studies identified several attributes that they valued in their Suppliers. These included the technical performance of their products; the level of technical flexibility of the Suppliers; the training package; the space heritage or experience of the suppliers; price; the relationship between the supplier and a university; and the proposed project schedule. Several of these attributes are explained further. The concept of technical flexibility refers to the set of technical options the Supplier offered and their willingness to develop new technology as part of the satellite project. A Supplier with low technical flexibility would propose to use technology that they had previously developed and tested in space; such a strategy reduces the risk of technical failure. Low flexibility may also mean that the Supplier has a pre-defined menu of combinations of satellite buses and payload. They develop new missions by mixing and matching among this menu, but they are hesitant to go beyond this range. A Supplier with high technical flexibility may also have a menu of commonly used technologies and combinations of satellites with payload. If they are flexible, however, they are willing to develop new technology and make alterations to their existing technical approaches. Such flexibility often increases the price and technical risk of the project. The term "space heritage" is used in the aerospace community to describe the level of spaceflight experience for organizations and technology. In the case study projects, the space heritage of the potential suppliers had two meanings. On one hand, it could refer to the overall experience of the firm with satellite projects of any kind. On the other hand, some Implementers were interested in the heritage of the Suppliers specifically with small satellite projects that were built with a non-traditional engineering philosophy. For Implementers that emphasized the relationship between the Supplier and a university, the concern related to either the opportunity for academic training from the university or to the research collaboration between the firm and university.

The Priority Supplier Attributes were applied either implicitly or explicitly to select from the set of potential suppliers – indicated here as Competing Suppliers that are seeking the Supplier Contract. In the case studies, the types of organizations that Implementers considered as Suppliers included government space agencies, small commercial firms, medium commercial firms, large commercial firms and state owned enterprises. The marketplace of organizations that sell small remote sensing satellites is small enough that it is feasible for an Implementer to give consideration to virtually all potential suppliers that have experience. The Competing Suppliers are located in the North America, Europe, Africa, Western Asia, Central Asia and East Asia. As discussed above in the section on the Organizational View, the different types of suppliers have different operational and business models depending on their context.

The last three dimensions within the Supplier Selection View focus on choosing a launch provider. The first function is to select a launch provider; this is done by various actors including the Implementer/Overseer (as Customer), the Satellite Supplier and the Consultant that supports the Implementer. The set of potential launch providers is also small and well known among the space community. Launch vehicles are manufactured and operated by a few government agencies and a few firms around the world. In some cases a Launch Service Provider acts as a liaison between the customer and the launch system operator. In these case studies, the Competing Launch Providers included government space agencies, more established commercial firms and a start up commercial firm. The appearance of start up space companies is a relatively recent phenomenon in the space marketplace. They play a similar role in the launch market that university spinoff firms play in the satellite market. There is a new community of launch vehicle manufacturers that seek to lower the cost of launching objects and people into space. Some of these new companies are founded and sponsored by independently wealthy entrepreneurs. This is in contrast to traditional launch vehicle manufacturers who had all their initial funding from governments. The new launch vehicle firms question traditional engineering approaches and seek to engage new markets while continuing to address government needs. The final dimension refers the function of differentiating among the competing launch providers which represent three different types of organizations. In these case studies, Implementers were concerned with the following attributes: technical constraints, technical performance, price, geography, multi-satellite launch capacity, familiarity and the newness of the supplier. Several of these warrant further discussion. The technical constraints of the launch provider refer to the requirements to integrate the satellite into the vehicle. Each rocket has a unique mechanical and electrical interface with the satellites it carries. Each rocket also has a unique set of hazards to the satellite in the form of vibrations and acoustic impact during launch. The intense sound and structural vibrations generated during can damage satellites if they are not build and tested to withstand them. The technical performance of the launch vehicle refers to the amount of mass the rocket can carry into space as well as the reliability of the rocket. Launching satellites into space remains a highly technical process with a high chance of failure. Some Implementers may value a potential launch provider with a long history that demonstrated their reliability record. The geography of the launch provider's facility is important due to the dynamics of satellite orbits around the earth and safety concerns. Some locations on earth are convenient for particular orbits. Most small remote sensing satellites fly in a polar orbit that takes them over the North and South Poles many times each day. Another potential orbit for a small satellite is to fly over the equator. The geography of the launch facility strongly impacts the amount of fuel and energy that is required to put a satellite into orbit. The launch process is generally tightly constrained in terms of having enough energy to lift the mass of the satellites into space. In order to launch a satellite into a polar orbit, it is convenient to be relatively far north or south of the equator. In order to launch into any equatorial orbit, it is convenient to launch close to the equator. The specific terrain near a launch facility is also important. For safety reasons, it is preferable to launch over water or over a large area of uninhabited land. In the case of an accident, the goal is to reduce the possibility that parts of the rocket damage property or injure people. Thus geography is a key consideration as part of launch provider selection. Another attribute is multi-satellite capacity. This refers to the ability of the launch vehicle to carry multiple satellites simultaneously and deliver them to the relevant orbits. When small remote sensing satellites are launched, Implementers often seek to save on the launch costs by sharing a launch. Also, if a group of satellite owners choose to operate their satellites in a collaborative constellation, it may be convenient to purchase launch services together on a multi-satellite vehicle. If a launch vehicle was originally designed to carry one large satellite, technical modifications may be required to adapt it to carry multiple smaller satellites. In another scenario, a launch vehicle may carry one large satellite and be adapted to also carry one or more small satellites.

Facility View

Table 6-10: Dimensions within Facility Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Facility View					
Supplier Facility Status	*Defining Supplier Facility State*	Temporary	Transitional	Purpose-Built	
Implementer Facility Status	*Defining Implementer Facility State*	Temporary	Transitional	Purpose-Built	
Implementer Facility Type	*Enabling Implementer Activity*	Data Reception	Satellite Operations	Satellite Integration and Test	Optical Laboratory
Satellite Control System Operator	*Controlling Satellite*	Implementing Organization	Overseer Organization	Satellite Supplier	
Satellite Reception System Operator	*Receiving Satellite Data*	Implementing Organization	National Remote Sensing Center (non-implementer)	Satellite Supplier	Commercial Antenna Farm
Satellite Environmental Test Facilities	*Hosting Satellite Environmental Tests*	Satellite Supplier	Government Research Organization	Commercial Firm	

The Facility View includes the project functions that relate to the evolution and operation of facilities. Facilities that provide infrastructure for design, manufacture, test and operation of satellite systems are vital to project success. The first dimension relates to the status of the Supplier's facility during the time of the project. As discussed above, the Suppliers were in various stages of organizational evolution and their level of facility infrastructure reflected this. This was paralleled by the experience of the Implementers. Early in their existence both Suppliers and Implementers worked in Temporary Facilities. These were work spaces that were not designed for the specific needs of the organizations; they were small and had little or no hardware laboratory work space. The temporary facilities were sometimes shared with other organizations or rented. Later, both Implementers and Suppliers moved to Transitional Status. In this phase they started to establish their own facilities in a gradual process. They pursued the process of defining their facility needs, raising funds, hiring partners and implementing the new buildings. After this process, they arrive in the status of having Purpose-Built facilities. These are facilities in which the size, equipment, work areas and location are designed to meet the needs of the organization. The three status options are used to represent the condition of facilities for the majority of the time during a given satellite project.

The Implementers in the case studies established different types of facilities to enable their activity. The potential facilities included data reception systems to accept imagery data delivered by the satellites; operations facilities to send commends and receive status data about the satellite; satellite integration and test facilities to work on components of the satellite; and an optical laboratory to test and calibrate an imager system. Calibration is particularly important if the Implementer has the goal of producing operational data.

The next three dimensions under the facility view specify which project actor takes on the role of controlling the satellite and receiving data and hosting satellite environmental tests. Each of these functions is required in every satellite project. The functions can be executed by one or more organizations. Also, each function requires installation and operation of appropriate facilities. The facilities for controlling a satellite include an antenna and computer system with relevant specifications matched to the satellite. Satellite control facilities are sometimes co-located with facilities that receive the satellite data. The characteristics of the antenna that receive data from the satellite are sometimes different from the antenna that send and receive control information. The function of controlling the satellite requires sending commands that tell the spacecraft when to take images and that make adjustments to the satellites operations. Controlling also includes receiving information about the operational status of the satellite to ensure that it is functionally properly or to diagnose problems. The amount of information that is sent and received for controlling is much smaller than the amount that is received as imagery data. For this reason, the specifications of the control antenna are often different from those of the data reception antenna. The data reception antenna typically needs a higher data bandwidth or reception rate. The reception function is only a one way transmission whereas the control function is two way. There are many options of how to configure the control and data reception stations. There are also options with regard to what type of organization plays the role of Satellite Control Systems Operator or Satellite Reception System Operator. In these case studies, the Control System Operator role was played by the Implementing Organization, Overseer Organization and Satellite Supplier. If the Supplier has access to control the satellite, they remain a close partner with the Implementer beyond delivery of the satellite into orbit. The organizations that play the role of Satellite Reception System Operator include the Implementer, National Remote Sensing Center (which was not the Implementer), Satellite Supplier and Commercial Antenna Farm. The commercial antenna farm refers to companies that offer the service of hosting antennas that are in a favorable geographic location and provide additional opportunities to send or receive data to satellites. Most small remote sensing satellites are flown in polar orbits. The nations that bought these satellites are all located far from the polar regions. These nations can only communicate with their satellites when the spacecraft pass directly over their stations several times per day. The satellites in polar orbit pass over commercial antenna farms located near the north and south pole many times per day. The business model of the commercial antenna farms is to serve many customers by allowing them to send and receive data when their satellites pass the poles. They transmit the information from the satellites to the Implementers electronically. This greatly increases the opportunity to download data, which opens more space in the satellite's limited data storage.

The function of hosting satellite environmental tests implies owning and operating specialized equipment that simulates the environment that a satellite experiences in earth orbit. Satellite test facilities include special machines to expose the spacecraft to intense temperature extremes, low pressure, high noise levels, vibrations and heavy force loadings. Other tests might be done to determine the specific structural characteristics of the satellite, such as the location of the center of mass, and to ensure that there is no electromagnetic interference among satellite components. In some cases, Implementers and Suppliers do not maintain all of these specialized facilities in their own locations, especially when they are in the temporary facility status. The test facilities can be sized to accommodate entire spacecraft or components. In these case studies, the test facilities were owned and operated by Satellite Suppliers, Government Research Organizations (in the Supplier nations) and commercial firms (that were not the primary Suppliers). Some of the satellites in these cases were tested in multiple environmental test facilities.

The Facility Architectural captures a key aspect of satellite projects because such facilities are necessary to decrease risk of technical failure, however they are very expensive to install and maintain. The facilities also required specially train technicians to operate.

Training View

Table 6-11: Dimensions within Training Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Training View					
Training Preparation Time	*Defining time engineers spent at Implementer before going to Supplier*	Weeks	Months	Years	
Training Preparation Approach	*Defining level of coordination for training preparation*	Individual Situations	Coordinated Group Approach		

Training Preparation Activities	*Preparing Engineers for Training*	Satellite Lectures	Technical Lectures	Mentors from Implementer	Independent Study
Training Transition Team Size	*Defining number of engineers that transition to Supplier together*	Individuals	Small Groups	Large Groups	
Training Schedule	*Defining time spent in training with Supplier*	Weeks	Months	Years	
Training Project Phase	*Defining project phase that trainees experience*	NASA Phase A	NASA Phase B	NASA Phase C	NASA Phase D
Theoretical Training	*Providing theoretical training to Engineers*	Technical satellite lectures	University Degrees	License to Technical Documentation	Non-technical training lectures and conferences
Practical Training	*Providing Practical Training to Engineers*	Group Mission Design Exercise	Skill-based training courses	Technical demos	Language classes
On the Job Training	*Providing On the Job training to Engineers*	On the job tasks under mentor	Building a training satellite		
Academic Trainer	*Providing Academic Training*	University Department	Individual Professors		
Certification Provider	*Providing Professional Certification*	University	Individuals		
Mentor-Trainee Meeting Approach	*Defining level of formality for mentor-trainee meetings*	Regular Informal Meetings	Regular Formal Meetings		
Mentor-Trainee Accountability System	*Defining level of formality for mentor-trainee accountability*	Informal System	Formal System		
Mentor Work Plan	*Defining the type of work plan by Supplier Mentor for Trainee*	Informal Work Assignments	Plan based on Training Program	Plan based on Project	
Supplier Guidance to Mentors	*Defining formality of guidance from Supplier to Mentors*	No Guidance	Informal Guidance	Formal Guidance	

Within the Training Architectural View are several categories of related dimensions; together this view characterizes the training experience of engineers from the Implementer Organization while they work at the Supplier Organization. The first set of dimensions addresses the functions related to the transition from the Implementer Organization to the Supplier Organization for training. Before engineers from the Implementer Organization are sent for training at the Supplier Organization, they may spend time in preparation at the Implementer Organization. The Implementer Organization in some cases creates a structured preparation experience. The length of time that engineers spend in the Implementer Site is often influenced by the Hiring Time Horizon dimension. If engineers are employees of the Implementers and they have already been working, they may have years of experience before going to the Supplier site. If engineers are hired specifically for the project, they may only work at the Implementer site for weeks or months before transitioning for the training. This is captured in the Training Preparation Time dimension. The next function defines the level of coordination that characterizes the time between hiring and departure for training. The training preparation approach may be highly individualized or coordinated. A coordinated approach might arrange group training or enrichment activities, whereas individual situations leave the engineers to define their own preparation plan. Some of the Training Preparation activities that Implementer Organizations provided in the cases include lectures on satellite technology, lectures on other technical topics, assigning mentors for the engineers from the Implementer and promoting independent study. The study topics were diverse. In some cases, the engineers could study technical documents from previous or current Implementer projects. In other cases, they focused on theoretical material such as textbooks. The engineers did not always know beforehand the satellite engineering specialty in which they would receive training. When they had this knowledge, it could guide their independent study. Finally the Training Transition Team Size defines the number of engineers that transition to the Supplier together. Implementers executed this function in various ways, sometimes sending individuals, small groups or the entire training group. The arrival order and team size tended to influence the type of reception provided by the Suppliers. If a large team arrived at once, the Suppliers planned a formal, structured welcome. If individuals or small group arrived in a staggered fashion, the Suppliers tended to have less orientation activities because it was harder to repeat them for each arrival.

The second set of related Training dimensions includes two functions that define how long the engineers are at the Supplier location and the phase of the project that the engineers experience. The Training Schedule dimension defines the time that the Implementer Engineers spend working at the Supplier site for training. The main engineering teams spend months or years in order to experience the majority of the work on their satellite. In a few cases, engineers that are generally stationed at the Implementer site spend a few weeks at the Supplier site for short term training. The Training Project Phase defines which part of the satellite project lifecycle the Implementer engineers experience. The options are labeled as phases of NASA's generic satellite lifecycle, which can be applied to most satellite projects. NASA Phase A is the conceptual design phase in which the needs of the customer are identified and translated into technical requirements that will drive the design. Based on these requirements an overall concept for the mission is proposed. Phase A also determines the feasibility of the project and finds whether new technology needs to be developed to achieve it. NASA Phase B is the preliminary design phase during which an initial detailed design is developed. NASA Phase C is the detailed design and fabrication stage in which the subsystems are fully designed and manufactured. NASA Phase D includes System Assembly, Integration, Test and Launch. The subsystems that were manufactured in Phase C are assembled into the complete satellite. The interfaces of the full satellite system including spacecraft, payload and ground station are integrated. The satellite is tested to ensure it can survive launch and the orbital environment. Finally, it is launched. The Training Project Phase Dimensions defines which of these experiences the Implementer engineers share while at the Supplier location or launch facility.

The third set of training dimensions capture the activities that are implemented by the Supplier to provide theoretical, practical and on-the-job training. These three categories are defined to be compatible with later discussions on individual capability building experiences. Theoretical Training includes satellite lectures, university degree programs, a license to access technical documentation, non-technical lectures and attendance at conferences. These are theoretical in the sense that they provide knowledge about satellite engineer but are not applied activities. The non-technical lectures include enrichment presentations provided by some Suppliers in areas such as leadership, communication and time management. Practical training allowed engineers to apply knowledge to specific tasks. The practical activities include a Group Mission Design Exercise, Skill-based training courses, technical demonstrations and Language Classes. The Group Mission Design Exercise is a tool used by several Suppliers to give the group of Implementer Engineers a challenging opportunity to practice satellite engineering. Each engineering team is given the task to design a satellite mission based on a set of requirements as if they are a Supplier. The skill-based training courses are counted as applied because they emphasize the practical aspects of executing a task such as soldering electrical components or using a software tool. Technical demonstrations are applied because they involve explanations of how to use hardware or facilities to accomplish tasks. In some case studies, language classes were relevant because the Suppliers and Implementers did not speak the same first language. In such a case the language could be a highly relevant skill to apply as part of the training experience. On the Jon Training (OJT) includes all the activities that the engineers participate in to directly execute satellite engineering tasks. Some of this training is done as assignments working for or with a mentor. The OJT experience also includes building a training satellite for some Implementer teams.

The fourth set of training dimensions highlight the types of organizations and individuals from outside the Supplier Organization that provide academic and professional training. The Supplier

Organizations provide the majority of the training, especially the On the Job aspects. For some of the academic and skill-based training courses, however, Suppliers hired specialists. They partnered with Academic trainers from universities, either by making an agreement with an engineering department or by inviting individual professors. Some Suppliers also hired Certification Providers to execute courses in areas such as soldering where there are industry standards for training. Both universities and individuals played the role of Certification Providers.

The fifth set of training dimensions characterizes the relationships between the Implementer Engineers and their mentors from the Supplier Organization. In all the case studies, the Suppliers followed a model of assigning each Implementer Engineer to work under the guidance one specific mentor. The Suppliers varied, however, in how they defined the Mentor-Trainee Relationship. The Mentor-Trainee Meeting Approach defined the formality of the meeting schedule. Most mentors met with their trainees regularly, but some established a formal schedule whereas others talked whenever issues arose. The Mentor-Trainee Accountability System defined the level of formality that the Supplier Organization encouraged mentors to use to guide their trainees. As indicated in the final dimension, some Suppliers encouraged highly formal systems with documentation of goals, milestones and assignments. Other Suppliers provided no guidance or encouraged an informal system for accountability. A similar pattern is seen in the function of the Mentor Work Plan. These covered three categories: 1) informal work assignments that were decided gradually; 2) a well defined plan based primarily on practical and on the job training; and 3) a work plan that was based on assigning the engineer to work on deliverables required to complete the project.

The Training Project Phase, the Mentor Work Plan and the three types of training activities specified above (Theoretical, Practical and On the Job) show the range of training experiences provided by the Suppliers to the Implementer Engineers. During each phase of the satellite project lifecycle very different activities take place. To the extent that the training is driven by the satellite project, the phase has a strong impact on the training activities. The three types of training all lead to different experiences, and the mentor approach will also play a strong role. Individual engineers, even from within the same Implementer team, may have different experiences based on the combination of training factors they experience with regard to Phase, Mentor Approach and Training Activity Types. This is demonstrated later in the discussion on Capability Building.

Contract View

Table 6-12: Dimensions within Contract Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*

Contract View							
Supplier Contract Contents	*Defining Contract between Implementer/ Overseer and Supplier*	Satellite	Training	Ground System	Launch Services	Intellectual Property License	Pre-launch Data
Launch Provider Contract Contents	*Defining Contract between Implementer/ Overseer and Launch Provider*	Exclusive Satellite Launch	Shared Satellite Launch				
Contract Signatory	*Signing contract on behalf of implementing nation*	Government-linked Company	Government Ministry	National Space Agency	National Research Agency		

The Contract View provides a limited set of information about the contract used by the Implementer to define their relationships with the satellite Supplier and Launch Provider. The Supplier Contract Contents defines what is included in the contract between Implementer or Overseer and Supplier. The potential items that may be included are the procurement of the satellite system, a training package, the ground support system (including hardware infrastructure and software), launch services (to negotiate and interface with a launch provider), a license for access to intellectual property and access to data similar to what the Implementer satellite will produce before launch. The decision of whether to include a license for access to intellectual property depends on the Supplier's posture toward their proprietary technology. The license can be crafted in different ways. Some licenses grant access for the customer to view and use the technology for internal activities, but not to pursue any external or business activities. Other licenses grant full use to appropriate the technology. Examples of both scenarios occur in these case studies. The Launch Provider Contract Contents may include an exclusive satellite launch or a shared satellite launch. Many of the small remote sensing satellites developed in these case studies share a launch, which reduces cost. The advantage of being the exclusive customer is having control over the schedule and reducing the risk of technical challenges from the other satellites. The choice of pursuing an exclusive satellite launch or shared launch is influenced by the desired orbital destination and the type of launch provider. The Contract Signatory signs the contract on behalf of the Implementing nation. In the cases this role was played by the government linked company (as Implementer), the government ministry (as Overseer), the National Space Agency (as Implementer) and the National Research Agency (as Implementer).

One dimension that is not included here due to lack of consistent data is an indication of the type of contract used by the Implementers. One Supplier, for example, prefers to use fixed price contracts, which put risk on the Supplier to maintain the product and schedule once the price is agreed upon. Traditional aerospace suppliers use contract types that place more risk on the customer, such as cost-plus. A cost-plus contract pays the Supplier for any costs they incur plus a fixed percentage of profit. The type of contract certainly influences the incentives for Suppliers as they management cost, schedule and technical risk throughout the project. Future research can investigate this in more detail.

Technical Product View

Table 6-13: Dimensions within Technical Product Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*				
Technical Product View						
Satellite Mass	*Defining mass of satellite*	Less than 100 kilograms	100 to 300 kilograms	301 to 800 kilograms		
Satellite Design Life	*Defining design life of satellite*	3 years	5 years	7 years		
Payload	*Delivery satellite service*	Communication payload	Low resolution imager (100s of meters)	Medium resolution imager (10s of meters)	High resolution imager (meters)	Science Payload
Data Downlink Band/Rate	*Defining speed of data delivery*	UHF (Slow)	S-band (med)	X-band (fast)		
Power Capacity	*Defining power generation capacity of satellite*	0 to 100 Watts	100 to 400 Watts	> 500 Watts		
Onboard Storage	*Defining amount of data storage on satellite*	64 Megabytes	1 Gigabyte	16-65 Gigabytes	128 Gigabytes	
Pointing Error	*Defining level of pointing error by satellite*	order of +/- 1 degree	+/- 1/10 degree			
Orbital Altitude	*Defining orbital altitude of satellite*	600 to 700 kilometers	>800 kilometers			
Orbital Inclination	*Defining orbital inclination of satellite*	Polar	Equatorial			
Satellite Shape	*Defining*	Cube	Hexagonal Prism	Heptagonal Prism		

	satellite outline					
Structural Arrangement	*Supporting satellite systems*	Central stacked trays	Support from outer walls	Supportive decks connected with beams	Central payload surrounded by subsystems	Stacked payload, above subsystems
Attitude Control Actuators	*Adjusting attitude of satellite*	Gravity Gradient Boom	Electromagnets	Reaction Wheels	Magnetorquer	Gyros
Solar Panels	*Generating power from sun*	Body mounted solar panels	Deployable Solar Panels			
Batteries	*Storing power from solar panels*	Nickel Cadmium Batteries	Lithium Ion Batteries			

The Technical Product Architectural View captures the technical performance of the satellite and key characteristics. The first three dimensions capture satellite features that are useful proxy indicators for the satellite's cost and complexity. These indicators are satellite mass, design life and payload. Satellites with small mass, short design life and a small number of payloads are relatively low cost and low in complexity. As the mass, design life and number of payloads increases, so does the cost and complexity. In these case studies, the Implementers and Suppliers pursued satellites with low cost and complexity compared to the overall satellite market. The mass remained under 800 kilograms, which is low compared to the large geosynchronous and scientific satellites that are the size of buses and weigh thousands of kilograms. Some of the satellites weighed less than 100 kilograms. The Design Life of a satellite is the length of time the Supplier claims the satellite will operate at full functional capacity. The satellite engineering process is rigorous and satellites often operate for longer than their design life. The Supplier assesses their risk when they define the design life; they tend to promise conservative lifetime performance. The contract may include penalties if the satellite does not last the full design life, further increasing the Supplier's risk aversion. The payload of the satellite is the component that delivers the service which is desired by the Implementer or customer. In this sense, the payload is the most important part of the satellite; all other components exist to support the payload in doing its function. The primary service for the remote sensing satellites in these case studies was to take optical images of specific locations on earth, identify to location and send the images and corresponding location data to ground stations on earth. The Payload dimension gives examples of all the instruments carried on the satellites in these case studies. The imager systems were in three categories of capability (low, medium and high resolution). Some satellites also carried secondary payloads for communication and science experiments. The communication payload mentioned here is a store and forward devise that can receive a message sent by an operator in one part of earth, store it and deliver it later to another location. This operational sequence is necessary because of the orbit; it does not allow real-time communication. In contrast, commercial communication satellites are ideal for real-time communication. Commercial communication satellites are located in geosynchronous orbit where they rotate around the earth at the same rate as the earth rotates around its axis. In this configuration, geosynchronous satellites always access the same part of the earth and one satellite is accessible to about one third of the planet. The store and forward payload included on some of the case study satellites did not cater to commercial communication. Instead it met the needs of the global amateur radio operator community. Around the world, individuals learn how to communicate using radio frequencies. They often leverage satellites with communication payload in the amateur frequency to send messages to each other.

The next five dimensions in the Technical Product View define specifications of the satellite. These are examples of the technical requirements that are defined in NASA Phase A. They further establish the performance and design approach of the satellite. The Data Downlink Band and Rate describe the speed at which imagery data is transferred from satellite to ground receiving stations on earth. The speed is important because the window of opportunity to deliver the data is limited. As small remote sensing satellites orbit the earth, they pass over their ground receive stations for a period of about 5 to 10 minutes. This may occur several times per day. Often careful coordination is required to ensure that all desired data is transferred from the satellite to the ground station during this short interval. A high data downlink rate is a valuable performance attribute. The different types of radio frequency communication systems are described by standard terminology using the bands. Each band covers a particular set of radio frequencies with specific characteristics. A system that operates on Ultra High Frequency band is relatively slow compared to S-band and X-band options. The Power Capacity dimension defines the amount of electrical power that the satellite can generate using solar panels while orbiting the earth. This number limits the amount of electrical power that the payload, computers, sensors and actuators can use. The Onboard Storage value defines the amount of data the satellite can store. The satellites in these cases ranged from 64 megabytes to 128 gigabytes. These values were on the same order of magnitude as personal computers from the same era; the values increased over time as electronics evolved in all industries. Together the Onboard Storage and Data Downlink Band/Rate define the amount of data the satellite can collect, store and deliver. Thus, they are key performance indicators. The Pointing Error dimension defines the level of error the satellite has in pointing to a specific location on earth. As pointing error decreases, the confidence that the satellite is pointing to the intended target for an image increases. The Orbital Altitude and Inclination define where the satellite flies as it goes around the earth. Altitude measure the height of the satellite above the earth. All the satellites in this study were relatively close to the earth in an area known as Low Earth Orbit. They all flew at a height between 600 and 800 kilometers. They used similar heights because of their similar mission. At these heights, their imager payloads operate effectively and their communication systems have enough power to send the information down to earth. The Orbital inclination defines the angle of the orbit with respect to the equator. A Polar orbiting satellite flies perpendicular to the equator, while an equatorial satellite flies parallel with the equator. Both types of inclination are used in these cases. Polar orbits are generally more common for remote sensing satellites. As a satellite flies in a polar orbit, the earth rotates below it. Gradually, the satellite flies over every location on earth in the course of a few days. Satellites that fly in equatorial orbits fly only over the countries that are near the equator. A satellite can only take images or send communications when it is flying over a particular location on earth.

The last five Technical Dimensions give further examples of technical specifications of the satellite. The Satellite Shape dimension defines the structural geometry of the spacecraft – such as a cube, hexagonal prism or heptagonal prism. The Structural Arrangement dimension describes how the sections of the satellite are arranged within the overall shape in order to support the subsystems and payload. Several arrangements are proposed, including stacking a series of trays and arranging all the subsystems along the inside of the external walls. The structural engineers that choose the arrangement seek a design that provides enough strength to withstand an intense launch while keeping the mass low. The Attitude Control Actuators are subsystems that adjust the direction the satellite points. These are the actuators that determine the pointing error. Items such as gravity gradient booms, electromagnets, reaction wheels, magnetorquers and gyros can be used to adjust the angle of the satellite with respect to the earth. The Solar Panels and Batteries provide the functions of generating and storing power from the sun. For the small remote sensing satellites in this study, this is the only source of electrical power available. The table gives some examples of the types of batteries used in these projects. The Solar Panels are listed as either body mounted or deployable. This decision is significant because it is an element that also impacts project complexity. Body mounted solar panels are attached to the outside of the external walls of the satellite. They do not move. As the satellite orbits the earth, it receives the sun's energy from different directions. Solar panels are most effective when they are directly aligned with the sun. Body mounted solar panels cannot adjust to the angle of the sun at any time. If they are pointed slightly away from the sun, they simply generate less power. Deployable solar panels are designed to counter this problem. They are attached to beams that are folded close to the satellite during launch. Once in space, the beams deploy to extend the solar panels. Some deployable solar panels can adjust to receive more direct sunlight as the satellite moves relative to the sun. This can improve the overall level of power the satellite can generate. It also increases the risk of technical failure because the solar panels may not deploy successfully. Deployment of mechanical structures in the micro-gravity orbital environment is inherently risky because it is difficult to test in the presence of earth's gravity.

This section has provided examples of the types of technical decisions that Suppliers and Implementers face as part of designing remote sensing satellites.

Technical Approach View

Table 6-14: Dimensions within Technical Approach Architectural View

Generic Forms	Function	Examples of Forms from Existing Projects			
Technical Approach View					
Satellite Platform Approach	*Defining heritage of satellite platform*	Heritage Platform with Multiple Flights	Heritage Platform with One Flight	New Platform	
Satellite Engineering Approach	*Defining Satellite Engineering Approach*	Small Satellite Approach	Traditional Approach		
Subsystem component source	*Defining approach for sourcing subsystem components*	Space qualified components	Commercial off the shelf components		
Constellation Participation	*Defining whether mission is part of constellation*	Part of constellation	Single satellite mission		
Subsystem manufacturer	*Manufacturing Subsystems*	Satellite Supplier	External Suppliers		

The Technical Approach view highlights several aspects of the decisions by the Supplier regarding their satellite engineer techniques. The Satellite Platform Approach defines whether the satellite is based on an old or new platform. The platform of the satellite, as in other industries, is the high level design of the spacecraft, excluding the payload. Satellite suppliers often use similar designs for the satellite bus or platform; they make small adaptations for new payloads. This is a risk reduction approach. The more satellites that are flown with a common platform, the more confidence a Supplier and customer have in its performance. In these case studies, some of the satellites use new platforms or platforms with only one previous flight. They are willing to accept the risk of a new platform in order to gain an increase in performance compared to old platforms. Other projects used designs based on a platform with heritage from multiple flights. The Suppliers fall into two categories with their overall Satellite Engineering Approach. One set uses the Small Satellite Approach, which is characterized by designs based on focused requirements, low mass, limited management overhead, and low cost due to the purchase of products that were not originally designed for space. This is in contrast with the traditional satellite engineer approach that evolved among the early space innovators. The traditional approach has gradually led to complex requirements, high mass, large management overhead and high cost due to methods and parts that are designed specifically for space. The complex requirements and high mass often result from the desire to make each satellite with as many functions as possible. The large management overhead is a result of the risk averse culture that seeks to use documentation and accountability to reduce the uncertainty related to space activity. The traditional approach to procuring electronic and structural components for satellites is to buy parts that are specially designed to withstand the launch and orbital environments. In addition, parts for satellites are tracked carefully as they pass through the supply chain to allow decision makers to be confident of their quality and history. All of this has reduced the risk of space operations to some extent, but it has greatly increased the cost. Those that adopt the small satellite approach seek to challenge the traditional techniques in order to develop satellites at lower cost. The small satellite approach was pioneered by researchers in several universities as well as several entrepreneurs. The Subsystem Component Source dimension follows from the previous discussion and notes whether the Supplier purchases special "space qualified" components or other components known as "commercial off the shelf," which were designed for general use. The dimension of Subsystem manufacturer also relates to Satellite Engineering Approach. The Small Satellite Approach often includes manufacturing the subsystems of a satellite by the Supplier. Traditional Suppliers have moved to serving more as System Integrators. They normally contract with external supplier to manufacture subsystems. The integrator brings all the subsystems together to assemble and test them. The Constellation Participation dimension captures another Technical Approach. Several satellites in these cases are commissioned as part of a collaborative constellation. A constellation of satellites is a group that orbits in a coordinated fashion. In these case studies, the constellations are made of satellites that are built to have similar technical characteristics and to interact in their operations. Thus, the decision to operate in a constellation impacts several technical dimensions, especially the orbital characteristics.

Management View

Table 6-15: Dimensions within Management Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Management View					
Project Milestones	*Monitoring project progress*	Project Reviews	Satellite Models		
Review Strategy	*Defining role of supplier and trainee during reviews*	Supplier and trainee engineers presented to customer management together	Supplier engineers presented; trainees and customer management reviewed	Supplier engineers did primary presentations; customer management reviewed	Trainee engineers did primary presentations to customer management
Management Priorities	*Prioritizing management effort*	Schedule	Cost	Risk	Technical Performance

The Management Architectural View captures several of the approaches used by the Supplier for project management. The Project Milestones dimension shows which types of goals were used to monitor project progress and move through the design process. The two options are project reviews and satellite models. Both can be used together. Project Reviews are events during which the Supplier and possible engineers from the Implementer Organization make presentations to representatives of the customers to show project progress and address concerns. There is a fairly standard set of reviews used in the aerospace industry. The names may vary across organizations, but the purpose is similar. The review cycle parallels the project phase cycle, such as NASA's Phase A through D. Common reviews include the System Requirements Review, Mission Design Review, Preliminary Design Review, Critical Design Review, Manufacturing Readiness Review, Test Readiness Review, Flight Readiness Review and Launch Readiness Review. Each review signifies the completion of one project phase and transition to the next. Suppliers used several strategies in terms of how they defined the role of the trainees during the reviews. The trainees were in an intermediate position with respect to the review audience. The main audience was the set of management and decision makers and perhaps consultants that represented the interests of the Implementer and Overseer. The Supplier had the role to demonstrate that they were delivering the expected service for the satellite and training. The trainee engineers could either partner with the Supplier to give the review; observe the review or partner with Implementer management to critique the Supplier. The other option was for Trainees to give parts of the review alone if they completed a portion of the work alone.

The Management Priorities for each project are high level goals that the Supplier and Implementer sought throughout the project. These priorities were generally driven by the Implementer and adopted by the Supplier. The priorities included controlling schedule, cost, risk and maintaining technical performance. Most Implementers had a clear preference of a particular priority that mattered greatly to them. As in any project management setting, there are constant tradeoffs among these four areas. The schedule was highly important to some Implementers, as introduced in the section on Technical Requirements. The Supplier could control their own efforts to develop the satellite within a set schedule; however the launch schedule was out of their control. Satellite launches are notorious for being delayed due to technical and legal issues.

Policy View

Table 6-16: Dimensions in Policy Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Policy View					
Project Political Champion	*Generating Political Support for Project*	National Head of Government	National Minister	National Head of State	
Project Approval Process	*Defining steps for government approval of project*	Cabinet review	Ministerial Review	Regional Government Review	Presidential Review
Policy Challenges	*Adding programmatic risk due to policy*	ITU Frequency Filing	Export Control	Immigration	

The Policy Architectural View captures three areas through which policy impacted the satellite project. In some cases there is a Project Political Champion that generates political support within the Implementer Nation. This champion role is played by the National Head of Government, National Minister or National Head of State. When such a champion is active, it has a strong impact on the project. If the political support is high, the funding support also tends to be high. This can influence the management priorities, technical requirements, technology strategy and posture toward risk taking. The level of political support can also influence the Project Approval Process dimension, which defines the steps for gaining approval from the government in the Implementer nation to fund the project. This dimension relates the level of space policy infrastructure in the nation. If there is limited infrastructure, the approval process may also be undefined. Alternatively, the approval process may mirror other types of government infrastructure. The satellite project proposal may compete with proposals for roads, dams and other areas of public investment. Examples of Project Approval Processes in these cases include Cabinet Review, Ministerial Review, Regional Government Review and Presidential Review. The final Policy Dimension is the set of Policy Challenges that add programmatic risk. Whereas the above dimensions relate to policy factors within the Implementer Nation, there are also policy challenges related to the international community. In these cases, there were policy issues related to Frequency Filing with the International Telecommunication Union, Export Control and Immigration. In order for some Suppliers to sell the satellite to the Implementers and to host engineers from the Implementers, they need to apply for licenses from their governments. The approval and timeliness is not guaranteed; this introduces risk into the schedule.

Cultural and Social View

Table 6-17: Dimensions in Cultural and Social Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*				
Cultural and Social View						
Educational Background of Trainee Engineers	*Defining educational preparation of trainee engineers*	Local University Degrees (National System)	Local University Degrees (International System)	Foreign University Degrees	Local Technical Degrees	
Cultural Challenges	*Adding programmatic challenge due to culture*	Language	Work Culture	Culture toward Authority	National Pride	Transition to living in Supplier Country

The final Architectural View captures examples of dimensions that relate to Culture and Social aspects of the satellite projects. The Educational Background of Trainee Engineers defined the preparation of the trainee engineers to some extent. Engineers came from a variety of educational experiences, including Local Universities, International Universities and Local Technical

Training. Among local universities, some used a domestic system from the Implementer Nation while others used an international system. The engineers' exposure to the different educational programs impacted their familiarity with foreign languages, cultures and teaching styles. When the Implementer Engineers went to live in the nation of the Supplier, they faced Cultural Challenges as they adapted to the new setting. These challenges were in areas such as language, work culture in the Supplier site, the culture toward authority and the logistical transitions of living in a new country with unusual food and customs. Finally, for some Implementer Engineers, national pride was a key motivation to participate in the project and it impacted their view of the effort.

6.1.1.3 Architectural Definition Step Seven

Table 6-18: Template for Generic Project Timeline

Project Year	*Project Events*	*Generic Events*
1		Facilitating Event
2		Project Initiation and Approval
3		Engineers at Supplier Location
4		System and Facility Development
5		Satellite Launch

The final step of the Architectural Definition process is to capture the time dynamics of the project. Here a generic timeline is introduced that shows the key events that occurred in all the satellite projects. In the next section, the actual timelines of each project will be presented according to these conventions. The Project Year replaces absolute time in order to maintain anonymity of the projects. In each project there is at least one event to facilitate the project, and initiate and approve the Project. The timeline also captures the years during which Implementer Engineers are at the Supplier Location and the system or facilities are in development. The facilities may be in the Supplier or Implementer site. The last generic event is the satellite launch. This template is used as the foundation for specific project timelines.

6.1.2 Research Question 2: How are the Architectures of Collaborative Projects Similar and Different?

This section continues to draw from the seven steps to define the architecture of a system. These steps are as follows: 1) Identify primary stakeholders, 2) Identify Constraints, Opportunities, Requirements and Objectives, 3) Define system function, 4) Identify Generic Forms, 5) Identify alternative specific forms to form dimensions, 6) Group dimensions into categories of Architectural Views, and 7) Create timeline of major events. In the section above, these seven steps were applied to the entire set of case study projects. The forms, functions, dimensions and views that emerged for this set of projects were introduced and the implications of selecting specific instances of forms were discussed. The coming section answers Research Question 2 by comparing the specific architectural approaches used in the various collaborative satellite projects. The section begins by comparing the context for each of the case study projects. It continues by considering several dimensions from each architectural view and showing the specific instances of form used in each case. The results are shown for six satellite projects executed by four countries and procured from three suppliers. Note that the BetaSat-R2 and BetaSat-R3 satellites were purchased as part of a single project, thus their results are shown together. Table 6-19 summarizes the main characteristics of the six satellite projects. All the projects are optical remote sensing missions. They vary in terms of the technical specifications of the imagery they produce.

Table 6-19: Summary of Key Project Characteristics

Satellite Projects	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Country	Nation Alpha		Nation Beta		Nation Gamma	Nation Delta
Satellite Type	Remote Sensing					
Satellite Imagery Performance	Medium Resolution	High Resolution	Medium Resolution	High and Medium Resolution	High Resolution	High Resolution
Supplier	Supplier Omega1	Supplier Tau1	Supplier Omega1		Supplier Tau1	Supplier Sigma1

The discussion about Research Question 1 explored the issues that drive decisions to apply specific instances of form to project functions. Many of these issues are potentially relevant across a variety of collaborative satellite projects. This section focuses on the specific factors, decisions and approaches that emerge from the experiences of Nations Alpha, Beta, Gamma and Delta.

6.1.2.1 Architectural Definition Steps One and Two

The first steps of the Architectural Definition Process are to identify primary stakeholders and explore their contextual constraints, opportunities, requirements and objectives. In these projects, the primary stakeholders are the Implementer, Overseer and Supplier Organizations. The specific institutions that played those roles in each country will be further discussed in Step Three.

Table 6-20: Contextual Opportunities and Constraints for Satellite Projects

Context	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2

Prior use of remote sensing services on national level	often	often	often	often	some times	often
Prior use of communication satellite service by national organizations	often	often	often	often	often	often
National Space Office (during time of project)	partial	partial	partial	yes	partial	partial
Past domestic satellite projects	few	few	none	few	few	few
Major space event: partnership opportunity	yes	yes	yes	yes	yes	yes
Major space event: Policy or facility established	yes	no	yes	yes	yes	no
Key Leader: Overseer Organization	yes	partial	yes	yes	yes	no
Key Leader: Implementing Organization	yes	yes	yes	yes	yes	No
National Vision: Space as part of development process	yes	yes	yes	yes	yes	no
National Vision: Accomplishment in space tech	no	yes	no	yes	yes	Yes
Level of political support	high	medium	high	medium	high	medium
National Space Policy Infrastructure	low	low	high	high	high	low

Table 6-20 considers the contextual factors that were introduced above and shows the extent to which they affected the six satellite projects. The first two factors consider the level of activity using satellite remote sensing and communication services before the project in question. The table indicates that both types of services were used often in almost all cases. Nation Gamma is the only exception where the use of remote sensing is shown at a medium level. In the area of remote sensing, the service is generally harnessed to address national concerns through the work of government agencies. In each of the four nations there were offices within the national government with the responsibility to acquire satellite data from foreign sources, convert the data into decision tools such as maps and distribute the data to other government agencies. In the area of satellite communication, the service was provided by both foreign and domestic commercial companies. In Nation Alpha, Nation Gamma and Nation Delta domestic, commercial companies started buying and operating (but not manufacturing) communication satellites before the first remote sensing satellite was purchased. In Nation Beta, the Implementer Organization pursued a domestic communication satellite project between BetaSat-R1 and the BetaSat-R2/R3 project. All of the nations had some level of experience harnessing satellite services before they sought their first domestic satellite manufacturing project.

The next two factors indicate the level of space activity during and before the satellite projects. One row indicates whether a national space office was established in the country during the time of the project. Most of the countries are labeled as "partial" because the national space office was in transition during the project. For Nation Alpha, an initial office was forming with a focus on research during the AlphaSat-R1 project. Due to the project, this office expanded into a coordinator of satellite projects. During AlphaSat-R2, the same office evolved again and was reopened as a space agency. The initiation of BetaSat-R1 happened simultaneously with the formation of the space agency in Nation Beta. By the time of the BetaSat-R2/R3 project, the Nation Beta space agency was operational. In GammaSat-R1, the national research office that served as a central space office was formed in conjunction with planning the GammaSat-R1 project. In Nation Delta, the national remote sensing agency expanded to include satellite technology and take on more responsibility of a national space coordinator because of the DeltaSat-R2 satellite. Most of these early satellite projects also involved the evolution of the national space office. With regard to previous experience with domestic space projects, only Nation Beta stands out with no earlier satellites. As mentioned above, commercial firms in the other three countries operated communication satellites before these remote sensing missions.

In all of the countries there was a major space event or opportunity that facilitated the initiation of the remote sensing satellite project. One facilitating element was the development of a relationship or an opportunity to form a relationship. Nation Alpha received an offer for a free launch of a small satellite, which triggered AlphaSat-R1. They pursued AlphaSat-R2 with Supplier Tau1 in part because the two teams saw a mutually beneficial partnership opportunity. Nation Beta pursued BetaSat-R1 in part because of the invitation to collaborate in a constellation from Supplier Omega1. When Nation Beta continued with their second generation of remote sensing satellites, they had invitations for collaboration from both Supplier Omega1 and from countries in their region. As Nation Gamma considered their GammaSat-R1 project, they observed the example of the collaboration between Nation Alpha and Supplier Tau1; they found it attractive. Finally, as Nation Delta defined their DeltaSat-R2 satellite project with Supplier Sigma1, the government of Nation Sigma supported the project by seeking opportunities for favorable trade agreements between the two countries. Projects were also facilitated by the establishment of new policies or facilities. As discussed above, the initiation of these projects coincided with the establishment of new space offices in Nations Alpha, Beta and Gamma. Also, in Nation Beta and Gamma there were formal policies that informed investment in space or science and technology research activity.

The role of key leaders in the Overseer and Implementer Organizations emerged as important contextual factors in most of the countries. The label partial is used to show that the leader transitioned to a new position during the timeframe of the project. In Nations Alpha, Beta and Gamma there were individuals within the Overseer and Implementing organizations that made strong, personal contributions to defining the satellite projects, selecting the suppliers and leading the teams. Each of these individuals demonstrated a personal believe in the value of the project to their country. These key leaders believed in the visions for how space could contribute to their national development process or how their country could achieve technical accomplishments in space, as shown in the next two rows of Table 6-20. These national visions were often defined under the guidance of national level leaders such as heads of state or ministers. The leaders at the level of the Overseer and Implementer Organizations took the broad national visions and defined explicitly how their satellite project would contribute. In Nation Alpha and Nation Beta, national level leaders defined specific milestones for their country to achieve a particular level of development. Key leaders in the satellite projects latched onto these national milestones and claimed that fostering of satellite engineering capability was a step toward the goal. During Nation Beta's second satellite project, they specifically set a vision for accomplishing a space technology milestone that had not been attempted even by more experienced space countries. They sought the opportunity for Nation Beta to stand out for their space achievements.

The level of political support varied across the six satellite projects. For both Nation Alpha and Nation Beta, support was high for their first satellite project, but slowed for their second project. In Nation Alpha, a key national leader that nurtured the first satellite project transitioned during the second satellite project, which reduced the political momentum. In Nation Beta, the dampened support manifested itself in several years of delay to secure funding for the second satellite project. For Nation Delta, the government did support the project because previous natural disasters had demonstrated the need for better geo-referenced information; but the Implementer felt the need to demonstrate the usefulness of the project in order to maintain political support. All six of these satellite projects were government funded, thus the level of political support was key to their existence.

The final contextual factor is the maturity of national space policy infrastructure. For three projects, the policy status is low. In Nation Alpha and Nation Delta, there are few legal, regulatory or policy documents to coordinate space activity, assign responsibility or propose a national strategy. Nation Alpha worked on developing a national space policy document during projects AlphaSat-R1 and AlphaSat-R2. Nation Beta created a national space policy and a proposed long term project timeline at the beginning of project BetaSat-R1 as part of establishing the national space agency. Nation Gamma had a similar experience, but it was not limited to space. As they founded Implementer Gamma1, they were crafting a vision to harness space and other advanced technologies to improve the research infrastructure in their country. Three of these projects were completed with limited space policy infrastructure, while in three cases the project activity helped foster the formation of space policy.

The discussion above showed how the six projects were similar and different in terms of several contextual factors that led to opportunities or constraints. The countries were similar regarding their past use of satellite service and previous satellite projects (except Nation Beta). Most countries developed a new or evolved space office as part of these projects, and most countries responded to an external stimulus that enabled or inspired their satellite project. There were also similarities in the importance of key space leaders and national vision, although the specifics of the vision differed. A potential trend was that early projects have higher political support, but it may waiver later. This was not the case for Nation Gamma, which was approved for funding of their second satellite before the launch of their first. Finally, the projects were complete with and without formal space policy infrastructure that outlined government regulations and coordination procedures for satellite projects.

Table 6-21: Technical Requirements for Satellite Projects

Technical Requirements	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Timing Objective						
Fast-paced project	yes	partial	yes	no	yes	no
Maintain data continuity	no	yes	no	yes	no	no
Technical Performance objectives:						
Medium resolution optical imagery	yes	no	yes	yes	no	no
high resolution optical imagery	no	yes	no	yes	yes	yes
operational imagery	no	yes	yes	yes	no	yes
commercially viable imagery	no	no	yes	yes	no	yes

Table 6-21 discusses the Technical Requirements sought by each project. First, the table indicates whether timing was a key requirement for the Implementer and Overseer. The issue of timing is highlighted because satellite projects are historically challenged by schedule. New and complex satellite projects are often delayed by unexpected technology problems. Schedule also becomes a risk during the launch phase when many external factors can cause delays. The satellites procured in these six projects were relatively simple and were expected to have short design and manufacturing schedules on the order of several years. For the AlphaSat-R1 project, the Implementer and Overseer sought a faced-paced project because they hoped to make use of a free launch slot and the national government leader encouraged fast project results. During AlphaSat-R2, the country initially sought a fast paced project, but this satellite was technically complex and new for the supplier. As they realized the level of technical challenge, the Implementer relaxed the goal of finishing quickly. The BetaSat-R1 project had an incentive for a short design and manufacturing that was driven by participation in a constellation. The schedule for the launch was defined by the group of constellation contributors. This was not the case in Nation Beta's second project; they launched separately from constellation contributors and set their own schedule. There was urgency for BetaSat-R2 and BetaSat-R3, however, because they sought to maintain the continuity of data from BetaSat-R1, which had reached the end of its design life. Nation Gamma sought a fast-paced project because that satisfied their political stakeholder who sought short term results from their research investments.

Table 6-21 also shows which the level of technical performance that each project sought from the data their satellite produced. The options include the highest level of imagery as well as the type of product they planned to produce, which may be primarily experimental, operational or commercially viable. Over time, the countries moved toward expecting high resolution imagery at a quality that was suitable for operational decision support by their government and for commercial sale. This progression partly reflects the natural maturity of the technology over time. When AlphaSat-R1 was launched with a medium resolution imager, its performance was good relative to the size and cost of the satellite. The BetaSat-R3 satellite was only slightly larger and more expensive, but showed a marked improvement in performance. This series of projects happened during a time period during which small satellites transitioned from being seen as experimental research projects to commercial tools. The requirements from the customers became more demanding because the technology became more capable while the price of small satellites remained much lower than traditional satellites. For the countries that sought commercially viable imagery, there was an expectation that they could sell the images to an international market of data consumers. For Nation Beta, the sale was done in the context of the constellation. For Nation Delta, the sale was done individually and through bilateral agreements with foreign firms and governments. In general, the sale of imagery was not necessarily expected to recoup the cost of the satellite.

Table 6-22: Capability Building Objectives for Satellite Projects

Capability Building Objectives	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Key long term objectives:						
Establish national capability to design and manufacture satellites independently	high	high	high	high	high	high

Create local high technology work opportunities for the country	medium	high	high	high	high	low
Key short term objectives:						
Learn to procure satellite system	high	low	low	low	low	low
Engineers participate in building, testing operating mission	high	high	low	high	high	low
Engineers experience lifecycle from design to operations	low	high	low	high	low	high
Train engineers enough so they can build satellites with support in future	low	low	high	high	high	low
Train engineers to effectively operate satellite	medium	medium	medium	medium	medium	high
Training Focus Area:						
Satellite Engineering focused	high	high	high	high	high	medium
Operations focused	medium	medium	low	medium	medium	high
Payload Engineering focused	low	high	low	medium	low	low
Focus on academic training via university degrees	low	low	low	high	low	medium

Table 6-22 compares the objectives set by each country for building capability in the people and organizations that were involved with satellites. For all six projects and all four nations, the long term goal was stated as achieving national capability to design and manufacture satellites independently. The case study projects were chosen because they shared this goal. For several of the Nations, especially Alpha, Beta and Gamma, there was also a developing goal to create high technology work in their country. For Nation Alpha, this goal later manifested in manufacturing several components of AlphaSat-R2 within their country. Nation Gamma saw the satellite projects as the flag ship in a series of initiatives that would enable its people to practice advanced technology.

All the nations realized that the long term goal would only be achieved over a series of satellite projects. The next section of Table 6-22 shows examples of the short term objectives that were applied to each project. Nation Alpha started off with modest goals for their first remote sensing satellite. They wanted to understand the procurement process and expose their engineers to the late phases of satellite manufacturing and testing. For the second Nation Beta satellite, the goals were more aggressive; the leaders from the Implementer and Overseer Organizations wanted the engineers to experience and entire satellite lifecycle. This implied working closely with the Supplier on a fresh satellite design, rather than a previously used platform. Nation Beta also increased their capability building goals from the first to second project. They conceived of the first project as an introduction that would prepare the engineers to later participate in a supervised project. For the second project, they sought to ensure that the engineers were exposed to the full satellite lifecycle. The final short term objective refers to learning operations. While all of the teams expected to learn to operate their satellite, Nation Delta put a higher priority on this. For other nations, a specialized team focused on operations while others learned the satellite engineering techniques. For Nation Delta, a team was trained first in satellite engineering and in operations. When they returned to Nation Delta, their work was primarily in operations. This reality is also demonstrated in the last section of Table 6-22 which shows the Training Focus Area for each project. The DeltaSat-R1 project is the only one that is highly operations focused for the entire team. The other projects focused more on the overall satellite engineering process and included operations as one of the disciplines. A few projects emphasized the design and manufacture of payloads for a subset of the Implementer Engineer team. For the BetaSat-R2 and DeltaSat-R2 projects, academic training was a high focus area, compared to other projects.

The analysis of capability building goals shows that four countries started with the objective of reaching the same long term destination. They plotted slightly different courses to achieve that destination over a series of satellite projects by setting priorities for what the engineers would learn at each stage. There is also an effect that the decision makers who set capability building goals for their first project have limited experience. They are not experts in the types of training or disciplinary specialties that could be included as part of a satellite project. After Nation Alpha and Nation Beta completed their first projects, they set goals for their second projects based on what they saw as lacking in the first. For AlphaSat-R1 and BetaSat-R1, the Implementer engineers were more involved in the later stages of the satellite lifecycle because the design was based on previous missions. Thus, both Nation Alpha and Nation Beta set a goal for their engineers to experience the design phase on a new satellite during their second mission. With their increased level of understanding of the satellite design process, they could specify more precise capability building goals.

6.1.2.2 Architectural Definition Steps Three to Six

The section above outlined contextual factors, technical requirements and capability building objectives. That discussion serves as a foundation for considering differences in the architectural dimensions among the satellite projects. In this section, each architectural view is revisited and several dimensions are examined to learn how countries were similar and different with regard to the specific instances of form that were implemented. For the sake of brevity and to emphasize more striking differences among projects, only a few dimensions from each Architectural View are discussed in the text. The rest of the dimensions are included in the Appendix.

Organizational View

Table 6-23: Selected Dimensions from Organizational View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Organizational View					
Implementer Organization	*Implementing Satellite Project*	Government-linked Company	National Space Agency	National Remote Sensing Agency	National Research Agency
Overseer Organization	*Overseeing Satellite Project*	Government Ministry	National Space Agency	National Remote Sensing Agency	National Research Agency
Supplier Organization	*Supplying satellite and training program*	Small, university spinoff firm	Medium Firm	Large Firm	
Implementer Visiting Team Size	*Defining number of people that visit Supplier from Implementer*	6 to 10 people	11 to 15 people	16 to 20 people	21 to 30 people

As before, the first Architectural View is Organizational. Four dimensions are highlighted from this view; they are the Implementer Organization, Overseer Organization, Supplier Organization and Implementer Visiting Team Size.

Table 6-24: Implementing Organization Dimension

Implementing Organization:	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Government Linked company	Yes	Yes	No	No	No	No
National space agency	No	No	Yes	Yes	No	No
National remote sensing	No	No	No	No	No	Yes
National research agency	No	No	No	No	Yes	no

Each nation appointed a different type of organization as their Implementer for the satellite project. The motivation for each model is related to the national vision, history of space activity and the socio-economic context of the nation. For Nation Alpha, the Implementer Organization was a government-linked company for both satellite projects. The company was formed as part of the AlphaSat-R1 project. This choice to place the responsibility for practical implementation of the satellite project in a commercial setting is parallel to other aspects of Nation Alpha's context. At the start of the AlphaSat-R1 project, Nation Alpha was in a period of industrial growth with new businesses and industries sprouting. There was growth in the high technology manufacturing sector. Other national technology initiatives were implemented by establishing quasi-commercial state owned enterprises. These blends of public and private effort drew their visions from government policy but their operational approach from private industry. This strategy by Nation Alpha indicates an assumption that the strength of government is to coordinate and foster technical activity, but the private industry has strength in executing technical tasks. For Nation Alpha, it was also logical to place a firm as the Implementer because there was an existing firm that offered satellite communication services. In a similar way, the strategy by Nation Beta to establish a National Space Agency as the Implementer also reflects the national context. The domestic economy was strongly driven by export of natural resources, and the role of private sector, domestic industry was not well established in advanced technology. The National Space Agency was established as part of a larger initiative to create government science and technology infrastructure for research and development. Nation Beta combined the role of coordinating space research, fostering space technology development and implementing projects in one government organization. This approach is also similar to that taken by other countries in Nation Beta's region, where the role of the public sector is strong relative to the domestic private sector. For Nation Gamma, the choice of creating a National Research Agency as the Implementer of the satellite project was driven by a vision that was not limited to the space sector. For Nation Gamma, the satellite projects were part of a larger emphasis on building science and technology capacity in their country. Nation Gamma had a strong economy, but they sought to rebalance the impact of foreign and domestic technology experts. In order to pursue long term socio-economic stability, they needed a research organization that would foster local expertise in many advanced technology areas. Unlike in Nation Alpha and Nation Beta, the concerns of the space program were not the primary factors that dictated the nature of the Implementer Organization. The Nation Gamma Implementer was created to execute satellite projects as well as other types of technology projects; although satellites were emphasized first. For Nation Delta, the Implementer Organization was appointed by evolving an existing organization that had experience in one aspect of the satellites to expand it to include the rest of the satellite lifecycle. In Nation Alpha, the National Remote Sensing Agency remained a partner to the new space agency, but did not participate in the BetaSat-R1 and BetaSat-R2 projects. In Nation Beta, the national remote sensing agency, which existed before the space agency, was gathered in as one of several field centers for the national space agency. Among these countries, only in Nation Delta did the national remote sensing agency convert itself into the national space agency by procuring a satellite.

Table 6-25: Overseer Organization Dimension

Overseer Organization	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Government Ministry or Department	Yes	Yes	Yes	Yes	Yes	Yes
National Space Agency	Yes	Yes	No	No	No	No

In all four nations, a government ministry or similar department played the role of Overseer Agency. The satellite projects were all approved, funded and monitored by these government bureaucracies. Nation Alpha had both a government linked company as an Implementer and a National Space Office that evolved into a full Agency. This created two layers of oversight. The National Space Agency was the official customer for the satellite projects and they contracted, non-competitively with the government linked company to implement. The company in turn contracted with the Supplier. Again, the blend of public and private action is unique to Nation Alpha. It reflects the growing contributions of the private sector of their economy as well as the close relationship between the public and private sector in technology initiatives.

Table 6-26: Summary of Suppliers and Supplier Status for each Satellite Project

Satellite Projects	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Country	Nation Alpha	Nation Alpha	Nation Beta	Nation Beta	Nation Gamma	Nation Delta
Supplier	Supplier Omega1	Supplier Tau1	Supplier Omega1	Supplier Omega1	Supplier Tau1	Supplier Sigma1
Firm Status	Small, university spinout firm	Small, university spinout firm	Small, university spinout firm	Medium Firm	Medium Firm	Large Firm

The six satellite projects in these case studies were supplied by three firms. This is an artifact of the research design. The projects were chosen because they allowed interesting comparisons of countries as they worked with different firms. Two of the firms were in the status of "Small, University Spinout Firm" during the early projects and progressed to the status of "Medium Firm" for later projects. The status of the firms for each project is summarized in both Table 6-26 and Table 6-27. Supplier Omega1 and Supplier Tau1 are considered "Small, university spinout firms" when they employed less than a few hundred people, shared extensive facilities with their home university and had informal organizational processes. Nations Alpha and Beta worked with Supplier Omega1 during this season, and Nation Beta worked with Supplier Tau1 while they were in such a season. Soon after, both Suppliers grew to be Medium firms because they increased their employment, established dedicated facilities outside the university and formalized their organizational processes to some extent. Even as Supplier Omega1 and Supplier Tau1 grew to be Medium firms, they remained much smaller and less formal than Supplier Sigma1. In contrast with the other firms, Supplier Sigma1 is a large aerospace firm that formed through mergers and acquisitions of other large aerospace firms. It is a multinational firm with locations and employees in many countries and well established infrastructure. The medium and small firms are at the opposite end of the aerospace market spectrum from Supplier Sigma1.

Table 6-27: Satellite Supplier Organization Dimension

Satellite Supplier Organization	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Small, university spinout firm	Yes	Yes	Yes	No	No	No
Medium firm	No	No	No	Yes	Yes	No
Large firm	No	No	No	No	No	yes

By focusing on the types of firms selected by the nations, Table 6-27 shows trends. Nation Alpha worked only with small, university spinout firms for their two early satellite projects. One key leader in the Overseer Organization who was instrumental in selecting the Supplier firms talked about being comfortable with the firms because of their close association with universities. This key leader was also a former university professor, as was the leader of the government linked company that served as Implementer. Even as Nation Alpha increased in their level of understanding of satellite technology and set ambitious technology goals for themselves, they preferred to work with new, unproven firms. Nation Alpha was the first major customer for Supplier Tau1. They took the same approach when selecting a launch provider for AlphaSat-R2. They worked with a new, small launch vehicle manufacturer (Supplier Lambda1) as their first satellite payload for a new rocket. While Nation Alpha chose to work with three emerging suppliers, Nation Alpha chose to work consistently with one supplier. Nation Alpha created their first project based on the invitation from Supplier Omega1 to collaborate. As will be discussed in the section on Supplier Selection, Nation Alpha did consider other Suppliers for their second generation project, but Supplier Omega1 won the competition. Both Supplier Omega1 and Nation Alpha had the opportunity to refine their relationship over time and learn how to work effectively together. Nation Gamma worked with Supplier Tau1 as a medium sized firm. They joined Nation Alpha and Nation Beta in pursuing non-traditional space suppliers while Nation Delta worked with a highly reputable Supplier (Supplier Sigma1) with many successful projects in the traditional space market.

Table 6-28: Implementer Visiting Team Size at Supplier Dimension

Implementer Visiting	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/	GammaSat-R1	DeltaSat-R2

Team Size at Supplier				BetaSat-R3		
6 to 10	Yes	No	No	No	Yes	No
11 to 15	No	No	Yes	No	No	No
16 to 20	No	Yes	No	No	No	Yes
21 to 30	No	No	No	Yes	No	no

The last dimension that is highlighted in the Organizational View is the size of the team of Implementer engineers that visits the Supplier. This dimension is introduced here because it relates to several other dimensions such as the approach to assigning team roles, the process for sending engineers from the Implementer Nation to the Supplier Nation and the level of coordination for training and mentoring. The AlphaSat-R1, BetaSat-R1 and GammaSat-R1 (all first national projects) tended to have smaller teams of less than 15 people. The AlphaSat-R2, BetaSat-R2 and DeltaSat-R2 teams were larger (16-30 people). Both Nation Alpha and Nation Beta reflected on their small team sizes from the first project and realized that the small teams did not include enough people to cover all the topics included in satellite engineering. During AlphaSat-R1 and BetaSat-R1, engineers were assigned to learn multiple roles in order to cover as many topics as possible. With their larger teams during AlphaSat-R2 and BetaSat-R2, each engineer was assigned to focus their learning on one topic within satellite engineering. When Nation Gamma sent a small team to train for their GammaSat-R1, they faced the same challenge of not being able to learn all the topics. The philosophy followed by Implementer Alpha1 and Supplier Tau1 to address this issue was to explicitly not cover a lot of topics. Supplier Tau1 advised Implementer Alpha1 to choose a small set of topic on which to focus. These were topics that were challenging in satellite engineering and that required internal capability in a satellite Supplier. They de-emphasized aspects of the satellite engineering process that could be effectively outsourced. Two of the larger teams (for BetaSat-R2/R3 and DeltaSat-R2) also stand out for having more formal work plans assigned by the Supplier mentors to the Implementer engineers. This will be discussed more in the Training Architectural View. These two larger teams also had a more structured transition to the Supplier Site, highly formalized academic lectures and a team orientation. The AlphaSat-R2 project also had a large team, but they worked with a newer organization and defined the team and the project as they went. Team size is linked to many dimensions.

Project Initiation and Approval View

Table 6-29: Select Dimensions from Project Initiation and Approval View

	Function	*Examples of Forms from Existing Projects*					
Project Initiation and Approval View							
Project Leader	*Appointing Project Leader*	New Leader	Existing Leader				
Organizational	*Appointing*	Founding	Appointing	Founding	Appointing		

Appointment	*Implementing Organization*	new government organization	existing government organization	new company	existing company		

Within the Project Initiation and Approval Architectural View, two dimensions are highlighted. The Project Leader dimension shows whether a new leader was appointed as part of establishing the satellite project. The Organizational Appointment shows whether a new or existing organization was appointed as Implementing Organization.

Table 6-30: Project Leader and Organizational Appointment Dimensions

Project Leader	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
New Leader Appointed	Yes	No	Yes	No	Yes	No
Existing Leader Continues	Yes	Yes	No	Yes	No	yes
Organizational Appointment	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Founding new government organization	No	Yes	Yes	No	Yes	No
Appointing existing government organization	Yes	Yes	No	Yes	No	Yes
Founding new company	yes	No	No	No	No	No
Appointing existing company	No	Yes	No	No	No	No

It is helpful to discuss the two dimensions together because they are related. Several projects started with both the founding of a new organization and the assignment of a new leader to head the organization. For the first remote sensing satellite projects in Nations Alpha, Beta and Gamma, this was the case. Nation Delta did not open a new organization or appoint a new leader for DeltaSat-R2 because the Implementer was an existing remote sensing agency. In Nation Alpha, the government Overseer and its leader were closely involved with the AlphaSat-R1 and AlphaSat-R2 projects. Their participation is captured as the continuation of the existing leader and appointing the existing government organization.

Personnel Management View

Table 6-31: Select Dimensions from Personnel Management View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*				
Personnel Management View						
Engineer Selection Organization	*Selecting Engineers for Training*	Implementing Organization	Implementer and Supplier			
Engineer Recruitment Source	*Defining Selection Pool*	Experienced Academics	Military Representatives	Experienced Industry Professionals	Recent Graduates & Young Professionals	National Citizens
Engineer Recruitment Process	*Announcing Training Opportunity*	Network with universities	Coordinate with Military	Advertise with media	Use personal networks	Recruit among expatriate community
Engineer Evaluation Process	*Evaluating Engineers for Training*	Application	Interviews	Tests		

Table 6-31 shows four dimensions from the Personnel Management Architectural View: Engineer Selection Organization, Engineer Recruitment Source, Engineer Recruitment Process and the Engineer Evaluation Process.

Table 6-32: Engineer Selection Organization Dimension

Engineer Selection Organization	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Implementer Organization	High	High	High	High	High	High
Supplier Organization	High	Medium	Medium	Low	Low	High

The first dimension captures the role of the Implementer and Supplier Organizations in selecting engineers to participate in the satellite project. For all the projects, the Implementer was involved; the projects differed regarding the role of the Supplier. For AlphaSat-R1 and DeltaSat-R2, the Supplier had representatives that sat on the panel to interview candidates. This is considered a high level of involvement because the Supplier had the opportunity to directly comment on the qualifications of candidate engineers before they were hired. During AlphaSat-R2 and BetaSat-R1, the Supplier had a medium level of involvement. They primarily gave advice to the Implementer about what education and professional background the engineers should have. For the remaining projects, the Suppler had a limited role in engineer selection.

Table 6-33: Engineer Recruitment Source Dimension

Engineer Recruitment Source	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Experienced Academics	yes	no	no	no	no	no
Military Representatives	yes	no	no	no	no	yes
Experienced Industry Professionals	yes	no	no	no	no	yes
Recent Graduates & Young Professionals	no	yes	yes	yes	yes	yes
National Citizens					yes	no

The first step for Implementer Organizations when they pursued the hiring process was to define a target population from which to recruit. As shown in Table 6-33, most of the projects targeted recent graduates and young professionals primarily. The AlphaSat-R1 project was different because they did not hire people for long term employment. They worked with universities, the military and industry to select experienced professionals to work temporarily on the satellite project. The DeltaSat-R2 project did hire people for long term employment under the Implementer, but they drew from a wider population range than the other projects. The leaders within the Implementers discussed their perceived tradeoffs when considering whom to hire. If they hired recent graduates and young professionals, they found the engineers to be open to training and molding, although their work ethic was immature. If they hired experienced professions with more seasoned overall professional skills, they found it to be harder to train and influence the engineers. When these projects started in all four Nations, there were very few engineers who had specific training or experience related to satellites. The purpose of defining the recruitment target population was not to find people that had the desired skills, but to find people that had the potential to learn the relevant skills.

Table 6-34: Engineer Recruitment Process Dimension

Engineer Recruitment Process	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Networked with domestic universities	yes	yes	no	no	yes	yes
Coordinated with military	yes	no	no	no	no	yes
Advertise with	no	yes	yes	yes	no	yes

media						
Use personal networks	yes	yes	yes	yes	yes	no
Recruit among expatriate community	no	yes	no	no	yes	no

After determining the target population for recruitment, the Implementers used various means to spread the word about the opportunity to join the satellite project, including networking with universities, asking the military to recommend candidates, advertising in public media, using personal networks and recruiting among engineers from the nation that were studying or working abroad. The use of personal networks emerged as a strong factor in all but one project. Most of the Implementers also advertised with the media; the two exceptions are easily explained. For the AlphaSat-R1 project, they did not use a large scale advertisement using news channels because the Implementer and Overseer worked directly with stakeholder organizations (universities and the military) to ask for nominations to the trainee team. For the GammaSat-R1 project, the Implementer preferred informal networks as a means to find talented engineers that shared the vision of the organization. It was a vision to harness technology and science research in order to advance the country.

Table 6-35: Engineer Evaluation Process Dimension

Engineer Evaluation Process	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Application and interviews	yes	yes	yes	yes	yes	yes
Tests	no	no	yes	yes	no	no

The four nations did not differ much in their evaluation process for the candidate engineers. All used applications and interviews, even when they recruited via information methods. In Nation Beta, there was the unique use of tests. Several Nation Beta engineers mentioned in interviews that testing job applicants is common when recruiting for government positions. The tests for Nation Beta focused on math from a secondary school level, communication and analytical skills. The test provided a filter before the applications were review or interview invitations were made. According to some in Nation Beta, the testing is important for employers because unemployment is relatively high and there are many people pursuing each job opening.

Supplier Selection View

Table 6-36: Selected Dimensions from Supplier Selection View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*

Supplier Selection View							
Supplier Selection Process	*Choosing satellite supplier*	Choose personal acquaintance	Join invitation for collaboration	Call for selective Tendering	Hire Consultant to Review	Open Call for Proposals	Travel to tour international suppliers
Priority Supplier Attributes	*Differentiating among suppliers*	Technical performance and flexibility	Training package	Space heritage	Price	University Relationship	Schedule

Two dimensions are highlighted that show contrasts in how the six projects selected a Supplier to provide training and the satellite. Only two projects overlap in their Supplier Selection Process, although there is much more overlap in the attributes that Implementers and Overseers sought when selecting their supplier.

Table 6-37: Supplier Selection Process and Priority Supplier Attributes Dimensions

Supplier Selection Process	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Choose personal acquaintance	No	Yes	No	No	No	No
Join invitation for collaboration	No	No	Yes	No	No	No
Call for selective tendering	No	No	No	Yes	No	No
Hire Consultant to Review	No	No	No	Yes	No	No
Open call for proposals	Yes	No	No	No	Yes	No
Travel to tour international suppliers	No	No	No	No	No	Yes
Priority Supplier Attributes	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Technology Performance	Yes	No	Yes	Yes	Yes	Yes
Technology flexibility	No	Yes	No	No	Yes	No
Training Package	Yes	No	Yes	Yes	Yes	No
General space heritage	No	Yes	No	No	No	Yes
Space heritage in small satellites	Yes	Yes	No	Yes	Yes	No
Price	Yes	No	Yes	No	Yes	No

University Relationship	Yes	Yes	No	Yes	No	No
Schedule	No	No	No	No	Yes	No

Table 6-37 shows the approaches used by each project for Supplier Selection. The approaches can be divided between those that are more formal and exhaustive and those that are less formal and rely on personal interaction. The information methods are listed first – choosing a personal acquaintance and joining a Supplier based on an invitation to collaborate (AlphaSat-R2 and BetaSat-R1 projects). The more formal approaches include an open call for proposals, selective tendering (inviting a few Suppliers for proposals), traveling to visit multiple suppliers and hiring a consultant to review potential offers. These tools were used for the AlphaSat-R1, GammaSat-R1, BetaSat-R2/R3 and DeltaSat-R2 projects. Nation Alpha used both formal and informal methods. They started with a more formal approach to review many suppliers, but changed to an informal approach for their second project. Nation Beta went the opposite direction. They used a more informal approach in the first project, then formalized for their second project. This is an interesting dichotomy because in some ways the more formal approach requires more technology knowledge or the support of consultant. A formal approach implies that the Implementer is evaluating a broad range of Suppliers and comparing the technical and cost characteristics. This is a challenging task; one might expect nations to start informally and become more formal over time. Nation Gamma used a formal, exhaustive process for their first project and sought to evaluate the offerings from most small satellite suppliers in the market. They chose to continue with the same supplier for their second remote sensing satellite through a more informal process.

As Implementers and Overseers reviewed the characteristics and project proposals of potential suppliers, they placed high priority on several attributes. Four or more projects highlighted technology performance, the nature of the training package and heritage in small satellites as key issues. The Implementers sought high technology relative to the time period and the cost, so that was a moving target over time and across suppliers. For the AlphaSat-R2 and GammaSat-R1 projects, technology flexibility was a key reason that Nation Alpha and Nation Gamma chose to work with Supplier Tau1. They found this supplier, with relatively little experience as a firm, to be willing to make changes to their technology to suit the customer. These two satellite projects were the Supplier's first sales of full satellite systems. The GammaSat-R1 project highly valued schedule as part of the selection process. The DeltaSat-R2 project stands out for choosing a Supplier with strong space heritage but less experience in small satellites. The satellite the Supplier Sigma1 sold to Nation Delta was small compared to their other satellites, but much larger than the other satellites in these case studies. Supplier Sigma1 was not focused on the small satellite market.

Facility View

Table 6-38: Selected Dimensions from Facility Architectural View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Facility View					
Supplier Facility Status	*Defining Supplier Facility State*	Temporary	Transitional	Purpose-Built	
Implementer Facility Status	*Defining Implementer Facility State*	Temporary	Transitional	Purpose-Built	

These two dimensions from the Facility Architectural View show the status of the Supplier and Implementer Facilities as either temporary (early in organization's history and not designed for their needs); transitional (changing from temporary to purpose built); or purpose-built (designed for needs of organization).

Table 6-39: Supplier Facility Status and Implementer Facility Status Dimensions

Supplier Facility Status	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Temporary	Yes	No	Yes	No	No	No
Transitional	No	Yes	No	Yes	No	No
Purpose-Built	No	No	No	No	Yes	Yes
Implementer Facility Status	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Temporary	Yes	No	Yes	No	Yes	No
Transitional	No	Yes	No	Yes	No	**Partial**
Purpose-Built	No	No	No	No	No	**Partial**

Table 6-39 shows how Supplier and Implementer Facility status evolved during the projects. As described above, two of the suppliers (Supplier Omega1 and Supplier Tau1) transitioned from being small, university spinoff firms to medium sized firms. Part of that transition included moving from temporary to transitional to purpose-built phases in their facilities. Supplier Omega1 worked with Nation Alpha (AlphaSat-R1) and Nation Beta (BetaSat-R1) in a temporary facility, and then they worked with Nation Beta (BetaSat-R2/R3) in a time of facility transition while establishing new purpose built facilities. Soon after the completion of BetaSat-R2 & R3, Supplier Omega1 completed a major facility transition into dedicated facilities. Supplier Tau1 worked with Nation Alpha in a transitional facility status then with GammaSat-R1 in a purpose-built facility. As the well established firm, Supplier Sigma1 was not making facility transitions during the DeltaSat-R2 project.

All of the Implementers made some level of facility change during their satellite projects, which adds to the complexity of executing the projects. Between the AlphaSat-R1 and AlphaSat-R2 projects, the Nation Alpha Implementer transitioned several times to gradually improve the facility they had in order to do hardware work. They eventually set up a satellite integration and testing facility that enabled them to do some integration work for AlphaSat-R2 at the Implementer Site. This facility included electronics and optical labs as well as clean room space and a crane for lifting the satellite. During the BetaSat-R1 and BetaSat-R2 projects, Nation Beta also made major facility transitions. They started in rented office buildings with no hardware work space. During the BetaSat-R2 project, they inaugurated a new campus to house the national space agency headquarters and a center focused on satellite engineering. They gradually worked toward installing hardware laboratories. During GammaSat-R1, Implementer Gamma1 was in an early facility that had primarily office space and little hardware space. They added a ground control and data receiving system, but also made plans for a dedicated building that would include hardware workspace. Nation Delta is shown as making partial transitions because the core part of Implementer Delta1 did not change due to the satellite project, they were already in a purpose-built facility. A new facility was established for the satellite operations team, however, at a location which was several hours drive from the main office.

Training View

Table 6-40: Selected Dimensions from Training View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Training View					
Training Project Phase	*Defining project phase that trainees experience*	NASA Phase A	NASA Phase B	NASA Phase C	NASA Phase D
Theoretical Training	*Providing theoretical training to Engineers*	Technical satellite lectures	University Degrees	License to Technical Documentation	Non-technical training lectures and conferences
Practical Training	*Providing Practical Training to Engineers*	Group Mission Design Exercise	Skill-based training courses	Technical demos	Language classes
On the Job Training	*Providing On the Job training to Engineers*	On the job tasks under mentor	Building a training satellite		
Mentor-Trainee Accountability System	*Defining level of formality for*	Informal System	Formal System		

	mentor-trainee accountability				

Table 6-40 shows five dimensions from the Training Architectural View. The first highlights the time dimension of the training experience for the Implementer engineers. The next three show what elements of training that engineers received in three distinct categories – theoretical, practical and On the Job. The final dimension provides a glimpse into the mentoring system for each project.

Table 6-41: Training Project Phase Dimension

Training Project Phase	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
NASA Phase A Mission and Requirements Definition	No	Yes	No	Partial	No	No
NASA Phase B Preliminary Design	No	Yes	No	Partial	Partial	No
NASA Phase C Detailed Design	Yes	Yes	Yes	Yes	Yes	Yes
NASA Phase D Assembly/ Integration/Test & Launch	Yes	Yes	Yes	Yes	Yes	Yes

The Training Phase is emphasized as an important factor influencing the training experience because each Phase of the satellite lifecycle requires different skills. The NASA Phases are used as a convenient summary of four segments in the middle of the satellite lifecycle – Mission & Requirements Definition, Preliminary Design, Detailed Design, and Assembly/Integration/Test & Launch. All the trainee engineers experienced the later phases of the project (Phase C and D). The projects varied in terms of how the engineers participated in Phases A and B. In some cases, the engineers arrived at the Supplier site later than expected. They were supposed to participate in Phase A and B, but their arrival was delayed by logistical or regulatory issues such as visa. Few engineers experienced all of NASA Phase A because that phase emphasizes the early design of a satellite. For all of the satellites except AlphaSat-R2 and BetaSat-R2, the satellite was based on a previously used design. The work for Phase A on a project that builds on a previously used design is greatly decreased compared to the Phase A work for a new design. During BetaSat-R2 the satellite was based on a new design. The visiting engineers from Nation Beta arrived at Supplier Omega1 in two groups. One group experienced Phase A and B of the BetaSat-R2 project. The second group primarily experienced Phase B of the BetaSat-R3 satellite and Phases C and D for both satellites. By identifying the satellite lifecycle phases that engineers experience, one can learn which skills they spent most of their time practicing. This is further explored in the section on capability building where the skills related to different parts of the satellite lifecycle are discussed. Table 6-41 shows that fewer engineers gained experience in the early design phases of a mission; more engineers from all projects gained experience in the later phases. In some projects, this reality was increased because people were hired gradually throughout the project and started to work at different phases. This was true for GammaSat-R1, for example.

Table 6-42: Theoretical Training, Practical Training and On the Job Training Dimensions

Theoretical Training	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Technical satellite lectures	yes	yes	yes	yes	yes	yes
University Degrees	partial	no	no	partial	no	no
License to Technical Documentation	yes	yes	yes	partial		partial
Non-technical training lectures	no	no	no	no	yes	no
Conferences	no	yes	no	no	yes	no
Practical Training	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Group Mission Design Exercise	yes	no	yes	yes	no	yes
Skill-based training courses	partial	partial	partial	yes	partial	partial
Technical Demonstrations	partial	partial	partial	yes	partial	partial
Language Classes	no	yes	no	no	yes	yes
On the Job Training	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
On the job tasks under mentor	yes	yes	yes	yes	yes	yes
Building a training satellite	no	no	yes	yes	no	no

The next three dimensions are combined because they are three parts of a whole. Together they define all the training experiences that the Suppliers provided for the visiting engineers from the Implementer team. Theoretical training aspects include lectures, university degrees and conferences. For all the projects, the training included introductory lectures about satellites and the satellite engineering process. These lectures were generally given to the group of visiting Implementer engineers when they arrived at the Supplier facility. In a few situations, engineers arrived at the Supplier facility in small groups or as individuals; this sometimes led to the lectures being held later in the visit. In only two projects, university degrees were pursued by part of the teams during the training at the Supplier location. The university was the same in both cases – University Omega1 which partnered with Supplier Omega1 to offer part time programs for the trainees. In the AlphaSat-R1 project, the Implementer engineers ultimately decided that there was not enough time to complete degrees and pursue the technical work at Supplier Omega1. During a longer stay at Supplier Omega1, about a dozen engineers from Nation Alpha did complete Master of Science degrees at University Omega1. They worked part time at the university and part time at Supplier Omega1 over a two year period. For about half of the projects, the contract between Supplier and Implementer included access to technical documentation about the satellite. This is included as theoretical training because it provides access to explicitly documented knowledge, but such documentation may not include the practical tacit information required to apply it. The blank box under GammaSat-R1 indicates that the data is uncertain as to whether a license was provided. The BetaSat-R2 and DeltaSat-R2 projects are shown as having partial access to the documentation because the license was limited to certain topics. For the BetaSat-R2/R3 project, for example, the Implementer received more information about the training satellite BetaSat-R3 than the newly designed BetaSat-R2. For the GammaSat-R1, Supplier Tau1 instituted a unique practice of providing lectures in non-technical areas such as time management, cultural sensitivity and leadership. Supplier Tau1 also stands out as the main partner that encouraged the visiting engineers to attend multiple conferences as observers and presenters. Engineers from both Nation Alpha and Nation Gamma attended conferences during their training period.

Ideally, the theoretical training laid a foundation that allowed the engineers to understand the physics and mathematical principles behind the practical and on the job training. Few of the engineers that received training with the Suppliers had previous theoretical training specific to satellite engineering. Suppliers offered several types of practical training that emphasized specific skills. The projects with Supplier Omega1 and Supplier Sigma1 all included a Group Mission Design Exercise during which the trainers gave the visiting engineers the assignment to conduct the early design of a mission. As mentioned above, the engineers were often not present for the early design phase of their own satellite, so the opportunity to do a practice design was significant in that light. Supplier Tau1 did not use the Group Design Exercise, in part because their overall training approach emphasized technical assignments related to completing the satellite task more than assignments related to practicing satellite engineering principles. All projects included some opportunities for learning specific skills, however. Most projects are shown as partial. This indicates that individual members of the Implementer engineer team pursued courses in areas such as programming, soldering or the use of a software modeling tool. These courses were defined based on their disciplinary specialty within the satellite engineering team, so each engineer needed different training. For the BetaSat-R2/R3 project, Supplier Omega1 provided a few skill-based courses to every visiting engineer in the areas of soldering and modeling satellite orbits. Similarly, Supplier Omega1 made an effort to expose all the BetaSat-R2 engineers to several types of technical demonstrations designed to instruct them in how to operate within satellite hardware laboratories. Other Suppliers exposed individual engineers to practical demonstrations related to their disciplines. In three of the projects language classes were an integral part of the training because the Suppliers and Implementers did not speak the same first language. This was true for the Nation Alpha working with Supplier Tau1; for Nation Gamma working with Supplier Tau1 and for Nation Delta working with Supplier Sigma1.

Throughout all the satellite projects, the Suppliers also provided On the Job Training. This was the primary opportunity for the visiting engineers to learn how satellite engineering is done in practice. In two projects under Supplier Omega1, the OJT was supplemented by the visiting engineers working on a training satellite. During BetaSat-R1, they worked on a model but did not bring it to a flight quality status. During the BetaSat-R2/R3 project, the BetaSat-R3 satellite started as a training model that was not designed to be launched. As the project progressed, the decision was made to fly BetaSat-R3 and it transitioned from being a training model to a full satellite project. This had both advantages and disadvantages from a training perspective. The advantage was that the Nation Beta engineers were not closely involved in a project for a flight satellite. They were still assigned to take on the primary responsibilities of building, integrating and testing the satellite. They worked in Supplier Omega1's facilities under supervision of supplier engineers. The decision to fly the satellite increased the urgency to do work of excellent quality. The decision also changed the risk profile for the Supplier. Although BetaSat-R3 was designed to be a practice model on which Nation Beta engineers could learn about satellite engineering, Supplier Omega1 wanted to ensure the success of the satellite since it was built under their name. After deciding to launch the BetaSat-R3 satellite, Supplier Omega1 increased the amount of oversight and guidance they provided to the Nation Beta engineers. The decision to launch created a tension between the need to have a successful satellite and the need to ensure that the Nation Beta engineers had a useful learning experience.

Table 6-43: Mentor-Trainee Accountability System Dimension

Mentor-Trainee Accountability System	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Informal System	Yes	Yes	Yes	No	Yes	Yes
Formal System	No	No	Partial	Yes	No	Yes

The final dimension from the Training View gives one example of the style of mentoring that dominated each project. The mentoring relationship was a major aspect of the training experience for each project. The Suppliers assigned individual mentors to each engineer. The mentors had great influence on the training experience because they defined the engineer's area of specialization, their daily work tasks and the level of formality or accountability that the engineer experienced. The term Formal Mentoring system is used here to mean that there was a common structure that defined for all trainees how they documented interaction with their advisor and work progress. For informal systems, there was no common structure and mentors defined their own ad hoc communication and documentation patterns. As on overall trend, most projects involved an informal relationship between the Supplier mentors and visiting engineers. During BetaSat-R2/R3, this was different because a newly hired training manager at Supplier Omega1 provided specific guidance to encourage consistent communication channels between mentors and visiting engineers. The training manager design templates for regular evaluations and encouraged mentors to write their expectations for the performance of the engineers in work plans. During the BetaSat-R1 project, there was a partially formal system because some mentors naturally chose to structure their mentoring approach by documenting tasks and meeting outcomes. The DeltaSat-R2 project is shown as a combination of formal and informal. The large Supplier Sigma1 did have a formal schedule for the overall training activities of the engineers. In the personal relationships between the engineers and mentors, there was a combination of formal and formal accountability patterns. In all the projects, there was some mechanism for the Suppliers to send feedback to decision makers at the Implementer Organization about the progress of the visiting engineers. It is not immediately clear which approach to mentoring is more effective to provide opportunities for capability building. A less formal mentoring relationship can be effective in a setting in which the visiting engineer is integrated into the Supplier team and working alongside Supplier engineers on project tasks. There may not be explicit meetings for the mentor to give the engineer feedback as a trainer, but there are natural opportunities for feedback through the normal project management process. A formal mentoring relationship may be more valuable when a visiting engineer is not naturally engaged with the same tasks as the mentor. Perhaps the visiting engineer is focused on a training satellite, on practical learning exercises to understand a programming or modeling technique, or on a part of the satellite project that is decoupled from the work by the mentor. In all these cases, a formal mentoring system may be needed to ensure regular communication between the mentor and trainee. This dynamic is proposed in Table 6-44.

Table 6-44: Potential relationship scenarios that align well with Informal and Formal Mentoring

	Informal Mentoring	**Formal Mentoring**
High Integration – ***visiting engineers work closely with supplier engineers on joint tasks for satellite project***	Potentially More Effective	Potentially less effective
Low Integration – ***visiting engineers work separately from supplier engineers on***	Potentially less effective	Potentially More Effective

learning tasks and decoupled satellite project tasks		

Contract View

Table 6-45: Select Dimension from Contract View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*					
Contract View							
Supplier Contract Contents	*Defining Contract between Implementer/ Overseer and Supplier*	Satellite	Training	Ground System	Launch Services	Intellectual Property License	Pre-launch Data

One dimension is featured from the Contract View to explore how the contents of contracts between Suppliers and Implementers were similar and different. As shown in Table 6-46, all of the contracts included a commitment by the Supplier to produce a satellite and provide training. The Implementers and Overseers in these projects explicitly sought Suppliers that could offer training. The training, however, was a secondary product from the perspective of the Supplier. For all the Suppliers, their primary business model focused on the design and delivery of satellites to customers. The engineers that worked in the Supplier firms were hired based on their skills in satellite engineering, not in training budding engineers. The Suppliers accepted a major challenge by contractually committing to provide training during a business satellite lifecycle. All the suppliers were at least partially responsible for providing the ground system and launch services for the satellite. These suppliers specialized in satellites, but they also viewed themselves as providing complete systems to their customers if desired. This meant they would interface between the customer and the company that provided the ground system and launch vehicle, if the contract included such services. The satellites in all cases were built in the Supplier facility (with the main exception being that AlphaSat-R2 was partially integrated in Nation Beta). The ground system needed to be set up in the Implementer nation in order to facilitate independent operations by the Implementer team. Either the satellite Supplier or representatives of the ground system supplier went to the Implementer Nation site to assist in setting up the equipment. As discussed above, some contracts included access to intellectual property. The training dimension emphasized the knowledge that engineers could gain from reading the documentation. The contract also defined how the Implementers could use the intellectual property after the project. Some contracts allowed the Implementers to have full use of the technology – even for future profit making activity. Other contracts allowed only internal use of the IP. The DeltaSat-R2 had one additional contractual perk. DeltaSat-R1 was based on a series of similar satellites. Before DeltaSat-R1 was complete, Supplier Sigma1 provided data from these similar satellites in order to start an early archive of the type of data that would be generated by DeltaSat-R2. Thus, Nation Delta received some benefit from the satellite even before it was launched.

Table 6-46: Supplier Contract Contents Dimension

Supplier Contract Contents	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Satellite	Yes	Yes	Yes	Yes	Yes	Yes
Training	Yes	Yes	Yes	Yes	Yes	Yes
Ground system	Yes	Partial	Yes	Yes	Partial	Yes
Launch services	Partial	Partial	Yes	Yes	Partial	Yes
Intellectual Property License	Yes	Yes	Yes	Partial	Partial	No
Pre-Launch Data	No	No	No	No	No	Yes

Technical Product View

Table 6-47: Selected Dimensions from Technical Product View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*				
Technical Product View						
Satellite Mass	*Defining mass of satellite*	Less than 100 kilograms	100 to 300 kilograms	301 to 800 kilograms		
Satellite Design Life	*Defining design life of satellite*	3 years	5 years	7 years		
Payload	*Delivery satellite service*	Communication payload	Low resolution imager (100s of meters)	Medium resolution imager (10s of meters)	High resolution imager (meters)	Science Payload

Three dimensions from the Technical Product Architectural View are emphasized here because together they provide an indication of the complexity level of each satellite. Using the values for the three Technical Product dimensions, the seven satellites can be grouped into two categories of higher and lower complexity. The complexity of a satellite generally increases with higher mass, longer design life and a higher performance payload. Design life is the estimated lifetime that Supplier proposes for the satellite. In order to increase design life, a Supplier will use design approaches that increase the amount of consumables, increase the confidence in the electronic components and locate the satellite in a longer lived orbit. The primary payloads for the seven satellites in these projects were optical imagers. The performance of an optical imager increases as the spatial resolution of its images increases. The measure of spatial resolution is the ground sampling distance or the smallest object that can be distinguished in an image. Thus a better spatial resolution has a smaller value.

Table 6-48: Mass, Design Life and Payload Dimensions

Mass	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Less than 100 kg	Yes	No	Yes	Yes	No	No
100 to 300 kg	No	Yes	No	Yes	Yes	No
301 to 800 kg	No	No	No	No	No	Yes
Design Life	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
3 years	No	Yes	No	No	No	No
5 years	Yes	No	Yes	Yes	Yes	Yes
7 years	No	No	No	Yes	No	No
Payload	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Communication Payload	Yes	No	No	No	No	No
Low resolution imager (100s of meters)	Yes	No	No	No	No	no
Medium resolution imager (10s of meters)	Yes	No	Yes	BetaSat-R3	No	Yes
High resolution imager (meters)	No	Yes	No	BetaSat-R2	Yes	Yes
Science Payload	Yes	No	No	No	No	No

Figure 6-2 and Figure 6-3 plot the three technical characteristics of the seven satellites. Each bubble represents a satellite, where the size of the bubble in Figure 6-2 shows the satellites' design life. The size of the bubble in Figure 6-3 shows the mass of the satellites. From both figures it is clear that there are two groups of satellites. The more complex satellites are AlphaSat-R2, GammaSat-R1, BetaSat-R2 and DeltaSat-R2. All of them have performance payloads and medium to high mass. In Figure 6-3 these four satellites are grouped in a circle. The three less complex satellites are also grouped together in Figure 6-3; they are AlphaSat-R1, BetaSat-R1 and BetaSat-R3. Five of the seven satellites have design lifetimes of five years. The shorter lifetime estimate for AlphaSat-R2 is understandable because it was a new design from a new Supplier in a new orbit. The Supplier provided a conservative estimate. The graph in Figure 6-2 is partly displaying the overall time trend of the performance improvement of satellites with a mass under 1000 kilograms. The satellites based on earlier designs are generally the less complex, lower performing satellites (AlphaSat-R1, BetaSat-R1 and BetaSat-R3). The satellites based on later designs are more complex and powerful. As the performance of systems in the small satellite class improved, customers demanded the best of each generation.

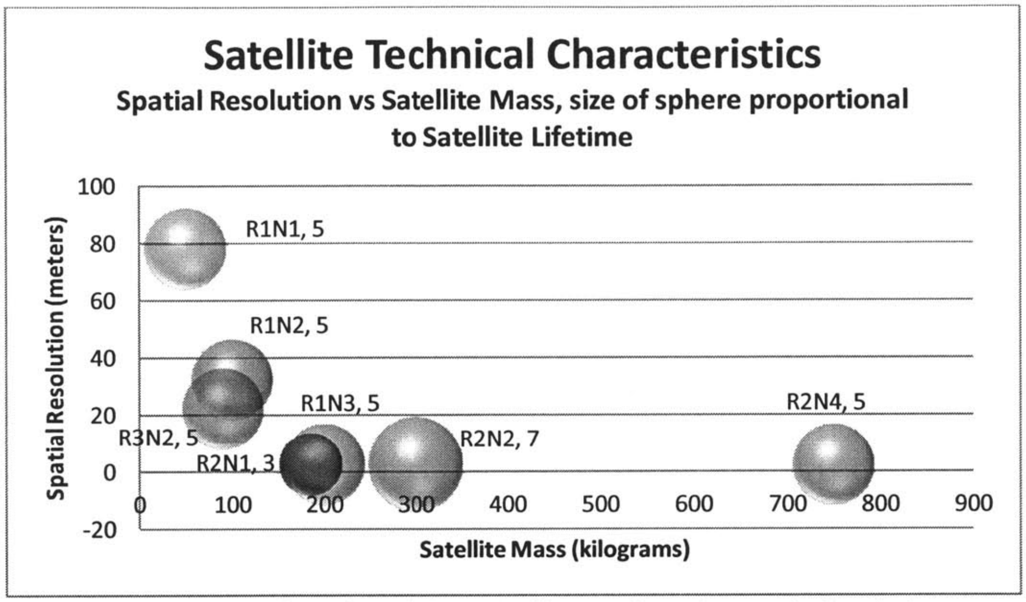


Figure 6-2: Graph of Spatial Resolution Vs Satellite Mass Shows Comparative Complexity

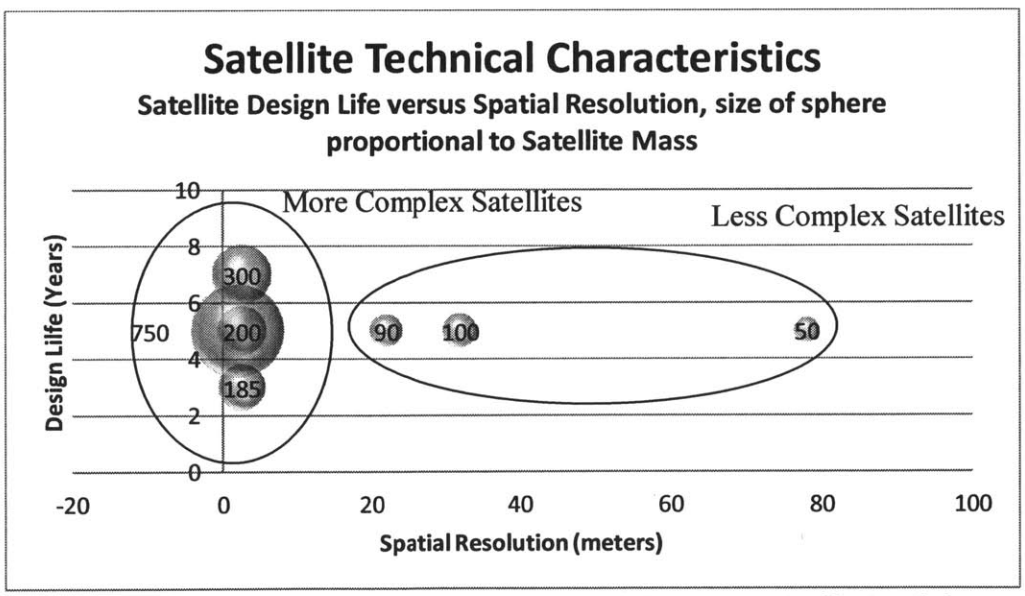


Figure 6-3: Graph of Satellite Design Life versus Spatial Resolution Compares Satellite Complexity

Technical Approach View

Table 6-49: Selected Dimensions from Technical Approach View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*

Technical Approach View					
Satellite Platform Approach	*Defining heritage of satellite platform*	Heritage Platform with Multiple Flights	Heritage Platform with One Flight	New Platform	
Satellite Engineering Approach	*Defining Satellite Engineering Approach*	Small Satellite Approach	Traditional Approach		

Two dimensions summarize the Technical Approach Architectural View. The Satellite Platform approach defines the number of times the core design for a satellite was used before the project. The satellite platform is the design of the satellite bus (spacecraft excluding payload) that can be repeated across missions. The platform includes a combination of subsystems that can accommodate a certain range of payloads. The Satellite Engineering Approach describes the overall philosophy of the satellite Supplier.

Table 6-50: Satellite Platform Approach and Satellite Engineering Approach Dimensions

Satellite Platform Approach	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Heritage platform - multiple flights	Yes	No	No	BetaSat-R3	Yes	Yes
Heritage platform - one flight	No	No	Yes	No	Yes	No
New platform	No	Yes	No	BetaSat-R2	No	No
Satellite Engineering Approach	**AlphaSat-R1**	**AlphaSat-R2**	**BetaSat-R1**	**BetaSat-R2/ BetaSat-R3**	**GammaSat-R1**	**DeltaSat-R2**
Small satellite approach	Yes	Yes	Yes	Yes	Yes	No
Traditional Approach	No	No	No	No	No	Yes

There is an almost even split among the seven satellites into the three categories. Three of the satellites - AlphaSat-R1, BetaSat-R3 and DeltaSat-R2 – were designed based on a platform that was previously used on multiple flights. The Supplier had experience observing how the components and materials for the satellite operated in space. The risk of a satellite mission is reduced by using a platform with the heritage of multiple flights. Two of the satellites – BetaSat-R1 and GammaSat-R1 – were based on platform designs that had been flown just once before. The other two satellites were new platforms and original designs. The AlphaSat-R2 new platform was the basis for GammaSat-R1 – both delivered by Supplier Tau1. For a customer who chooses a satellite, long platform heritage reduces risk but may also reduce technical performance. Both Nation Alpha and Nation Beta chose to accept the risk of a new platform in their second satellite projects in order to have further control over the specifications and to allow their engineers to participate in a fresh design.

The second dimension shows which satellites were built with a small satellite versus a traditional satellite engineering approach. All the projects were built by Suppliers who follow the small satellite philosophy except for DeltaSat-R2 working with Supplier Tau1. This is not representative of the satellite market. Again, it is a result of the case study selection and the strong relationships within the space community. The core leadership of Supplier Tau1 learned satellite engineering from Supplier Omega1 and University Omega1. They continued with the same design philosophy that Supplier Omega1 taught. Both Supplier Omega1 and Supplier Tau1 seek to build relatively small, focused satellites that are affordable and use the latest electronic components. These electronic components were not necessarily designed to operate in space, but they are capable of better performance than many space qualified components because they are newer. The small satellite approach also includes working with small, closely knit teams. The program management aspects are designed to reduce overhead and avoid unnecessary formality or documentation.

Management View

Table 6-51: Select Dimension from Management View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Management View					
Review Strategy	*Defining role of supplier and trainee during reviews*	Supplier and trainee engineers presented to customer management together	Supplier engineers presented; trainees and customer management reviewed	Supplier engineers did primary presentations; customer management reviewed	Trainee engineers did primary presentations to customer management

One major difference between the satellite projects was the division of labor during project reviews. Project reviews are a management tool to monitor and communicate progress. For satellite projects there are industry wide patterns of reviews that are designed to ensure each phase of the satellite lifecycle is complete before proceeding. Generally, the Supplier is responsible for presenting review material to their customer to demonstrate their effort. Because the visiting engineers from the Implementer Organization worked alongside the Supplier on the satellites, their role in the reviews was ambiguous. Different satellite projects defined roles in several ways. The two projects with Supplier Tau1 were AlphaSat-R2 and GammaSat-R1. For these projects, the Supplier and trainee engineers presented to the customer management together. This aligns with other aspects of the Supplier Tau1 training approach. They integrated the visitors closely into their teams. For the BetaSat-R1 and DeltaSat-R2 projects, the Supplier engineers did the review presentations and the trainees joined the customer management to review the work. The task of presenting and the task of reviewing are both technically challenging. In either case, the goal is to ensure that no problems are overlooked. The BetaSat-R2 and BetaSat-R3 satellite projects were procured together, but the visiting Implementer engineers from Nation Beta had different roles in the two projects. BetaSat-R2 was primarily the responsibility of the Supplier engineers. The visiting Nation Beta engineers shadowed the supplier engineers to learn their process. The Nation Beta engineers had more responsibility to work on BetaSat-R3. Thus they had more responsibility in the BetaSat-R3 reviews. The Nation Beta engineers presented to their own management with the coaching of the Supplier team to demonstrate the progress of BetaSat-R3. The review process provides an opportunity for trainee engineers to demonstrate their knowledge by either presenting or reviewing the work of the supplier. Reviews are often high pressure events where engineers give a presentation and answer questions by external reviewers or high level management. The review creates an environment that tests the knowledge of the trainee engineers, especially when they are given responsibility.

Table 6-52: Review Strategy Dimension

Review Strategy	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Supplier and trainee engineers presented to customer management together		Yes	No	No	Yes	No
Supplier engineers presented; trainees and customer management reviewed		No	Yes	No	No	Yes
Supplier engineers did primary presentations; customer management reviewed		No	No	BetaSat-R2	No	No
Trainee engineers did primary presentations to customer management		No	No	BetaSat-R3	No	No

Policy View

Table 6-53: Select Dimension from Policy View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*			
Policy View					
Project Political Champion	*Generating Political Support for Project*	National Head of Government	National Minister	National Head of State	

Table 6-54: Project Political Champion Dimension

Project Political Champion	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
National Head of Government	Yes	Partial	No	No	Yes	N/A
National Minister	No	No	Yes	Yes	No	N/A
National Head of State	No	No	No	Yes	No	N/A

As discussed in the section on Contextual Opportunities and Constraints, all of the satellites in these case studies were funded by governments. The role of a high level political champion to initiate and maintain political support and funding was important in each project. This champion role was played by people in different positions, especially the head of state, head of government or a national minister. In Table 6-54 the label partial indicates that the political champion left office during the timeframe of the project. The impact of the political champion can be especially high at the very beginning and ends of projects. At the beginning, it may be necessary to convince the nation or key decision makers that pursuing a satellite project is a good idea. At the end of a project, several of these satellites experienced launch delays. The political champion worked to help keep public support of the satellite projects despite disappointing delays and uncertainty about the resolution. This was important for AlphaSat-R2, BetaSat-R2 and BetaSat-R3. Political Champions and their team members sometimes have to address policy challenges and barriers by coordinating and negotiating with other nations. There was not one obvious political champion for the DeltaSat-R2 project, but there were policy challenges that the Nation Delta government had to resolve with their partners. (The table shows N/A because the data was not applicable in this case study.) One negotiation brought together representative of the Supplier Nation, the Implementer Nation, the launching nation and a neighbor of the launching nation to resolve a dispute that delayed the launch. When Nation Alpha worked with Supplier Lambda1 for launch, there were policy challenges that required careful coordination with Nation Lambda. The Project Political Champion thus plays the role of both support and problem solver in these projects.

Cultural and Social View

Table 6-55: Select Dimension from Cultural and Social View

Generic Forms	*Function*	*Examples of Forms from Existing Projects*				
Cultural and Social View						
Educational Background of Trainee Engineers	*Defining educational preparation of*	Local University Degrees (National	Local University Degrees (International	Foreign University Degrees	Local Technical Degrees	

	trainee engineers	System)	System)			

The final architectural view considers Cultural and Social aspects of the satellite projects. Here the key example of social issues is the variation in types of educational training. The data captures the type of university that engineers from the projects attended. Little was available on this topic for AlphaSat-R1 (thus table is labeled N/A), but note that the engineers were farther along in their careers than those from other cases. Many had already worked as professors or professionals in industry.

Table 6-56: Education Background of Trainee Engineers Dimension

Educational Background of Trainee Engineers	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
Local university degrees (national system)	N/A	Most	Most	Some	Some	Some
Local university degrees (international system)	N/A	Few	Few	Few	Some	Few
Foreign university degrees	N/A	Few	Few	Few	Some	Some
Local technical diplomas	N/A	Few	Few	Some	Few	Few

For the remaining projects, there is a blend of engineers with various backgrounds. The Nation Beta engineers were generally educated within their own country. Some attended universities and received their Bachelor of Engineering; others attended polytechnics and received technical diplomas. The training for technical diplomas emphasizes practical knowledge over theoretical aspects. The group that had this type of training was largely in the second group of trainees that visited Supplier Omega1 and worked on BetaSat-R3. They arrived during the last phases of BetaSat-R3. In this way, their training in technology fit their assignment to work on the assembly and integration of BetaSat-R3. The engineers from GammaSat-R1 had diverse backgrounds, in part because the universities located in Nation Gamma are a mix of local and international institutions. Several international systems are available within Nation Gamma. The type of system influences the language of instruction and the curricular offerings. Several engineers took advantage of nation programs to sponsor studies toward a Bachelors degree at a foreign university. This was true for several engineers from Nation Delta and Nation Gamma. The engineers that studied abroad before traveling to the Supplier site for satellite training had the advantage of being more accustomed to living in a new location and potentially using a second language in a working environment.

6.1.2.3 Architectural Definition Step Seven

The timeline in Table 6-57 shows the major events for all six satellite projects in the case studies. Five generic events are shown for each project: Facilitating Events, Project Initiation and Approval, Trainees at Supplier Location, System and Facility Development and Satellite Launch. The projects are displayed to give accurate relative dates, although the absolute dates are hidden to preserve anonymity. The project duration is defined based on the years from initiation to launch, although the project continued in an operational phase after launch. The first project to start was AlphaSat-R1. The period from project initiation to launch was six years. The next project was BetaSat-R1, which lasted for years. The project for AlphaSat-R2 started around the same time as BetaSat-R1 and lasted nine years from initiation to launch. The DeltaSat-R2 project lasted four years. The BetaSat-R2 project lasted five years; The GammaSat-R1 project started around the same time and launched within three years. The project timing is highly influenced by the launch. The actual time to design and build these satellites at the Supplier site is between 2 and 5 years. Both of Nation Alpha's satellites faced multiyear launch delays. For various reasons, the Implementer and Overseer Organizations took responsibility for arranging the launches and it was a complex and time consuming process. Finding the launch for AlphaSat-R2 was even more complex because of the requirement to go to an uncommon orbit. During project years 12 to 15, AlphaSat-R2 was essentially complete, but the Nation Alpha team continued to work on it and improve it while they sought a launch.

The timelines also show how long engineers from the Implementer teams spent visiting and working at the Supplier sites. These training periods range from one to four years. For projects AlphaSat-R1, BetaSat-R1 and DeltaSat-R2 one large team spent the entire period with the supplier. For projects AlphaSat-R2, BetaSat-R2, BetaSat-R3 and GammaSat-R1, the transitions between the home nation and Supplier nation were more fluid or the teams arrived in groups. The most fluid living situation was that of the GammaSat-R1 team. The Nation Gamma engineers traveled frequently between Nation Gamma and Nation Tau in order to maintain responsibilities in both places while being primarily based in Nation Tau with Supplier Tau1. These projects occurred over a period of about two decades. During this time, the small satellite technology transitioned from being the realm of university research to being used for commercial data production.

Table 6-57: Joint Timeline for Six Satellite Projects

Project Year	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
1	Facilitating Event; Project Initiation					
2	Project Initiation					
3						

4	Project Initiation; Trainees at Supplier Location; System & Facility Development	Facilitating Event				
5	Trainees at Supplier Location; System & Facility Development					
6			Facilitating Event: Project Initiation			
7	**Satellite Launch**	Project Initiation; Trainees at Supplier Location; System & Facility Development	Project Initiation			
8		Trainees at Supplier Location; System & Facility Development	Facilitating Event; Trainees at Supplier Location: System & Facility Development			
9		Trainees at Supplier Location; System & Facility Development	Trainees at Supplier Location; System & Facility Development			
10		Trainees at Supplier Location; System & Facility Development	Project Initiation; Trainees at Supplier Location; System & Facility Development			

			; Satellite launch			
11		Trainees at Supplier Location; System & Facility Development				Project Initiation
12		System & Facility Development		Facilitating Event	Facilitating Event	Trainees at Supplier Location; System & Facility Development
13		System & Facility Development		Project Initiation; Trainees at Supplier Location; System & Facility Development	Project Initiation; Trainees at Supplier Location; System & Facility Development	Trainees at Supplier Location; System & Facility Development
14		System & Facility Development		Trainees at Supplier Location; System & Facility Development : System & Facility Development	Trainees at Supplier Location; System & Facility Development	Trainees at Supplier Location; System & Facility Development
15		System & Facility Development		Trainees at Supplier Location; System & Facility Development	Trainees at Supplier Location; System & Facility Development	Satellite Launch
16		Satellite Launched		Trainees at Supplier Location; System & Facility Development	Trainees at Supplier Location; Satellite launch	
17						
18				Satellite Launch		

6.1.3 Reflections on Project Architecture

The discussion above defined a seven step process by which to describe the architecture of an existing system. This section reflects on the approach as well as the implications of the architectural descriptions of the six collaborative satellite projects.

Critique of Definition of Architecture

There are some weaknesses in the seven step process used here to describe the architecture of an existing system. The seven steps are as follows: 1) Identify Primary Stakeholders for which the system is designed to produce value; 2) Identify the constraints/opportunities, requirements and objectives of the stakeholders; 3) Define the functions required to achieve Part 2; 4) Identify the generic objects of form that execute the functions; 5) Identify the set of alternatives for specific forms; 6) Group the dimensions (combinations of function, form and generic forms) into categories that represent stakeholder views; and 7) Summarize how the system changed over time. The weaknesses of these seven steps relate to their handling of stakeholders, project structure, the interactions between elements of form, and the set of potential forms. The first step for architectural definition is to define stakeholders. The description above focuses only on the primary stakeholders of the Implementer and Overseer Organizations. These are certainly important stakeholders, but a much richer description of stakeholder objectives and concerns can increase understanding of the system. The second area of weakness is the treatment of project structure. System structure is an aspect of architecture that describes the arrangement of system elements in physical space or the relationships between elements of form. A deeper exploration of stakeholder relationships is one aspect of describing system structure, but structure can also be considered in terms of relationships between other forms such as individuals and technology. The third weakness of the view above is that it does not provide a convenient way to consider the interactions between elements of form in the project systems. The assignment of a specific instance of form to a particular function in one Architectural View may impact the opportunity to assign form to a function in another Architectural View. The fourth weakness is that the discussion above is limited by the data from six collaborative satellite projects. It shows potential options for forms that can be assigned to functions based on the set of forms used by the six projects. In general, there may be additional examples of form that are valid options. These additional options are not presented above. Each of these weaknesses is discussed further below.

Stakeholders

The discussion on system context identified the Implementer and Overseer Organizations as the Primary Stakeholders of the collaborative satellite projects. This is a useful first step; it allows a definition of the project requirements and objectives based on a narrow set of organizations. In general, however, a stakeholder is any organization that is impacted by or that impacts a system. The actual list of stakeholders for collaborative satellite projects is much longer. Some of the generic categories of stakeholders that might be involved in any of the six collaborative satellite projects include the following: Satellite Data End Users, Citizens in the Implementer Country, National Government of the Implementer Country, Government Funding Bodies in Implementer

Country, Government Regulatory Bodies in Implementer Country; Complementary Firms in Implementer Country; Competitor to Implementer; Implementer and Overseer Employees; Launch Provider; Launch Vehicle Manufacturer; Launch Facility Operator; Supplier, Supplier Subcontractor, Supplier Competitor; Supplier Employees; Supplier Government Regulator; Supplier Community. Depending on the context, some of these categories may overlap in various ways. The purpose of a stakeholder analysis is to examine the nature of the relationship between actors in a system in order to better understand how their needs are aligned or misaligned. The Implementer is the central stakeholder in the collaborative satellite projects. They interact with many of the other stakeholders, but the analysis can also consider non-central interactions that do not involved the Implementer.

Figure 6-4 provides a starting point to extending the consideration of stakeholder relationships and needs in collaborative satellite projects. The figure is a Stakeholder Value Network for a generic collaborative satellite project similar to those described in this thesis. A Stakeholder Value Network is a tool to show the flow of value in the form of exchanges by actors in a system. Value is a benefit that comes at a particular cost to a stakeholder. There are four types of value flows in a Stakeholder Network; they are political, information, goods & services and financial. These four types of value cover a broad range of interactions. Figure 6-4 shows many of the generic stakeholder categories introduced above. The stakeholders are shown in boxes that are color coded to identify their countries. Each stakeholder is associated with the Implementer, Launch Provider or Supplier. In general, some of the stakeholders, such as subcontractors to the supplier, may be from additional countries. The value flows in the network are color coded to indicate whether they are can be described as political, information, goods/services or financial flows. The Implementer is placed at the center of the network. The Implementer works closely with the Implementer Employees, Overseer, Supplier and Launch Provider to pursue the project. In some cases, the Implementer interacts with other parts of the national government and regulators by way of the Overseer. The Overseer is usually a government organization that represents the Implementer in matters of funding, regulation and aligning activity with the national vision. Part of the Implementer's purpose is to provide benefit to the General Public in their country by delivering information about the state of the environment in the Implementer's country. In some cases, the Implementer does not interact directly with the general public; there are government data users that receive information from the Implementer and convert that into services that more directly impact the general public. For example, if the Implementer operates a satellite that captures images of an area with risk of flooding, they may send those images to a government office concerned with emergency management. This emergency management office will process the information and combine it with other types of data to produce a recommendation to the government and to citizens about how to reduce their risk. They may issue a warning that some citizens should temporarily relocate. Through such a process, there is value flow from the Implementer to the General Public. The value loop is completed if the Public returns political support to the Government Data Users, and they return political support to the Implementer.

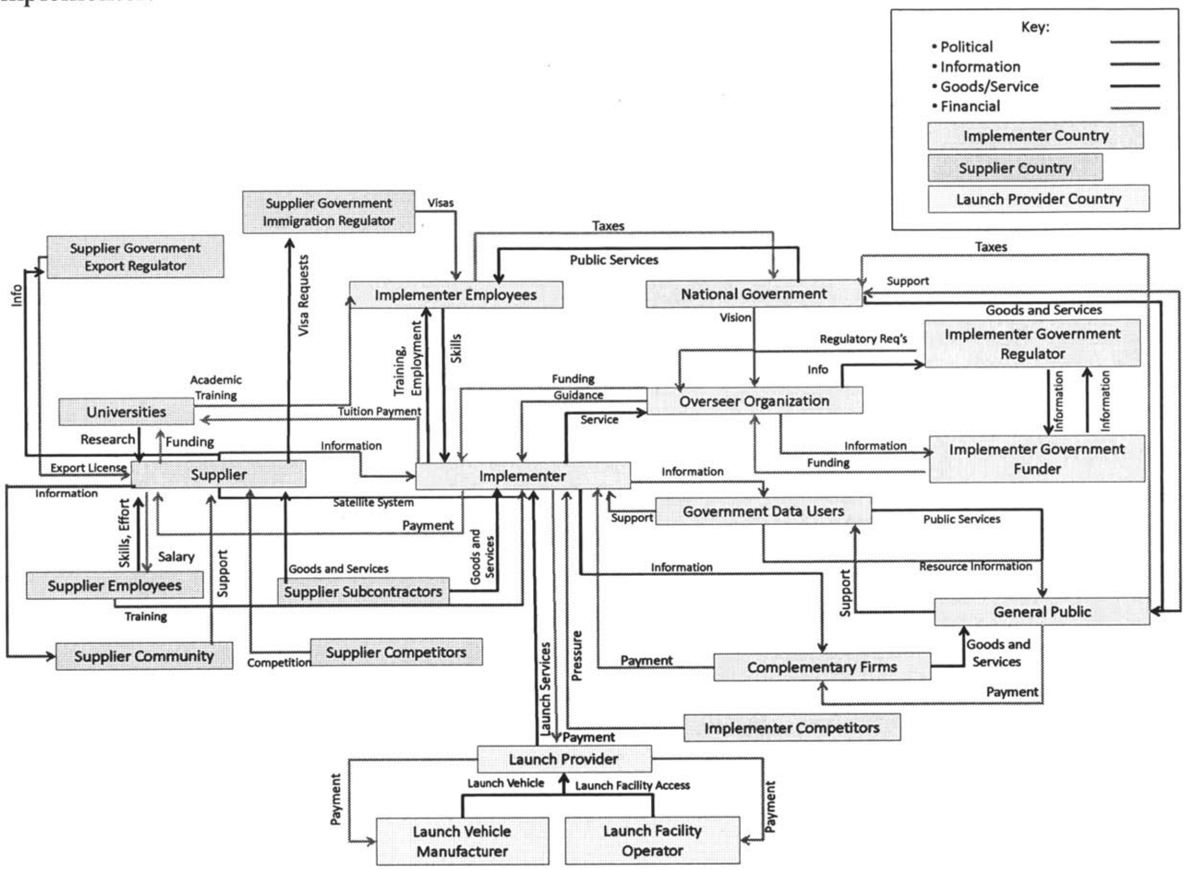


Figure 6-4: Preliminary Stakeholder Value Network for Generic Satellite Project

The Supplier and Launch Service Provider each exist in their own context with a set of close stakeholders. There are a few examples of value flowing across country contexts. One value loop relates to the process of getting visas that allow engineers from the Implementer Organization to spend months working at the Supplier Organization. In this value loop, the Supplier submits requests for visas to the Immigration Regulator in their country. The Immigration Regulator grants visas to the Implementer Employees. The Employees provide skills and work effort to the Implementer who provides payment to the Supplier. A stakeholder analysis, using a tool such as a Stakeholder Value Network, is one way to broaden the description of the architecture of a system. There are other frameworks to analyze stakeholders. Some consider issues such as power instead of value flows. Future work can collect data for the specific collaborative satellite projects to see how their stakeholder interactions are similar and different.

Structural Aspects of Project Architecture

The Stakeholder Value Network is one way to explore the structure of the satellite project architecture. There are many other aspects of system structure as well. The structure of a system defines the relationship between elements of system form. The structure may show a literal relationship, such as the layout of objects in physical space. Structure can also show figurative relationships, such as the relationships between teams in an organizational hierarchy. The approach presented above has limited discussion of structure. This is partly due to the available data and partly due to the focus on the functional aspects of the architecture. There are five major categories of form in the collaborative satellite projects: Individuals, Organization, Technical Products, Technical Equipment and Facilities. A description of structure could elucidate relationships within and between these categories. Individuals have relationships with each other both within and across organizations. In these projects, most individuals work within small teams that are defined based on function. The functional teams sometimes need to work closely with other functional teams to achieve their goals. One potentially useful description of structure would be to show how individuals on different small teams interacted. For example, while an Implementer Engineer was working at the Supplier on the Operations Team, which other engineers from the Supplier Organization did he work closely with? In addition, which engineers who were based at the Implementer Organization did he work closely with? The structure of these team interactions could reveal examples of who had common learning opportunities. Each of the three Suppliers had different Organizational Structures. For two of the Suppliers, they began as small, university out firms and grew into medium sized, independent firms. As they grew, their organizational structure evolved. Nation Beta worked with Supplier Tau1 at two stages of their organizational evolution. A structural description could explore potential impacts of the change on the Implementer engineers. The major technology products in these projects are the satellites. Each satellite has particular structural architecture that is defined by the needs to withstand the operational environment and launch. There is also a structure that defines the way the satellite interacts with other aspects of the larger technical system – including the launch vehicle, ground station, image processing system and data customers. Finally, satellite projects take place in the context of technical equipment and facilities. These also have a structure that may be described. Some of the equipment and facilities are generic – such as the desks and offices where engineers work. Some of the equipment and facilities are highly specialize to satellite engineering. The physical arrangement of equipment and facilities may impact the project participants. For example, the arrangement of desks and office space may influence interaction patterns between engineers and the size of work facilities may influence the number of people that participate in specific engineering activities. There is potential to learn from further descriptions of structure in future work.

Interactions between Forms

The third weakness of the architectural definition is that it does not indicate potential interactions between elements of form. The architecture is divided into Views. Each view is composed of various dimensions. A dimension includes one instance of a function, a generic object of form that executes that function and a set of specific objects of form that may be assigned to the function. The process of architecting a system means assigning a specific object of form to each function. The Views and Dimensions are one convenient way to introduce the functions and set of decisions. The functions are listed in tables as if each decision of a specific form is independent of other decisions. In reality, there is the potential for dependencies between different dimensions. Choosing a particular object of form in one dimension may influence or constrain the choice of form in another dimension. The data generated in this study gives initial indications of some of these relationships, but future work is needed to confirm and clarify them.

Table 6-58 gives some examples of the relationships identified between dimensions in different architectural views or between contextual factors and architectural dimensions. This is not an exhaustive list, but it illustrates the types of reasoning that underlie this discussion. The first example considers how the choice of Supplier Organization influences the Role Assignment Philosophy through which engineers from the Implementer Organization are appointed to specific technical responsibilities during their visit to the Supplier. Once a Supplier is chosen, several characteristics of the organization influence the potential role assignments for visiting engineers. The team structure is often the basis for matching engineers to mentors. The satellite lifecycle influences the choice because it determines the specific activities that Supplier engineers pursue as they develop a satellite. The procurement approach determines the types of technology that Suppliers buy and their level of interaction with subcontractors. All of this influences the nature of responsibilities for engineers working in the Supplier context. Further examples are explained in the table.

Table 6-58: Examples of Relationships between Project Dimensions

Influencing		Influenced		
Architectural View	Dimension	Architectural View	Dimension	Description
Organizational	Supplier Organization	Personnel Management	Role Assignment Philosophy	The Approach to assigning roles for the engineers during training is influenced by the choice of Supplier organization. Characteristics of the Supplier such as their team structure, project management approach, satellite lifecycle, technology development or procurement approach all influence the potential roles that engineers can take during training.
Organizational	Implementer Visiting Team Size	Personnel Management	Role Assignment Philosophy	The size of team of engineers that visits the Supplier influences the Role Assignment Philosophy. With fewer team members, Implementers may prioritize which roles they want engineers to have or give them multiple roles.
Organizational	Supplier	Supplier	Supplier	Several dimensions of the Supplier

	Selection Process, Priority Supplier Attributes, Competing Suppliers	Selection	Organization	Selection View come together to determine which Supplier Organization is chosen. The Supplier organization selection is a function of the set of competing suppliers, the priority attributes and the selection process.
Technical Approach	Constellation Participation	Technical Product View	Orbital Characteristics	Constellations are a group of satellites that fly in a coordinated orbit, thus choosing to join a constellation influences the orbital characteristics of altitude and inclination.
Technical Approach	Satellite Engineering Approach	Technical Product	Mass, Payload, Lifetime, etc	The satellite engineering approach influences all the technical product dimensions, especially mass, payload and lifetime. The small sat approach tends toward smaller, less complex satellites. They trade cost for reliability and performance to some extent.
Policy View	Project Approval Process	Contextual Constraint and Opportunity	Level of Space policy infrastructure	If there is high policy infrastructure, the approval process is likely to be more structured.

Set of Potential Forms

A final critique of the architectural definition used to answer the research questions is that it only includes the set of potential forms for each function that were used in case study projects. This was done purposely, in part to provide scope. The forms were also limited because they represent the set of examples for which there is concrete evidence. In general, however, it is possible for other potential forms to be included. As a caveat to the reader, the set of options proposed for the Implementer Organizations, Supplier Organizations, Supplier Selection Process, Engineering Evaluation Process and other dimensions may be larger in theory than presented above. Future work could consider more examples from other projects or propose examples that have not yet been used.

Reflection on the Similarities and Differences of the Project Architectures

One of the benefits of defining and exploring the architectures of the six collaborative satellite projects is that the architectural analysis highlights specific ways in which the projects are similar and different. At a high level, the six collaborative projects are very similar. In each case, the countries chose to pursue long term capability to build satellites locally by procuring a small, remote sensing satellite and paying for training. These same countries could have chosen other methods to reach the same goal. Based on the examples of other countries, here are a few alternative approaches: 1) Send engineers from the country to study at foreign universities. When they return, have these graduates start a local satellite project and lead local students. 2) Start satellite activities with a very simple university project that can be built with minimal outside support, such as a CubeSat. 3) Start a government satellite project and hire external consultants to work alongside government engineers in local facilities. 4) Buy a satellite to operate but do not pay for satellite engineering training. The four countries did not pursue any of these alternatives, thus they appear on the surface to be very similar. The detailed architectural analysis, however, reveal many differences that may have significance in impacting their project outcomes.

Table 6-59 presents some of the Architectural Dimensions in which Nations showed variation or similarity as they assigned forms to functions. This is not an exhaustive list, but it illustrates an overall trend that the countries made different choices more often than similar choices. In some cases the variation is subtle. For example, in the dimension of Engineer Selection Organization, all Implementers played that role, but they varied in how the Supplier Organization partnered with them in that role. Other dimensions are much more distinct. The types of implementer organizations, supplier organizations, team sizes, supplier selection processes, approaches to theoretical and practical training – all of these dimensions represent significant variation among the case study projects.

Literature in the Technological Learning community has not generally explored the many options facing learning organizations as they pursue foreign technology sources to help them gain new capabilities. The dimensions in both columns of Table 6-59 show that there are many decisions to be made as part of interacting with a foreign technology source. Within each decision there are several options. Technological learning literature does not provide empirical examples or theoretical guidance about which options to consider. Other types of literature may provide helpful guidance, however. This will be explored further in a later section.

Table 6-59: Examples of Architectural Dimensions that showed more and less variation among projects

Examples of Architectural Dimensions with *Variation* Among Projects	**Examples of Architectural Dimensions with *Similarity* Across Projects**
1. Implementing Organization 2. Supplier Organization 3. Implementer Visiting Team Size At Supplier 4. Role Of Supplier As Engineer Selection Organization for Implementer Engineers 5. Implementer Engineer Recruitment Process 6. Supplier Selection Process 7. Training Project Phase (that visiting engineers experienced at supplier) 8. Theoretical training	1. Overseer organization 2. Role of Implementer as Engineer Selection Organization 3. Engineer Recruitment source 4. Engineer evaluation process 5. Priority supplier attributes 6. Implementer facility status 7. Supplier facility status 8. On the Job Training Approach

9. Practical training 10. Mentor-trainee accountability system 11. Complexity of Technical Product 12. Satellite Platform Heritage 13. Satellite Engineering Approach 14. Role of Implementer Engineers in Reviews 15. Educational Background of Implementer Engineers	

Collaborative Satellite Projects as Complex, Socio-Technical Systems

As a final reflection on the architectural analysis, the answers to Research Questions 1 and 2 are helpful in demonstrating the nature of the collaborative satellite projects as complex, socio-technical systems. The list of Architectural Views and Dimensions clearly displays the social and technical components of the systems and their functions. The analysis also shows that the projects are complex even though their time scale and the number of people directly involved is small compared to some complex systems such as a large corporation. The complexity of the collaborative satellite projects is increased by the participation of organizations and individuals from several organizations, located in several countries with several types of nationality, work culture and educational backgrounds. These collaborative satellite projects provide a compelling laboratory for studying the architecture of complex, socio-technical systems. They are complex enough to be interesting, but not so complex that it is difficult to document their architectures.

6.2 Observations in Capability Building

The next two research questions explore the evidence regarding capability building from the collaborative satellite projects. Research Question 3 asks, "What capability building experiences do individuals have?" while Research Question 4 considers capability building achievements at the organizational level. In preparing for answering the research questions, this section identifies the relevant capabilities that individuals and organizations may build in the context of collaborative satellite projects and defines capability building.

6.2.1 Technological Capabilities in Satellite Engineering

Technological Capability for both individuals and organizations refers to the ability to effectively apply technology (products, processes and knowledge) to productive activity. The capabilities required to participate in a certain technical area include applying the skills and mastering the knowledge required to achieve the goals of that discipline. In the general area of satellite engineering, there are many distinct skills and knowledge sets that make up the relevant capabilities. These capabilities can be categorized using three axes: topic, level of application and level of codification. The topic defines the discipline within satellite engineering to which a capability relates. In satellite engineering the spectrum of topics includes those based on technical principles and those related to project and program management. Level of applications describes whether a capability is more theoretical or more applied. Theory is general and outside the context of particular system. Application customizes general theory according the context of a specific scenario. Level of codification describes whether a capability is based more on tacit or explicit knowledge. Tacit knowledge is difficult to express in words, whereas explicit knowledge is well documented or easy to document. A given topic may include elements which vary along the spectrum of application level and codification level. The three axes of topic, level of codification and level of application are shown graphically in Figure 6-5.

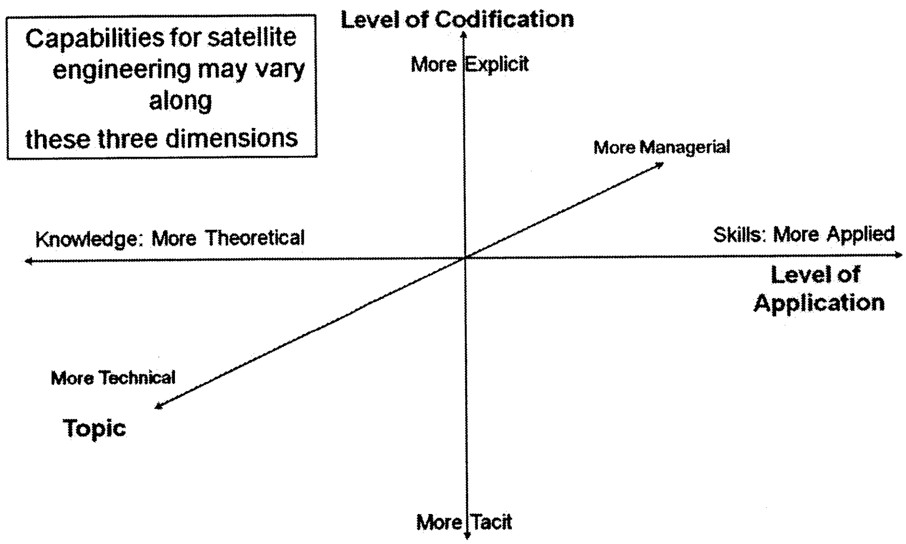


Figure 6-5: Three axes of satellite engineering capabilities are topic, codification and application

An illustrative example that shows how a single topic can include multifaceted aspects is the topic of requirements management. This is one of the early steps of the satellite development process; it involves defining the technical performance requirements that will satisfy the needs of the customer or stakeholder. After the definition of requirements, the management continues by documenting requirements, specifying them at increasing levels of detail, managing changes and verifying that requirements are met. Referring to the application axis in Figure 6-5, there are both theoretical and applied aspects of requirements management. Referring to the codification axis, there are both tacit and explicit aspects of requirements management. Examples of these variations are given in Table 6-60. The table is created by choosing a specific point along the Topic Axis and exploring the plane that varies along the application and codification axes.

Table 6-60: Example showing how the topics of Requirements Management have elements along codification and application axes

Topic: Requirements Management		**Application Axis**	
		Theoretical	**Applied**
Codification Axis	**Explicit**	• Understanding physics principles that govern system performance	• Applying physics principles to define a feasible requirement
		• Understanding the documented guidance to write requirements with one actor,	• Writing requirements with one actor applying one action to one object

		one action and one object	
		• Understanding the process of documenting requirement changes	• Using the documentation process to update a requirement
	Tacit	• Understanding the concepts that characterize requirements that effectively capture and communicate stakeholder needs	• Writing clear, unambiguous requirements • Translating stakeholder goals into technical requirements

Table 6-60 explores various facets of the work to generate, document and manage changes in requirements for a satellite system. The table is divided into quadrants that represent different combinations of codification and application. Examples of tasks are placed into quadrants according to their nature. In each row examples are paired to show how a particular task is multifaceted. The top row shows two sides of the capability to ensure that a requirement for a satellite system is feasible because it is based on sound physics principles. On one hand, this capability is theoretical because it includes having knowledge of the general physics principles that govern the system performance. On the other hand, this capability is applied because the physics knowledge is used in the context of a specific requirement and system. This capability straddles two sides of the application axis, but it is only on one side of the codification axis. The knowledge that this capability is based on is explicit. The physics principles that govern the system performance are well documented. This is true unless the system is attempting a truly novel activity that is not yet defined by science, but that scenario is ignored here. The guidance that requirements should consider physics principles to write feasible requirements is also well documented. Thus, this capability is explicit, theoretical and applied. Similar explanations can be made for the next two rows. There are both theoretical and applied aspects to writing requirements with the correct scope of one actor, action and object and to using a documentation process to update a requirement. The knowledge on which both of these capabilities is based is explicit. In contrast, the last row of Table 6-60 gives an example of a capability within the topic of requirements management that is theoretical, applied and tacit. The applied task is to write clear requirements that translate stakeholder goals into technical needs. This task is based on a theoretical understanding of the concepts that describe effective requirements. The pair of capabilities is described as tacit because the concepts that describe effective requirements are not well documented or easy to document. Defining what makes a clear, unambiguous requirement relies on intuition and an understanding of human information processing. The process of translating stakeholder goals into technical requirements relies on a creative process that happens within an engineer based on their experience and training. There is not a clear set of steps to guide that creative process. Engineers improve in this skill through experience. Thus, this pair of capabilities is tacit. Requirements management, as one topic within satellite engineering, includes multiple levels of codification and application. The same can be said for the other capabilities within satellite engineering that are introduced below.

In order to observe capability building within the case studies, the items included in the Topic Axis from Figure 6-5 are defined at both the individual and organizational level. At the level of individual capability for the Implementer engineers, one convenient way to divide the topics for satellite engineering is based on the skills and applied knowledge required to achieve each step of the satellite lifecycle. This is done in Table 6-61. The lifecycle includes defining the project, defining and managing requirements, applying software tools to design the satellite system, manufacturing the satellite hardware and developing software, testing hardware and software, and launching and operating the satellite. Throughout the lifecycle there are activities that apply management tools to monitor and control the project. In each lifecycle phase, specific topics within satellite engineer are evoked, as shown in Table 6-61. Each topic includes one or more activities that further specify the capabilities.

Table 6-61: Overview of Individual Capabilities

Capabilities for Individual Implementer Engineers divided by Topic	
Satellite Engineering Topics	***Activities Within Satellite Engineering Topics***
Project Definition	Project Proposal And Approval
	Technology Evaluation And Development
	Training Program Definition
	Organizational Establishment
	Supplier Selection
	Requirements Generation
	Launcher Selection
Requirements Management	Requirements Gathering And Management
Software Tools	Discipline Software Application
Design	System Modeling
	Functional Design
	Physical Design
	System Analysis
	Process Planning
	Operations Planning
	System Budget Management
Procurement, Manufacture, Assembly, Integration	Material Selection And Planning
	Material Procurement
	System Procurement
	Manufacturing
	Subsystem Integration, Including Software
	Software Development
Testing, V&V	Functional Subsystem Testing
	Functional System Testing
	Environmental Testing
	Verification + Validation

Management & Documentation	Risk Assessment + Management
	Stakeholder Communication
	Anomaly Management
	Schedule Management
	Financial Management
	Personnel Management
Launch	Launch Campaign Execution
Operations	Operations And Ground Station Maintenance

At the level of organizations, a similar capability framework is defined that captures activities achieved by the group. This framework is designed to parallel work done in other technical areas, therefore it builds on ideas by Dahlman and Westphal. This framework emphasizes Production Capability, Investment, and Innovation Capability[cclix] as core skills within technology enterprises in many industries. Because of the unique features of the satellite industry, the framework is altered to address the space lifecycle. Satellites have a dual nature compared to many consumer products. Satellites can be thought of both as products and as infrastructure that produces a product. A satellite is the product of a government or commercial organization that manufactures satellites. Some organizations have the business model of operating satellites and producing useful services and information products. In this view, satellites are a production facility for data or communication service. Thus, the idea of "production capability" is used to refer both to the production of satellites and the production of information services by using satellites.

The proposed framework also considers role of production, investment and capability at two levels. One is at the level of an individual satellite project. The second is at the level of the operation of a satellite development organization. There are aspects of these three areas (production, investment and innovation) at both levels. During a single project, the production capabilities are demonstrated by operating the satellite as a production facility for information. This is a technically challenging task. If the satellite exhibits unexpected behavior, the operations team must work with whatever information the satellite sends to determine and correct the problem. They cannot access the satellite directly; instead they rely on a limited set of status updates from the satellite. Production capability is also demonstrated by the process of manufacturing, assembling and testing a satellite. This process utilizes a set of specialized equipment and facilities. For each satellite project, there is a need to exercise investment capability in order to define the project, interact with a potential customer or end user to gain project approval and to design the system. During the project approval and definition process, initial designs for the satellite and operations approach are proposed in order to prove the feasibility and estimate the cost of the end product. Once the project is approved, a full, detailed system design is done. This harnesses all the technical specialists in the satellite subsystems. Innovation, in the context of a single satellite project, refers to inventions and innovations related to developing new products. Inventions refer to the development of new technology, while innovations refer to applying the invention in an economic context. Innovation during a project implies that a technical product is developed, such as a specific camera or subsystem component. There may also be scientific research that supports the long term invention of such products.

At the level of operating a satellite development organization over the long term, there are also aspects of production capability, investment capability and innovation capability to acquire. A satellite development organization may be a government or commercial entity. In the case studies there are examples of both. Production capability at the organizational level refers to operation of the complex and specialized infrastructure required to facilitate a series of satellite projects. Some of the infrastructure is for specific subsystem teams; some is for testing and assembling the entire satellite system. At the level of a satellite organization, investment capability includes establishing infrastructure, defining a series of projects and working for business development or government approval of a series of projects. Here a satellite program refers to a series of related projects that moves the organization or customer toward an overall goal. For example, a new satellite owner may plan to buy a series of satellites, each of which has increasing performance and complexity. Investment skills at the organizational or program level are similar to that of a single project, but require longer term planning and strategy. Also, the establishment of infrastructure for satellite assembly and testing is a unique skill set. This involves defining requirements for the infrastructure, selecting equipment suppliers and managing the procurement and commissioning process. Innovation capability at the organizational level refers to process inventions and innovations. In the satellite context, this could refer to the satellite manufacturing and test process or to other organizational processes, such as managing technical risks, addresses unexpected problems or organizing personnel. The framework distinguishes between incremental and major inventions or innovations. The incremental changes build on what was previously done, while the major changes bring a radical new approach.

Table 6-62: Overview of Organizational Capability Categories

	Individual Satellite Project	**Satellite Development Organizations**
Production Capability	• Satellite System Operation • Satellite System Manufacture, Assembly, Test	• Satellite Infrastructure Operation and Maintenance
Investment Capability	• Satellite Project Business Development or Approval • Satellite Project Definition • Satellite System Design	• Satellite Program Business Development or Approval • Satellite Program (Multiple Projects) Definition • Satellite Infrastructure Establishment

Innovation Capability	• Incremental Product invention (creation) • Incremental Product innovation (implementation) • Major Product Invention • Major Product Innovation • Scientific Research	• Incremental Process invention (creation) • Incremental Process innovation (implementation) • Major Process Invention • Major Process Innovation

Within the high level titles shown in Table 6-62 are more precisely defined activities. Table 6-63 and Table 6-64 provide more detailed definitions of what skills are implied in each of the activities introduced in Table 6-62 for the individual satellite project and for the satellite development organization.

Table 6-63: Detailed Definition of Activities within Organizational Capabilities for a Satellite Project

	Individual Satellite Project	Detailed Definitions
Production Capability	Satellite System Operation	• Operation Management: Mission Planning, Anomaly Resolution, Information Management • Operation Engineering: Apply Subsystem Expertise to Mission Planning and Anomaly Resolution
	Satellite System Manufacture, Assembly, Test	• Materials Selection and Procurement • Component Selection and Procurement • Manufacturer (external) selection and contracting • Manufacturing (internal) • Subsystem Functional Testing • Subsystem Environmental Testing • System Assembly and Integration • System Functional Testing • System Environmental Testing
Investment Capability	Satellite Project Business Development or Approval	• Development of feasibility studies and funding proposals • Stakeholder needs evaluation and communication
	Satellite Project Definition	• Supplier elicitation, review and selection • Contracting with System Supplier • Development of project requirements and preliminary system concept
	Satellite System Design	• System modeling • Functional and physical design • System analysis • Process Planning • Systems Budget Management • Application of system design software

Innovation Capability	Incremental/Major Product invention (creation)	• Application of scientific principles to technology development
	Incremental/Major Product innovation (implementation)	• Application of technology to mission requirement • Risk Management • Evaluation of Technical Maturity
	Scientific Research	• Evaluation of current state of scientific and technical understanding • Proposal and Design of scientific investigation • Scientific experimentation, data collection and analysis • Inference and reporting of results

Table 6-64: Detailed Definition of Activities within Capabilities for a Satellite Development Organization

	Satellite Development Organizations	Detailed Definitions
Production Capability	Satellite Infrastructure Operation and Maintenance	• Test programming and execution using equipment • Repair and maintenance of physical capital required for satellite operation, assembly and test
Investment Capability	Satellite Program Business Development or Approval	• Development of feasibility studies and proposals • Stakeholder needs evaluation and communication
	Satellite Program (Multiple Projects) Definition	• Development of program proposal and program architecture • Evaluating infrastructure and personnel needs for program
	Satellite Infrastructure Establishment	• Feasibility studies • Implementation project management • Procurement of equipment • Soliciting and selecting bids • Contracting and oversight • Hiring and training of personnel • Start up of Operations
Innovation Capability	Incremental/Major Process invention (creation)	• Application of scientific, management or social science principles to define new satellite engineering process, testing techniques, or management approaches
	Incremental/Major Process innovation (implementation)	• Implementation of new satellite engineering process, testing techniques, or management approaches

The discussion above provided detailed definitions of the Topics Axis that defines what capabilities are relevant to satellite engineering. These topics are defined with the understanding that most activities in Table 6-63 and Table 6-64 have aspects that map to several parts of the Codification and Application Axes. They are both tacit and explicit; they are both applied and theoretical.

6.2.2 Capability Building in Satellite Engineering

The next task of this section is to define capability building and how it will be observed using the case study data. To answer Research Questions 3 and 4, capability building will be defined and observed at both the individual and organizational levels.

Advances in technological capability can be identified by three types of achievements. The first is learning a new topic (moving to a new location on the Topic Axis); the second is completing a task at a new level of autonomy; the third is completing a task at a new level of complexity. Autonomy refers to the level of independence an individual or organization has when accomplishing a task or learning a concept. Complexity refers to the technical nature of the activity. It is driven by the technical complexity of the system on which individuals and organizations work. As defined in the section on architecture above, remote sensing satellites can be considered more complex as they increase in mass, payload performance and design life – for example. Some capability building advances happen as an increase in two or three of these axes at the same time, but the only requirement for capability building is an increase in at least one factor. The graphic in Figure 6-6 shows these three axes of capability building, the graph is analogous to Figure 6-5. Both graphics begin with defining the set of topics and noting that these topics range from more managerial to more technical. The first set of axes in Figure 6-6 emphasized the nature of these topics with regard to the level of application or codification. This set of axes emphasizes that capabilities within specific topics can be achieved at different levels of autonomy and complexity. Capability building happens when more topics are learned at high levels of autonomy and complexity.

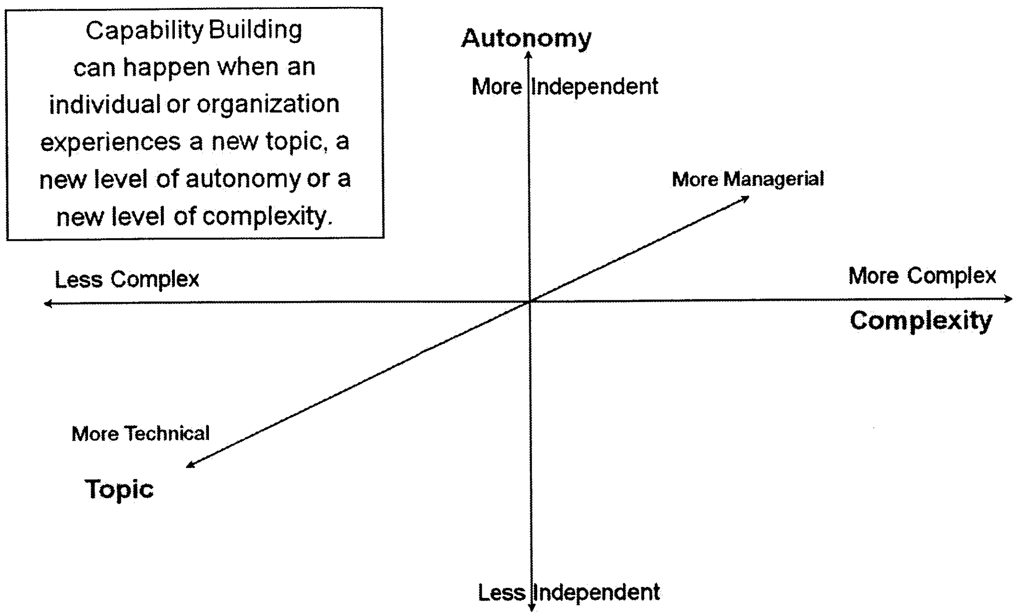


Figure 6-6: Three axes of satellite engineering capability building are topic, autonomy and complexity

Individuals and organizations can build capability when they have the opportunity to work in new topics or at new levels of autonomy and complexity. In these case studies, some of the opportunities for individual capability building came through theoretical training, practical training and on the job experience. The opportunity to learn through training or experience does not guarantee that capability building will effectively occur. A full definition of capability building considers both the opportunity to experience a topic through training or experience, as well as, the quality of the learning from that experience.

The quality of capability building captures the level of proficiency an individual or organization achieves in completing a task. In the context of this research, observing the level of proficiency gained in various topics is difficult. The difficulty is due to the low level of control the researchers had over the research setting; the research methods that used exploratory interviews; and the research perspective of collecting data after satellite project is completed. The current research claims to observe only opportunities for capability building rather than observing the quality of capability building for the individuals. At the organizational level, capability is seen as a binary variable. If an organization has not completed a particular task, it is defined to not have that capability. If an organization has completed a task, it is defined as having that capability for at least the short term. In the long term, the capability may erode due to loss of personnel or memory.

Based on these definitions, scales are defined to consider different capability levels for both individuals and organizations. The scale for various levels of opportunities for individual capability building combines two aspects of capability: the level of application and the level autonomy. The level of application is used to distinguish between the different types of training and job experience, which may be practical or theoretical. The job experience may be supervised by the Supplier or done independently within the Implementer organization. These divisions lead to seven levels of autonomy for activities done by individuals, as summarized in Table 6-65. The row for Related Practical Experience accounts for work experience that engineers had in other fields outside satellite engineer that may prepare them for some aspect of their satellite work. The row labeled "Awareness" refers to experiences that do not provide direct training or detailed explanations about satellite technology, but that provide information about the nature and capabilities of satellites. A caveat to the list of opportunities for capability building is that it emphasizes experiences that are facilitated by a trainer or supervisor. Some of the rows can be drive by either a trainer or the learning engineer or both. For example, practical training can be led by an instructor or by an individual practicing a new skill such as the use of a software tool.

Table 6-65: Introducing the scale long which individuals build capability

Scale of Opportunities for Individual Capability Building
Independent On the Job Experience
Supervised On the Job Experience
Practical Training
Related Practical Experience
Theoretical Training
Related Theoretical Training
Awareness

A second scale defines the achievements that indicate capabilities for organizations. This scale emphasizes levels of autonomy. It can be used in combination with the list of organizational level capabilities defined in the section above to capture the topic and level of autonomy for activities done by the Implementer Organizations. By considering the changes in an organization's autonomy over time, the scale in Table 6-66 provides a means by which to compare their capabilities. Note that is version of the scale does not explicitly show the level of complexity. That axis will be addressed in the text as it becomes relevant. The bottom level of autonomy is to execute an achievement in the context of training under a Supplier Organization. The next three levels may be in the context of formal training or other types of partnerships with external organizations. Achieving an activity with support in an external facility implies that the Implementer is both sharing an partner's facility and receiving guidance on how to complete their task. The level for "achieved locally with external assistance" captures the case when an Implementer executes a task in their home facility but they rely on the technical guidance of the Supplier or other consultant. The mutual partner in the fourth autonomy level is distinct. It is not a training relationship. A mutual partnership implies that the Implementer works on an equal basis with a partner; the two organizations have similar technical capability in the area they pursue together. The final level is to achieve a task independently. The Implementer may still contract with suppliers or manufacturers, but they are in full control of the outcome of the activity.

Table 6-66: Introducing the levels at which organizations achieve capabilities

Levels of Autonomy for Organizational Achievements
Achieved Independently
Achieved with mutual partner
Achieved locally with external assistance
Achieved with support in external facility
Achieved during Training

By combining these two scales for individual and organizational capability building with the frameworks that define specific capabilities in satellite engineering, an operational method emerges that allows analysis. Table 6-67 shows the tool to observe individual opportunities for capability building.

Table 6-67: Introducing Framework used to Observe Individual Capability Building

Framework for Observing Opportunities for Individual Capability Building									
Scale of Capability Building Opportunities									
Independent On the Job Exp.									
Supervised On the Job Exp.									
Practical Training									
Related Practical Exp.									
Theoretical Training									

Topics in Satellite Engineering	Project Definition	Requirements	Software tools	Design	Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
Awareness									
Related Theore-tical Training									

The approach to answer Research Question 3 is to review the evidence from interview data with Implementer engineers and populate Table 6-67 with the opportunities for capability building that the engineer experienced. Such an analysis is possible because the interview questions probed each interviewee to learn their professional background, educational training, the activities they pursued during the training at the Supplier site and other relevant experience. This method does not measure the quality of the learning by the engineer, but it does measure a necessary pre-cursor – exposure to learning opportunities. No assumption is made about the quality of learning by the engineers based on this analysis, but a general reflection is provided in a later section based on impressions gained during field work.

The process to complete the table for the engineers is as follows. The first step is to review the original interview text and identify opportunities for capability building. For each opportunity, it is associated with a particular topic from satellite engineering. The full definition for each topic, as described in Table 6-61, guides the matching process between capability building opportunities and satellite engineering topics. In some cases, the connection is obvious because the opportunity was during a satellite project. In other cases, it is less obvious, especially the opportunities for related theoretical training and related practical experience. For these examples, the goal is to capture training and job experience that were indirectly related to satellite engineering. The analysis seeks to assign these non-satellite activities to the satellite engineering topic that is most closely related. All the engineers have educational experience at the university level; for most of them it is not specifically on the topic of satellite engineering. This education is generally shown as "Related Theoretical Experience" and associated with the Design aspect of satellite engineering. It is matched to design because the academic knowledge for most engineering majors is most helpful in preparing engineers for design work that is based on physics principles. University training is often less relevant to topics such as manufacturing, testing and operations. There is a time element to the analysis as well. Part of the motivation for the analysis is to explore the capability building benefits that the Implementers received by working with the Suppliers. For this reason, the interview data and these analysis tables capture experiences from three time periods that are defined with respect the satellite project: 1) Before visiting the Supplier; 2) During the visit to the Supplier; and 3) After the visit to the Supplier. The opportunities are coded to refer to each time period.

Data is available about capability building experiences for a selection of the engineers from each Implementer Organization. The research process did not permit interviewing each individual engineer. This gap was ameliorated, however, by learning about the relevant divisions among the engineers and sampling across the groups when possible. Each project had unique circumstances that created groupings within the engineering team that were relevant to the capability building opportunities. Few engineers were interviewed from the AlphaSat-R1 and BetaSat-R1 projects. These were the earliest projects and many of the engineers that participated in them were not available for interviews. For the AlphaSat-R2 project between Nation Beta and Supplier Tau1, the Implementer created a team with two groups of engineers. One group focused on the imager payload; they arrived at Supplier Tau1 about a year earlier than the rest of the team. The second group focused on the spacecraft bus. Interviews were held with representatives of both groups; the interviews spanned all available engineers that were still with the organization. For the BetaSat-R2/R3 project between Nation Beta and Supplier Omega1, the Implementer created a team of two distinct Cohorts. Cohort 1 was selected first and spent three years with Supplier Omega1. This group studied for graduate degrees, and they were present for early lifecycle phases of the satellites. The second cohort spent about one year with Supplier Omega1. They did not study for graduate degrees and they participated in later satellite lifecycle phases. Interviews were held with several representatives of both cohorts. The GammaSat-R1 project with Supplier Tau1 included two natural divisions. One group of veterans was hired early in the project. They helped define the Implementer Organization and the satellite project before going to visit Supplier Tau1. A later group of engineers was hired to focus on technical work. Representatives of both groups were interviewed. Nation Delta partnered with Supplier Sigma1 on the DeltaSat-R2 satellite project. There was only one large group of engineers that spent time in Nation Sigma. Here the natural divisions related to the specialty areas to which the engineers were assigned. The interviews sampled across various specialties and various levels of overall professional experience by the engineers.

An analogous process is used to analyze Organizational Capability Achievements by combining the Levels of Autonomy with the list of organizational capabilities in satellite engineering. This is done in Table 6-68 and Table 6-69. There are two versions of the Organizational analysis because the capabilities can be defined at the level of a single satellite project or the level of a satellite development organization. In the cases under study, there are space agencies, national research organizations or government linked companies that are seeking to build some or all of these capabilities listed in the tables. The data from the case studies captures whether or not the countries achieved these various capabilities. It also indicates the level of autonomy with which they achieved them. Table 6-68 and Table 6-69 provide a template to answer Research Question 4 by showing the achievements and levels of autonomy for each country.

Table 6-68: Introducing Framework used to Observe Organizational Capability Building for a Satellite Project

Individual Satellite Project	***Achieved during Training***	***Achieved with support in external facility***	***Achieved locally with external assistance***	***Achieved with mutual partner***	***Achieved Independently***
Satellite System Operation					
Satellite System Manufacture, Assembly, Test					
Satellite Project Business Development or Approval					
Satellite Project Definition					
Satellite System Design					
Incremental/Major Product invention (creation)					
Incremental/Major Product innovation (implementation)					

Table 6-69: Introducing Framework used to Observe Organizational Capability Building for a Satellite Program

Satellite Development Organizations	**Achieved during Training**	**Achieved with support in external facility**	**Achieved locally with external assistance**	**Achieved with mutual partner**	**Achieved Indepen-dently**
Satellite Infrastructure Operation and Maintenance					
Satellite Program Business Development or Approval					
Satellite Program (Multiple Projects) Definition					
Satellite Infrastructure Establishment					

Incremental/Major Process invention (creation)					
Incremental/Major Process innovation (implementation)					

6.2.3 Research Question 3: What Capability Building Opportunities do Individuals Have?

The capability building opportunities for every engineer that was interviewed are compiled in tables based on Table 6-67. In this section, a selection of these tables are introduced and discussed. Several individual examples as well as some summary tables are presented from the satellite projects. The individual examples span the group divisions that were explained in the previous section in order to show variety. In the tables, the experiences are color coded to show the passage of time over several periods. Each table covers three or four time periods. The first time period is shown in blue, second in green, third in red and fourth – if relevant – is shown in orange. The time-based color codes provide visual evidence that the engineers are experiencing new topics areas at higher levels of autonomy over time.

Nation Alpha: AlphaSat-R1

The hiring strategy for AlphaSat-R1 involved selecting a core team of engineers to participate in the training with Supplier Omega1. Other engineers were gradually hired to work at Implementer Alpha1. The engineers hired for the core trainee team were drawn from existing positions in academia, the military and industry. The plan was to hire these engineers temporarily and then return them to their original positions. Most engineers trained at Supplier Omega1 during AlphaSat-R1 followed that plan. One engineer continued to work at Implementer Alpha1 where he gradually rose to a senior management position. Table 6-70 and Table 6-71 show some of the capability building experiences of this engineer. As the color key indicates, blue writing indicates experiences before joining Implementer Alpha1 and training at Supplier Omega1; green text indicates experiences while training at Supplier Omega1, and red text indicates experiences after returning to work at Implementer Alpha1. For this example, the text that describes each capability building experience is shown in order to illustrate the types of data that were collected in the interviews. Later tables use the same color scheme but do not included descriptions of the experiences. The table showing the experiences of this engineer/manager is very large. It is divided into two sections for presentation and discussion. The first section includes early activities in the satellite lifecycle – Project Definition, Requirements Management, Software Tools and Design. The second section of the table (Table 6-71) shows the later satellite activities.

Table 6-70: First part of Capability Building Profile for Nation Alpha Engineer

Color Key	**Blue = Before Training at Supplier Omega1** **Green = During Training at Supplier Omega1** **Red = After Training at Supplier Omega1**

Independent Implementation	Part of committee to develop national space policy; Leadership for project definition and proposal - AlphaSat-R2 and successor mission	Mission level requirement management for AlphaSat-R2		
Supervised On the Job Experience		Mission study of satellite like AlphaSat-R2; Design modifications for AlphaSat-R1; Experimental payload for AlphaSat-R1		Project for Attitude Control; Mission study of satellite like AlphaSat-R2; Design modifications for AlphaSat-R1; Experimental payload for AlphaSat-R1
Practical Training				Training for AlphaSat-R1 at Supplier Omega1 on Attitude Control
Related Practical Experience	University research on solar cars (Technology Evaluation and Development)			Work at foreign government aerospace laboratory; Lecturer in aeronautics in Nation Alpha; University research on solar cars
Theoretical Training				Space related classes in Bachelors degree; Satellite engineering lectures at Supplier Omega1
Related Theoretical Training				BE and MS in Aerospace from foreign university
	Project Definition	Requirements Management	Software tools	Design

Before this engineer came to work at Implementer Alpha1, he had several capability building experiences that provided related theoretical training and related practical experience. He studied aerospace engineering at the undergraduate and graduate level in a foreign university. He took several space related courses during his first degree. He had the opportunity to work briefly in a foreign aerospace laboratory to gain experience in both design aspects as well as the satellite testing phase. When he returned to Nation Alpha, he worked as a university lecturer for aeronautics. He did research related to solar cars that provided experience in both technology evaluation and design. This engineer also participated in a committee that worked to develop the national space policy for Nation Alpha before he participated in the AlphaSat-R1 project.

The engineer was selected to join the core trainee team that went to work at Supplier Omega1 during the AlphaSat-R1 project. His time at Supplier Omega1 started with theoretical training via lectures about satellite engineering. He was assigned to focus on the attitude control subsystem. He had practical training related to design, manufacturing, assembly, integration and testing for that subsystem. While working at Supplier Omega1 he also did several activities that gave him "supervised on the job experience" to implement focused projects. He did an independent project related to attitude control, worked on designing the mission for Nation Alpha's next satellite, performed analysis in response to changes in the launch vehicle and worked with a team to develop an experimental science payload for AlphaSat-R1.

After the AlphaSat-R1 project was over, the engineer continued to work at Implementer Alpha1 for many years. As a manager within Implementer Alpha1, he worked across the various satellite topics. He was in leadership during the project definition of AlphaSat-R2; he helped identify the requirements, managed the installation of new assembly and integration facilities at Implementer Alpha1, led the team during the integration of AlphaSat-R2 at the new facility, provided leadership during the AlphaSat-R2 launch preparation and campaign. As a high level manager he was also generally responsible for work such as stakeholder communication, personnel management and technical reviews.

Table 6-71: Second part of Capability Building Profile for Nation Alpha Engineer

Management for Flight model integration of AlphaSat-R2 and installation of AIT facilities	Leadership for camera calibration for AlphaSat-R2	Senior Manager of Implementer Alpha1 - stakeholder communication, personnel management, oversees design reviews; Project leadership for AlphaSat-R2 and Cubesats	Leadership for AlphaSat-R2 launch activities	Leadership for AlphaSat-R2 launch activities	**Independent Implementation**
Project for Attitude Control; Participate in AlphaSat-R1 manufacturing; Experimental payload for AlphaSat-R1	Project for Attitude Control; Participate in AlphaSat-R1 testing; Experimental payload for AlphaSat-R1			Project for Attitude Control - demonstrate operation	**Supervised On the Job Experience**

Training for AlphaSat-R1 at Supplier Omega1 on Attitude Control	Training for AlphaSat-R1 at Supplier Omega1 on Attitude Control				Practical Training
	Work at government aerospace laboratory in Nation Omega - satellite testing facility				Related Practical Experience
					Theoretical Training
					Related Theoretical Training
Procurement, Manufacture, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations	

As the colors indicate, this engineer progressed through increasingly autonomous experiences. He began with theoretical training and related experience in a narrow set of topics and ended with responsibilities across the spectrum of satellite engineering topics. As a manager within Implementer Alpha1 he moved beyond training to independent implementation of the strategies that defined the AlphaSat-R2 project and other activities within the firm. In each time period, his scope of activities increased along with his level of responsibility. This is strong evidence of capability building.

AlphaSat-R2

The capability building data from several engineers that were hired for AlphaSat-R1 are presented here. For AlphaSat-R2, Implementer Alpha1 hired people for long term employment in contrast to the approach from the AlphaSat-R1 project. Most of the engineers were young professionals or recent university graduates. Engineers were hired both to travel to work with Supplier Tau1 and to stay at Implementer Alpha1 in order to build up the local team and facilities. Three examples of individual capability building are presented here. They are chosen to show the diversity of technical assignments among the engineers. The first engineer worked on the imager payload team. This team started to work at Supplier Tau1 about one year earlier than the rest of the AlphaSat-R2 team from Nation Alpha. The second example is an engineer that worked on the satellite bus in the communication subsystem team. The third engineer did not spend substantial time training at Supplier Tau1. His responsibility was to set up the new assembly and integration facilities at the Implementer Alpha1 site. His level of autonomy stands out as much higher than the other engineers because the tasks were not done in the context of a training program. He was simply working for Implementer Alpha1. The final table for AlphaSat-R2 shows a summary of the group results.

Table 6-72: Capability Building Profile for Engineer from AlphaSat-R2 Project (1)

Color Key	Blue = Before Training at Supplier Tau1 Green = During Training at Supplier Tau1 Red = After AlphaSat-R2 Project								
Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									
Theoretical Training									
Related Theoretical Training									
	Project Definition	Requirements	Software tools	Design	Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations

Table 6-72 describes some of the capability building opportunities that one of the engineers on Implementer Alpha1's payload team experienced. Before going to Nation Tau to train during the AlphaSat-R2 project, this engineer prepared with theoretical training. He pursued a Bachelors Degree in aerospace engineering from a dual program with universities in both Nation Alpha and abroad. His classes included some preparation for the software tool he would later use in his work on AlphaSat-R2. After being hired to work at Implementer Alpha1, he had some practical training before leaving for Supplier Tau1. He worked with various teams at Implementer Alpha1 and learned from more experienced engineers. He worked on learning the design and analysis tools that were used at Implementer Alpha1 for mechanical design. He was selected to move to Nation Tau and work on the imager payload team for AlphaSat-R2. At Supplier Tau1 he had more practical training and on the job experience in topics ranging from requirements to testing. Early on for practical training, he learned the specific design and analysis tools that were used at Supplier Tau1 and did several modeling tasks to demonstrate he was ready to participate in the project work. His on the job experience focused on the mechanical design for the structures that supported the imager payload. He worked on tasks such as defining requirements for the structures, using software to design the structure, analyzing the design to ensure it was sound, procuring materials to build the structure, assembling the structure and testing it. He worked closely with the Supplier Tau1 team through the lifecycle tasks of the payload mechanical team. After the AlphaSat-R2 project was completed when the engineer was working at Implementer Alpha1, one of his independent responsibilities was to work as the lead mechanical engineer for the payload section of a proposed remote sensing aircraft. He worked on activities such as project definition and design for this system.

This engineer's capability profile as shown in Table 6-72 indicates that much of the time spent at the Supplier facility focused on supervised on the job experience more than theoretical or practical training.

Table 6-73: Capability Building Profile for Engineer from AlphaSat-R2 Project (2)

Color Key	Blue = Before AlphaSat-R2 Project Green = During AlphaSat-R2 Project Red = After AlphaSat-R2 Project								
Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									
Theoretical Training									
Related Theoretical Training									
	Project Definition	Requirements	Software tools	Design	Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations

Table 6-73 shows the capability building profile for an engineer that worked on the satellite bus team during the AlphaSat-R2 project. This engineer changed roles during the long AlphaSat-R2 project. He started off as a communication engineer and later worked as the System Engineer for AlphaSat-R2 after the team and the satellite moved to Nation Alpha. The System Engineer coordinates the technical team and ensures that all the subsystems function together. Before going to Supplier Tau1 for training, this engineer had both experience relating to multiple levels and topics. He received his theoretical training from both Nation Alpha and foreign universities. When he first started working at Implementer Alpha1, he had theoretical and practical training by learning from the materials about the AlphaSat-R1 project. He also worked on a project to understand one specific satellite component for attitude control. He was hired before AlphaSat-R1 launched. He briefly visited Supplier Omega1 and observed testing for AlphaSat-R1. He was also present at Implementer Alpha1 for the commissioning and operation of AlphaSat-R1. Before going to work at Supplier Tau1, this engineer was sent to a different country to work on another project. Implementer Alpha1 had formed a design partnership with an aerospace firm that was separate from the relationship with Supplier Tau1. This engineer worked with the team at this aerospace firm on the preliminary design of a space vehicle that was to support AlphaSat-R2. This experience gave the engineer practice in both design and management because he presented in reviews. That project was terminated before the design was matured and the engineer went to Nation Tau to work on AlphaSat-R2 with Supplier Tau1. While in Nation Tau, the engineer worked had practical training and on the job experience related to the communication subsystem for AlphaSat-R2. He learned and applied software tools for analysis; designed a specific communication component; manufactured his component by selecting components, materials and manually soldering it; testing his component and presenting during project reviews that were hosted by the Supplier Tau1 team. During his on the job experience he had a well defined responsibility to execute the lifecycle for a specific piece of hardware.

AlphaSat-R2 was designed in Nation Tau, integrated in Nation Alpha and tested in Nation Tau. During the integration and testing phase, this engineer became the system engineer for the project. In this role he had more supervised experience and independent experience related to assembly, testing, management and launch. His role gradually became more independent as the Supplier Tau1 team handed over responsibility to the Implementer Alpha1 team. After AlphaSat-R2 was tested in Nation Tau, it spent several years in Nation Alpha preparing for launch. This engineer was a key technical leader during this period. The work he helped lead included calibrating the imager, interfacing with the supplier and launch provider and preparing the satellite for launch. Through this experience the engineer transitioned from a trainee working under the Supplier's supervision to a technical leader working independently within Implementer Alpha1. As the capability profile shows, he had experiences at many topics and levels before going to work with Supplier Tau1.

Table 6-74: Capability Building Profile for Engineer from AlphaSat-R2 Project (3)

Color Key	Blue = Before AlphaSat-R2 Project Green = During AlphaSat-R2 Project Red = After AlphaSat-R2 Project								
Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									

Theoretical Training									
Related Theoretical Training									
	Project Definition	Requirements	Software tools	Design	Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentatio n	Launch	Operations

Table 6-74 profiles the capability building experiences of an engineer that did not go for training at Supplier Tau1. He was hired to work at Implementer Alpha1 and his role focused on establishing and using new facilities for the integration and testing of AlphaSat-R2 in Nation Alpha. This engineer came to work at Implementer Alpha1 after doing a Bachelor's Degree in electrical engineering in a foreign university. He worked briefly in a audiovisual company doing research and development. He was hired to work at Implementer Alpha1 just before the launch of AlphaSat-R1. He participated in the launch campaign for AlphaSat-R1 and contributed as an electrical engineer. During the AlphaSat-R2 project, he worked on the definition, design and development of satellite integration facilities in Implementer Alpha1. He covered virtually the entire spectrum of satellite engineering topics at a high level of autonomy. He was not supervised by the Supplier for this task; he was only supervised by the Implementer Alpha1 management, such as the senior manager introduced earlier in this section. In the project definition area, he worked on proposing the project, selecting suppliers and generating requirements. He continued to define and manage those requirements as they prepared tender documents to send to potential contractors. He received and reviewed contractor proposals. He worked on the design of the Assembly, Integration and Test (AIT) facility with support of contractors. During the implementation he monitored the construction work and procured materials. Once the facility was completed he also worked as a team leader during the fabrication and integration of the satellite in the new facility. He helped with functional testing of AlphaSat-R2. Throughout these tasks he had management and documentation responsibilities to monitor personnel, finances and schedule. This AIT facility project allowed him to work independently of a trainer to experience a full project lifecycle.

Group summary for AlphaSat-R2

Table 6-75 summarizes capability building trends for all the engineers that were interviewed who followed the pattern of training with Supplier Tau1 and returning to work at Implementer Alpha1. The three sections of the table capture three time periods. The first section shows capability building activities before training with Supplier Tau1. The second is for during the training and the final table shows activities since the training. The intensity of the colors in Table 6-75 shows volume of people. Each person is counted once in a box if they had any examples of activities in their individual table. The darker boxes show activities that had more engineers represented. These summary tables include data from seven engineers, so the maximum number for any square is seven. The first part of the table shows that the majority of the activity before going to Supplier Tau1 was in the area of Related Theoretical Training that pertained to design. There is also a broad scattering of experiences throughout the rest of the table before working with Supplier Tau1.

During the Supplier Tau1 visit, there is a clear concentration of experiences at the level of supervised on the job training in the middle project lifecycle phases. The time with Supplier Tau1 did not focus on project definition and launch. It was focused on the design, manufacture and testing of the satellite and imager. As a trainer, Supplier Tau1 emphasized on the job experience more than practical training that did not directly contribute to completing the project. They did provide some theoretical training to all of the visiting engineers. In the last section of Table 6-75, the dark boxes at the top show that the group of engineers has moved into a high level of autonomy by working on all the satellite topics. The overall movement of dark boxes from lower to higher in the table is an indication of capability building for these individuals. They all transitioned from theoretical training to practical experience to on the job experience and started to work independently after the AlphaSat-R2 project. The time period represented by this table is on the order of a decade.

Table 6-75: Group Summary of Capability Building Profiles for AlphaSat-R2 Project

Before Training at Supplier Tau1									
Independent Implementation	0	0	0	0	0	0	0	0	0
Supervised On the Job Experience	0	0	0	1	0	0	1	1	0
Practical Training	1	0	2	1	0	1	0	0	1
Related Practical Experience	2	0	0	1	0	0	1	0	0
Theoretical Training	1	0	2	2	1	0	0	0	0
Related Theoretical Training	0	0	1	5	1	0	0	0	0
Awareness	0	0	0	0	0	0	0	0	0
No Experience	0	0	0	0	0	0	0	0	0
	Project Definition	Requirements	Software tools	Design	Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
During Training at Supplier Tau1									
Independent Implementation	1	1	0	1	1	1	1	0	1
Supervised On the Job	0	2	3	[illegible]	5	[illegible]	2	1	0

	Project Definition	Requirements	Software tools	Design	Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
Experience									
Practical Training	0	0	3	3	2	2	0	0	0
Related Practical Experience	0	0	0	0	0	0	0	0	0
Theoretical Training	0	0	0	[illegible]	1	0	0	0	0
Related Theoretical Training	0	0	0	0	0	0	0	0	0
Awareness	0	0	0	0	0	0	0	0	0
No Experience	0	0	0	0	0	0	0	0	0

After return to Nation Alpha from Supplier Tau1

	Project Definition	Requirements	Software tools	Design	Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
Independent Implementation	6	3	3	3	3	4	6	3	1
Supervised On the Job Experience	1	0	0	1	1	2	2	1	1
Practical Training	0	0	0	1	1	1	0	0	0
Related Practical Experience	0	0	0	0	0	0	0	0	0
Theoretical Training	1	0	0	2	0	0	1	0	0
Related Theoretical Training	0	0	0	1	0	0	0	0	0
Awareness	0	0	0	0	1	0	0	0	0
No Experience	0	0	0	0	0	0	0	0	0

Nation Beta – BetaSat-R2/R3 Satellite Project

Implementer Beta1 created a two part team for the BetaSat-R2/R3 project. For both teams, the Architectural Dimensions of Hiring Time Horizon and Recruitment Source were similar. Implementer Beta1 created the teams by assigning some engineers from the previous BetaSat-R1 and BetaSat-C1 projects. The majority of the engineers were hired freshly into Implementer Beta1 in order to participate in the BetaSat-R2/R3 project. The engineers were generally recent graduates or young professionals, with a few seasoned professionals. The total team of engineers sent from Implementer Beta1 to work at Supplier Omega1 numbered in the mid-twenties. This large group was divided into two sections that had different experiences. The first section, known as Cohort 1, was gathered at the beginning of the satellite project. They were a combination of new hires and a few veterans. They spent three years at Supplier Omega1. Most members of the second Cohort were hired after the BetaSat-R2/R3 project started. They spent about one year at Supplier Omega1 later in the satellite lifecycle. Capability building profiles are presented here for five engineers from the BetaSat-R2/R3 project. These were chosen because they span both Cohorts and the engineers have a variety of professional backgrounds. Eleven engineers were interviewed and their capability building profiles are combined in a group summary. The Capability Building template for the Implementer Beta1 engineers is customized to reflect their experiences as of the time of the interviews. The columns for Project Definition and Launch Campaign experience were not found to be as relevant; they are removed for ease of presentation. The time period covered by the set of tables below is different for each engineer because they have different professional backgrounds.

Table 6-76: Capability Building Profile for Engineer from BetaSat-R2/R3 Satellite Project (1)

Color Key
Blue = Before visit to Supplier Omega1
Green = During visit to Supplier Omega1
Red = After visit to Supplier Omega1

	Requirement	Software tools	Design	Procurement, Manufacture, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Operations
Independent Implementation							
Supervised On the Job Experience							
Practical Training							
Related Practical Experience							
Theoretical Training							
Related Theoretical Training							

This engineer described in Table 6-76 pursued theoretical training before joining Implementer Beta1, earning a Bachelor of Science in Electrical Engineering from a university in Nation Beta. He continued studies on information technology in Nation Beta during the first year of his employment with Implementer Beta1. He was selected to travel to Supplier Omega1 as part of Cohort 1. At Supplier Omega1, he pursued theoretical training focused on satellite engineering a university in Nation Omega while working with the Supplier. He earned a graduate degree and had short courses and technical lectures from the Supplier team. Early in his time at Supplier Omega1 he had practical training in areas such as software tools and a hands-on research project as part of his graduate degree. He had opportunities for supervised on the job experience in all the satellite lifecycle phases from requirements to operations planning. His team assignment was to work as the systems engineer for the Implementer Beta1 team. He was a technical coordinator, especially for BetaSat-R3 which the Implementer Beta1 engineers worked on. After the satellite development for BetaSat-R2 and BetaSat-R3 was completed, the Implementer Beta1 team moved on from Supplier Omega1. This engineer remained in Nation Omega to pursue a further studies related to satellite engineering at the Master's and Doctoral level. He also took a coordinating role in a burgeoning small satellite project at Implementer Beta1. The Implementer organization hired a set of new engineers that were not trained abroad. This team worked with some veterans to begin the initial design and requirements definition for a local small satellite project.

Table 6-77: Capability Building Profile for Engineer from BetaSat-R2/R3 Satellite Project (2)

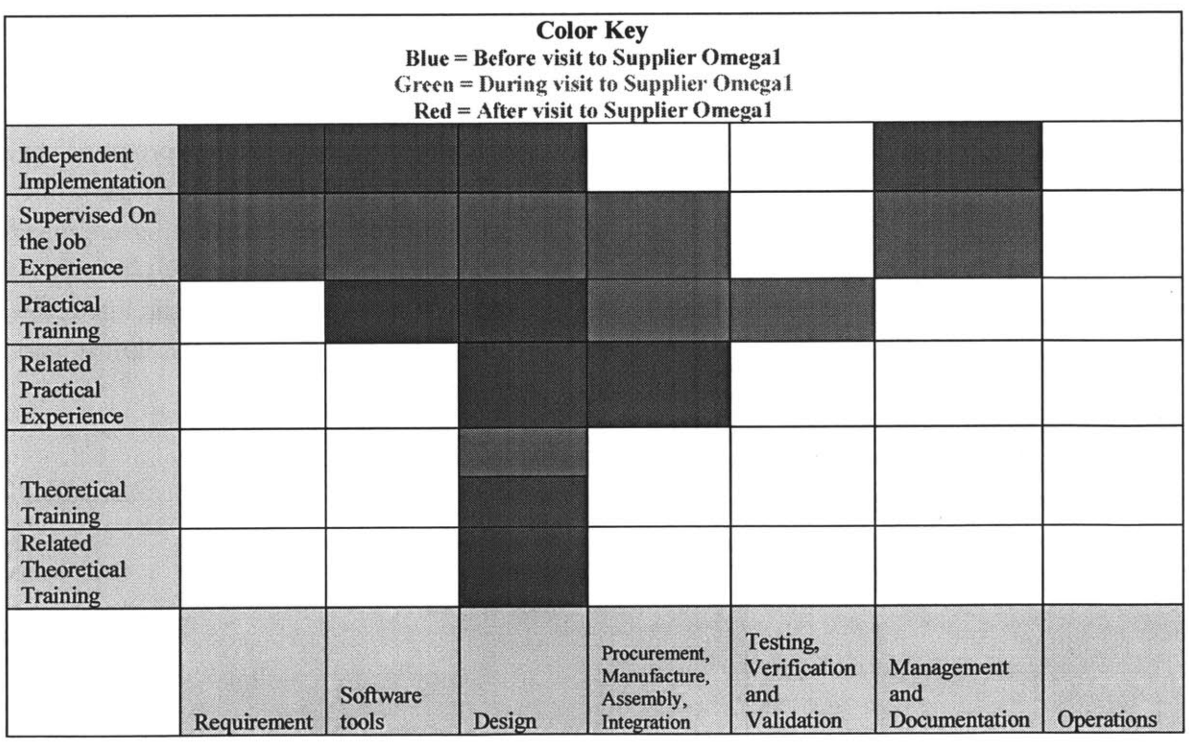
Color Key
Blue = Before visit to Supplier Omega1
Green = During visit to Supplier Omega1
Red = After visit to Supplier Omega1

	Requirement	Software tools	Design	Procurement, Manufacture, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Operations
Independent Implementation							
Supervised On the Job Experience							
Practical Training							
Related Practical Experience							
Theoretical Training							
Related Theoretical Training							

The engineer in Table 6-77 has a very similar capability building profile to the first example from Nation Beta. This engineer was also part of the first Cohort of engineers sent from Implementer Beta1 to Supplier Omega1 to work in the BetaSat-R2/R3 satellites. Like the engineer above he did a Bachelors Degree in Electrical Engineering in Nation Beta. He worked within Implementer Beta1 for several years before going to Supplier Omega1. During this early work experience he had exposure to operations for BetaSat-R1 and to requirements. He worked to help define requirements for the future BetaSat-R2 as the project was being defined. When he went to Supplier Omega1 he was assigned to a role related to the software and computer system that handle data on the satellite. He had practical training in software tools. While he was working with Supplier Omega1, he studied for a graduate degree at the university in Nation Omega as the previous engineer did. Some of his practical training was through a hands-on research project during his graduate studies. He had the responsibility to ensure the completion the subsystem related to data handling on BetaSat-R3. This responsibility gave him supervised on the job experience in all the lifecycle phase from requirements to management and documentation. After the Implementer Beta1 team left Supplier Omega1, this engineer also pursued further graduate education related to satellite engineering in a university in Nation Omega. He worked briefly on the requirements definition phase of a small satellite project within Implementer Beta1.

To summarize both examples from Cohort 1 engineers, both of these stories have strong examples of theoretical training at the undergraduate and graduate level. They also had a broad range of practical training and on the job experience that covered many satellite life cycle phases while at Supplier Omega1. Both of these engineers took on technical leadership roles within their team for the work on satellite BetaSat-R3. Both also contributed to early lifecycle phases at the independent implementation level in a satellite project at Implementer Beta1. A final similarity is that both had limited practical experience outside of their work at Implementer Beta1 and Supplier Omega1. The next two engineers have more examples of Related Practical Experience in other industries.

Table 6-78: Capability Building Profile for Engineer from BetaSat-R2/R3 Satellite Project (3)



The engineer whose profile is summarized in Table 6-78 was part of the second Cohort to visit Supplier Omega1 from Implementer Beta1. Before spending time at Supplier Omega1, this engineer had both theoretical and practical training in several organizations. He earned his Bachelor's and Master's Degrees in Mechanical Engineering from two universities in Nation Beta. Before going to work for Implementer Beta1, the worked in the oil industry as a sales engineer. He also spent several years teaching math and physics at the secondary school level. When he first joined Implementer Beta1, he was appointed to a team of engineers that was being sent for training as part of the procurement of the BetaSat-C1 communications satellite from an international partner. About fifty Implementer Beta1 engineers were sent to the site of the manufacturer for BetaSat-C1. During this project experience, the engineer was working on the structural and mechanical subsystem team. He had months of theoretical training and exams about all the technical specialties in satellite engineering. He had practical training related to the use of software tools for modeling the structural design of space system. He also learned design techniques for the structures team and applied them to a satellite design project. The communication satellite project was an opportunity to build awareness about the entire satellite lifecycle. This was partly done via site visits to satellite engineering facilities in the host country. After returning to Implementer Beta1, this engineer was sent to Supplier Omega1 as part of the second Cohort of visiting engineers. He worked on the structural and thermal aspects of the satellite. His training at Supplier Omega1 began with theoretical lectures on an overview of satellite technology. Later he had practical training in the skill of soldering electronics for space applications and structural testing for satellites. He had supervised on the job experience across a wide range of satellite lifecycle phases from requirements to management and documentation. He learned and applied new software modeling and analysis tools. He contributed to the Manufacturing, Assembly, Integration and Testing of the BetaSat-R3 satellite. He gave presentations during project reviews. This engineer summarized his two training programs by saying that the first project gave him a strong theoretical foundation and the second gave him more opportunities for hands on work. After returning to Implementer Beta1, this engineer started building up independent implementation experience across several lifecycle phases. He worked with a team to begin the requirements analysis and early design of a small satellite to be built by Implementer Beta1. He applied the software tools for the structural discipline and participated in the project reviews at Implementer Beta1.

Table 6-79: Capability Building Profile for Engineer from BetaSat-R2/R3 Satellite Project (4)

Color Key **Blue = Before visit to Supplier Omega1** **Green = During visit to Supplier Omega1** **Red = After visit to Supplier Omega1**							
Independent Implementation							
Supervised On the Job Experience							

Practical Training							
Related Practical Experience							
Theoretical Training							
Related Theoretical Training							
	Requirement	Software tools	Design	Procurement, Manufacture, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Operations

Table 6-79 describes the capability building profile of another engineer that went to Supplier Omega1 as part of Cohort 2. This engineer pursued related theoretical training via a Bachelor's degree in Electrical Engineering in Nation Beta. He was hired to Implementer Beta1 as part of a wave of recruitment to select the second Cohort for visiting Supplier Omega1. Before he was hired to Implementer Beta1, this engineer spent about nine years working on power plants. As he summarized, this first major phase of his career involved high voltage systems; then he transitioned to very low voltage systems when he started working on satellites. The related practical experience on power plants was relevant to design, procurement, assembly, integration as well as management and documentation. Right after he was hired to Implementer Beta1, he had several opportunities for theoretical and practical training in preparation for the visit to Supplier Omega1. He spent about nine months at Implementer Beta1 before departing for Nation Omega. The training included satellite lectures from veteran Implementer Beta1 engineers and practical lessons related to general computer tools. When he went to Supplier Omega1, the firm and related university provided short courses and technical lectures; this continued the theoretical training. The engineer joined the Implementer Beta1 engineers who were working on the power system for BetaSat-R3. He had practical training related to the design of BetaSat-R3. He also had practical training in techniques such as space quality soldering, solar cell manufacturing and battery testing. His on the job experience concentrated on the later satellite lifecycle phases such as manufacturing, procurement, assembly, integration, test and management. He presented on the BetaSat-R3 power system in several project reviews while at Supplier Omega1. Upon returning to Implementer Beta1 his main responsibilities were in maintenance of the systems in the ground station that was designated to operate the remote sensing satellites. They were already operating BetaSat-R1, and they prepared to operate BetaSat-R2 and BetaSat-R3 with new antennas and computer equipment. This engineer was concerned with the power system and mechanical aspects of the ground station. He also provided mentorship to the team working on the small satellite project on an ad hoc basis. These work assignments gave him independent implementation experience in the areas of design, procurement, assembly and operations.

Table 6-80: Capability Building Profile for Engineer from BetaSat-R2/R3 Satellite Project (5)

Color Key Blue = Before visit to Supplier Omega1 Green = During visit to Supplier Omega1 Red = After visit to Supplier Omega1							
Independent Implementation							
Supervised On the Job Experience							
Practical Training							
Related Practical Experience							
Theoretical Training							
Related Theoretical Training							
	Requirement	Software tools	Design	Procurement, Manufacture, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Operations

The previous two examples showed the capability building profiles for engineers with 4 to 9 years of professional experience before joining Implementer Beta1. Table 6-80 shows the path for an engineer in Cohort 2 that starting working at Implementer Beta1 as a fresh graduate. He earned his Bachelor's degree in Mechanical Engineering in a university in Nation Beta. After being hired to Implementer Beta1 he had initial theoretical training on satellite engineering from veteran engineers for several months. When he arrived at Supplier Omega1 the theoretical lectures continued from the firm and university engineers. This engineer was working on the camera payload aspects of the satellite. He spent time in a separate facility under Supplier Omega1 that specializes in imager payload systems. There he had practical training in software tools that are used to design and analyze the structural aspects of imagery payload systems. He practiced design and manufacture during a project to create a lens. Other practical training introduced techniques to operation in clean rooms on optical equipment for assembly, integration and test. He had further exposure to testing during tests of the fully assembled BetaSat-R2 and BetaSat-R3. He also had some practical training related to management when he contributed to preparations for project review presentations. This engineer's activities at Supplier Omega1 are driven more by practical training than supervised on the job experience. The reason for this is the topic area to which he was assigned. He was on the team that worked on the imager payload. This topic is a highly specialized and technically different from other topics in satellite engineering. The core disciplines that are required to build satellite buses are electronics and mechanics. The core discipline required to build an imagery payload system are mechanics and optics. The required knowledge in optics to work in the area of supervised on the job experience is deep, and it was a new topic for this engineer. Also, Supplier Omega1 historically focused their effort on the design and implementation of the spacecraft bus rather than imager payloads.

They had recently acquired the organization that specialized in imager payloads where this engineer worked. This topic area was outside the historical strengths of this engineer and Supplier Omega1. When this engineer returned to Implementer Beta1 he applied the software tools for structural design of imager payloads to the small satellite project.

Table 6-81: Group Summary of Capability Building Profiles for BetaSat-R2/R3 Satellite Project

Before Training at Supplier Omega1							
Independent Implementation	1	0	1	0	0	0	0
Supervised On the Job Experience	0	2		0	0	0	1
Practical Training	0	5	1	0	0	1	1
Related Practical Experience	0	1	3	3	0	4	5
Theoretical Training	1	0	8	1	0	1	0
Related Theoretical Training	0	1	9	0	0	0	0
Awareness	1	1	1	1	1	1	1
No Experience	0	1	0	1	1	1	1
	Requirement	Software tools	Design	Procurement, Manufacture, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Operations

During Training at Supplier Omega1							
Independent Implementation	0	1	1	1	1	1	1
Supervised On the Job Experience	3	4	3	7	6	8	4
Practical Training	2	5	7	7	8	4	2
Related Practical Experience	0	0	1	0	0	0	0
Theoretical Training	0	0	8	0	0	0	1
Related Theoretical Training	0	0	0	0	0	0	0
Awareness	0	0	0	0	0	0	1
No Experience	0	0	0	0	0	0	0

	Requirement	Software tools	Design	Procurement, Manufacture, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Operations
After Training at Supplier Omega1							
Independent Implementation	3	3	4	2	0	1	3
Supervised On the Job Experience	0	0	0	0	0	0	0
Practical Training	0	0	0	0	0	0	0
Related Practical Experience	0	0	0	0	0	0	0
Theoretical Training	0	1	3	0	0	0	0
Related Theoretical Training	0	1	2	0	0	0	0
Awareness	0	0	0	0	0	0	0
No Experience	0	0	0	0	0	0	0
	Requirement	Software tools	Design	Procurement, Manufacture, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Operations

Table 6-81 provides a group summary for the Nation Beta team that worked on BetaSat-R2 and BetaSat-R3 by combining the capability building profiles of eleven out of the twenty six engineers. In each section of the table, the darker boxes show higher number of engineers with experience in particular area. The first stage of the three part table shows capability building opportunities before engineers went to Supplier Omega1 for training. As expected, the highest concentration of experience before the BetaSat-R2/R3 projects is related theoretical training. Most of the engineers studied at universities in Nation Beta in a general engineering discipline. They did not pursue majors directly focused on satellite engineering, but they studied majors that are part of the core set of knowledge for building satellites – especially mechanical and electrical engineering. Their training was a combination of university engineering degrees and polytechnic degrees. Before leaving for Nation Omega, most engineers had theoretical training and practical training via instruction from veteran Implementer Beta1 engineers or individual study on previous projects. A smaller number has related practical experience outside of Implementer Beta1. In Nation Beta, young graduates are required to work for a year of service in either a government or commercial entity; it is like an internship. This mandatory service year is not reflected in Table 6-81.

The second stage of the group capability building profile shows a high concentration of practical training and supervised on the job experience across the satellite lifecycle topics. There is a dark area for theoretical training related to design. This reflects the introductory satellite engineering lectures that Supplier Omega1 provided to most engineers when they first arrived. There are slightly higher numbers for the on the job and practical experience in the later satellite lifecycle phases, starting with procurement/manufacture and continuing to management and documentation. This reflects the fact that Cohort 2 was present for the later project phases of both BetaSat-R2 and BetaSat-R3. For both Cohorts, their most autonomous activities related to the implementation of BetaSat-R3, although Cohort 1 also participated in the design aspects.

The third stage of group capability mapping shows a split between independent implementation and theoretical training. Some engineers returned to Implementer Beta1 and worked on small satellite projects in Implementer Beta1 or on the ground station. Others continued their studies. Overall, there is a progression in terms of autonomy. The group moved from primarily theoretical training and related practical experience to supervised on the job experience and finally to independent implementation. The time element is important to interpreting the graphics. The time period before visiting Supplier Omega1 varies for each individual depending on their professional experience. At the time of data collection, it was too early to observe the outcomes of the independent implementation activities to develop small satellites locally at Implementer Beta1. The teams were in early project phases. Another aspect to consider is the level of complexity of the technology. Those engineers that continued theoretical training after training at Supplier Omega1 have the opportunity to advance in the complexity of their work even though autonomy is decreasing. They started doctoral programs that will give them a theoretical foundation for satellite missions that are more complex than those previously pursued by Implementer Beta1.

Nation Gamma – GammaSat-R1 Project

Implementer Gamma1 was in its formational stage as it began the GammaSat-R1 project. The hiring process populated both the organization and the team slots. An early group of about five engineers was hired to help define and initiate the organization. They were also the part of the pioneering set of engineers that went to work with Supplier Tau1. Implementer Gamma1 continued to hire engineers for long term employment throughout the GammaSat-R1 project. If the engineers were willing and able to live abroad for long periods, they were sent to participate in GammaSat-R1 development at Supplier Tau1. The target population for engineers hired to Implementer Gamma1 was recent graduates with majors relevant to satellite engineering. Two examples of capability building profiles are given below. Table 6-82 summarizes experiences for one of the engineers that was hired as part of the pioneering team that both defined the Implementer Gamma1 organization and initiated the GammaSat-R1 project. Table 6-83 summarizes the story of a later hire that joined during the GammaSat-R1 project. The tables are divided into three time periods. First, it shows the experiences of engineers before they go to work with Supplier Tau1 in blue. The second time period shows work on the GammaSat-R1 project in green. The third time period shows work on the next remote sensing satellite project – GammaSat-R2 – in red. The GammaSat-R2 project started before the launch of GammaSat-R1, so the capability building experiences continued almost without interruption. Compared to other implementers, the timing of visits to Supplier Tau1 was less defined for Implementer Gamma1 engineers. Rather than going and staying for a set period, engineers from Nation Gamma traveled frequently back and forth to Supplier Tau1 and stayed for several months each time.

Table 6-82: Capability Building Profile for Engineer from GammaSat-R1 Project (1)

Color Key
Blue = Before visit to Supplier Tau1
Green = During GammaSat-R1 Project
Red = During GammaSat-R2 Project

	Project Definition	Requirements	Software tools	Design	Manufacturing, Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									
Theoretical Training									
Related Theoretical Training									

The engineer profiled in Table 6-82 earned a Bachelor's degree in electronics at an foreign university. He was hired by Implementer Gamma1 before it was formally opened. This gave him opportunities for independent implementation in the area of project definition for both the IMPLEMENTER GAMMA1 organization and the GammaSat-R1 project. He participated in selecting the supplier, defining the training package by the supplier and selecting a launch provider. During the GammaSat-R1 project, he had theoretical training via lectures from the Supplier engineers on satellite engineering. He also started to learn the theoretical background he would need for his assignment in the area of attitude control for the satellites. The attitude control team is concerned with measuring and correcting the orientation of the satellite with respect to the earth. This engineer did independent study early in his time at Supplier Tau1 to understand new theoretical topics on stochastic feedback control. In the earlier satellite lifecycle phases of GammaSat-R1 he participated in practical training activities. Later in the project life he was able to work at the level of supervised on the job training. The practical training included learning to use the software for his discipline in attitude control and for modeling orbits. There was also on the job experience in the areas of design and functional testing. He joined Supplier Tau1 engineers as they tested sensors that help measure the satellite's orientation. His on the job experience continued in the launch phase. He went to the launch location and worked with the Supplier and Launch provider while leading the team of engineers from Implementer Gamma1 who were present. During GammaSat-R2, this engineer had experiences at higher levels of autonomy and across a broader range of satellite lifecycle phases. He worked at the level of independent implementation to join the Implementer Gamma1 team to define the GammaSat-R2 project and training package. They once again selected Supplier Tau1. This engineer took on a new role as system engineering and leader for the software team among the Implementer Gamma1 engineers. This gave him on the job experience in requirements, software tools, design, implementation and management during the first part of the GammaSat-R2 project.

Table 6-83: Capability Building Profile for Engineer from GammaSat-R1 Project (2)

Color Key
Blue = Before Visit to Supplier Tau1
Green = During GammaSat-R1 Project
Red = During GammaSat-R2 Project

Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									
Theoretical Training									
Related Theoretical Training									
	Project Definition	Requirements	Software tools	Design	Manufacturing, Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations

The engineer profiled in Table 6-83 joined Implementer Gamma1 after the GammaSat-R1 project started. He studied for a Bachelor's degree in Computer Science initially in an international school, but he finished in a university within Nation Gamma that uses an international system. He had related practical experience that helped him prepare for working on flight software for GammaSat-R1 and GammaSat-R2. He had been writing computer programs as a hobby for years. When he first joined Implementer Gamma1, his theoretical training started with independent study about approaches to software for space systems. He continued theoretical training when he first moved to Nation Tau and received introductory lectures from Supplier Tau1. During the GammaSat-R1 project, he had practical training across several satellite lifecycle phases as he learned about requirements, tools, design, testing and management as they related to the software for the satellite's main on-board computer. He transitioned to supervised on the job experience as he began to create independent software designs and join the team in solving software problems facing the project. He was at the ground station in Nation Gamma during the launch of GammaSat-R1. He returned to Supplier Tau1 and worked on GammaSat-R2 at the level of supervised on the job experience. He had independent experience at Implementer Gamma1 during visits to Nation Gamma. He worked with newly hired engineers to train them on the topic of software for space systems.

Table 6-84: Group Summary of Capability Building Profiles for GammaSat-R1 Project

Before Training at Supplier Tau1									
Independent Implementation	2	0	0	0	0	0	0	0	0
Supervised On the Job Experience	0	0	0	0	0	0	0	0	0
Practical Training	0	0	0	0	0	0	0	0	0
Related Practical Experience	0	0	1	2	0	0	3	0	2
Theoretical Training	0	0	0	3	0	0	0	0	0
Related Theoretical Training	0	0	0	6	0	0	0	0	0
Awareness	0	0	0	1	0	0	0	0	0
No Experience	0	0	0	0	0	0	0	0	0

	Project Definition	Requirements	Software tools	Design	Manufacturing, Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
During GammaSat-R1 Project with Supplier Tau1									
Independent Implementation	0	0	0	0	0	0	1	1	1
Supervised On the Job Experience	0	0	1	4	4	6	2	5	1
Practical Training	0	1	5	5	4	5	3	2	1
Related Practical Experience	0	0	0	0	0	0	0	0	0
Theoretical Training	0	0	0	7	1	2	0	0	0
Related Theoretical Training	0	0	0	0	0	0	0	0	0
Awareness	0	0	0	0	0	0	0	0	0
No Experience	0	0	0	0	0	0	0	0	0

	Project Definition	Requirements	Software tools	Design	Manufacturing, Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
During GammaSat-R2 Project with Supplier Tau1									
Independent Implementation	2	0	0	1	0	0	1	0	0
Supervised On the Job Experience	0	4	3	4	2	3	2	0	0
Practical Training	0	0	0	0	0	0	0	0	0
Related Practical Experienc	0	0	0	0	0	0	0	0	0

	Project Definition	Requirements	Software tools	Design	Manufacturing, Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
Theoretical Training	0	0	0	0	0	0	0	0	0
Related Theoretical Training	0	0	0	1	0	0	0	0	0
Awareness	0	0	0	0	0	0	0	0	0
No Experience	0	0	0	0	0	0	0	0	0

Table 6-84 shows a group summary for seven engineers from Implementer Gamma1. For consistency the table only shows data for engineers that worked on both GammaSat-R1 and GammaSat-R2. As was the case with the other countries, before working with the Supplier Organization, the main capability building experiences were in the areas of related theoretical training and a limited amount of related practical experience. Most engineers were hired directly after their first university degree and some of these practical experiences were short term internships. The core team of pioneering engineers from Implementer Gamma1 did have unique Independent Implementation experience in Project Definition, however. The middle section of Table 6-84 shows that most engineers had theoretical training, practical training and on the job experience during the GammaSat-R1 project. This was their first exposure to applying their engineering training to satellite development. For GammaSat-R2, those engineers that started during GammaSat-R1 have uniformly transitioned from practical training to supervised on the job experience. This means they spent less time learning the skills for their assignments and more time contributing as part of the joint team led by Supplier Tau1.

Nation Delta – Satellite DeltaSat-R2

Implementer Delta1 hired engineers for both the DeltaSat-R1 project and for long term employment in the organization. Almost all of the engineers that went to visit Supplier Sigma1 were new hires that were brought in around the same time. The engineers had a mixed background with regard to previous experience; some were fresh graduates from their first university degrees. Many had further studies or professional experience. Three examples are summarized below. One is an engineer with strong academic training; the other is an engineer that came with more professional training. The third example follows the path of an engineer the moved to a new organization in Nation Delta after training with Supplier Sigma1. There is no group summary for the Implementer Delta1 engineers because not enough engineers were interviewed.

Table 6-85: Capability Building Profile for Engineer from DeltaSat-R1 Project (1)

Color Key:
Before visit to Supplier Sigma1
During Visit to Supplier Sigma1
After visit to Supplier Sigma1

Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									
Theoretical Training									
Related Theoretical Training									
	Project Definition	Requirements	Software tools	Design	Manufacturing, Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations

Table 6-85 profiles an engineer took on a technical leadership role among the Implementer Delta1 engineers. He studied for his Bachelor's Degree in Mechanical Engineer in Nation Delta. He did graduate study in aerospace engineer at the Master's level in an foreign university. He worked for several years in the petrochemical industry applying mechanical engineering to the refinery process. He also worked in a similar capacity at an energy company. Wishing to change industries, he pursued graduate study in aerospace engineer at the Master's level in a foreign university. During his masters degree he had practical training in software as he applied computational tools to complete his research project. Implementer Delta1 hired this engineer after his Master's degree and sent him to Supplier Tau1. He spent the first nine months in theoretical training with courses on all the satellite engineering disciplines and on project management issues. He had practical training experiences in a broad range of lifecycle phases. Some of the practical training was in the context of group activity and some was based on his individual assignments. The group activities for practical training included a team design project to define a satellite mission based on some given requirements. The team project included work related to requirements, design, management and launch planning. The group also had practical training opportunities through visits to clean room facilities where the satellite was worked on and visits to subcontractor facilities – these experiences touched on manufacturing and procurement. This engineer was assigned a technical leadership role to coordinate the technical aspects of the satellite within the larger earth observation system that also included the ground system for control and image reception. In this leadership role he had both practical training and supervised on the job experience in several satellite lifecycle phases. He applied software tools and worked on tests related to mechanical analysis as part of "on the job" tasks. As part of his leadership role he was concerned with monitoring the tasks of other Nation Delta engineers that worked on aspects of the spacecraft. This gave him an opportunity for personnel and schedule management experience. He also participated in interactions between Supplier Sigma1, Implementer Delta1 and the Launch Provider. He was concerned with the interfaces between the satellite and launch vehicle. The final stage of practical training at Supplier Sigma1 focused on operations. All the engineers participated in that. Throughout the time at Supplier Sigma1 this engineer worked on the level of independent implementation in the areas of requirements and management/documentation. He served on a committee that worked on behalf of the leadership of Implementer Delta1. Part of his role was to ensure that requirements were achieved by Supplier Sigma1 and to provide oversight at accept the Supplier's progress at each milestone. After completing the formal training phase at Supplier Sigma1, the engineer's capability building experiences continued to cover several levels of autonomy, as shown in the red boxes of Table 6-85. As the Implementer Delta1 team prepared for the launch of DeltaSat-R2, the Supplier Sigma1 team sent trainers to certify the Nation Delta engineers as satellite operators. This engineer had practical training in operations, and then supervised on the job experience. He later worked on operations independently. He continued as a technical leader, leading the daily operations activities. Before launch he also visited the Launch Provider with the Supplier in order to review a change in launch plans. In the operational phase, his continued to have responsibilities related to personnel management. As Implementer Delta1 began envisioning their next satellite project, he also began to work on project definition at the independent implementation level with a focus on technology evaluation. He had an additional opportunity for practical training outside the context of the DeltaSat-R1 project. He spent one month in training on small satellite technology at the site of a foreign partner. The capability building profile for this engineer shows increases and decreases in autonomy over time. During the visit to Supplier Sigma1 the engineer has some high levels of autonomy due to his role as a customer representative on behalf of Implementer Delta1. He was not just receiving mentorship from the Supplier; he was also evaluating their project outputs and documents. He and his committee made recommendations to the leadership about technical concerns with the project. Another choice led to lower levels of autonomy after going from Nation Sigma to Nation Delta. The Supplier Sigma1 team went to Nation Delta and taught the engineers there new skills that were not their primary activity while in Nation Sigma. This means they returned to the level of practical training temporarily but gradually moved up to independent implementation in operations.

Table 6-86: Capability Building Profile for Engineer from DeltaSat-R1 Project (2)

Color Key: **Before visit to Supplier Sigma1**

During Visit to Supplier Sigma1 After visit to Supplier Sigma1									
Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									
Theoretical Training									
Related Theoretical Training									
	Project Definition	Requirements	Software tools	Design	Manufacturing, Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations

Table 6-86 shows the capability building profile for another engineer from Implementer Delta1. This engineer studied telecommunications engineering at a university in Nation Delta. He later studied the same topic at the Master's level at a university in Nation Sigma. Thus he had exposure to the host country before going to visit Supplier Sigma1. Before working for Implementer Delta1, this engineer worked for another part of the Nation Delta government. It was the government authority for communication. In this position, he had related practical experience in the areas of management and operations. He did planning for the ground segments that were part of satellite communication systems. He also served on a national committee that planned a previous national small satellite payload project with a foreign partner. This engineer was hired into Implementer Delta1 as part of the team that was sent to visit Supplier Sigma1. Like the engineer described above, he spent about nine months doing theoretical training with satellite engineering courses from Supplier Sigma1. He was later assigned to the role of managing the ground segment aspects for the Implementer Delta1 team of engineers. He participated in the team design project and work on the ground segment requirements and design. He had practical training on the software that Supplier Sigma1 uses for ground stations. He learned about procurement, manufacturing and assembly of satellites via visits to clean rooms and practical training tasks related to assembly. His primary responsibility was to learn to lead the ground station team for DeltaSat-R1 once they returned to Nation Delta. While in Nation Sigma, he had practical training and supervised experience as the leader of the ground segment team. When he returned to Nation Delta he worked at the independent implementation level in this role. His work included harnessing specialized operations software and addressing personnel and facility management for operations.

Table 6-87: Capability Building Profile for Engineer from DeltaSat-R1 Project (3)

Color Key:
Before Visit To Supplier Sigma1
During Visit To Supplier Sigma1
After Visit To Supplier Sigma1
In New Position After Leaving Implementer Delta1

	Project Definition	Requirements	Software tools	Design	Manufacturing, Procurement, Assembly, Integration	Testing, Verification and Validation	Management and Documentation	Launch	Operations
Independent Implementation									
Supervised On the Job Experience									
Practical Training									
Related Practical Experience									
Theoretical Training									
Related Theoretical Training									

Table 6-87 profiles the capability building experiences of an engineer that worked for Implementer Delta1 during the DeltaSat-R1 project. He moved to a new position sometime after returning from the visit to Supplier Sigma1. This engineer studied for his Bachelor's and Master's degrees in Mechanical Engineering at a foreign university. He briefly held a job related to management in the automotive industry before starting to work at Implementer Delta1. He was sent to Supplier Sigma1 where he started with the same nine months of theoretical training as his team mates. This covered design and management issues. He was assigned to the structural team of DeltaSat-R1. He had practical training on satellite structures during the team design project in areas of requirements, design and management. He also had practical training in a different topic via a course on software engineering for telecommunications. This was outside his core topic. As part of the work on the structures aspects of DeltaSat-R1, he had practical and on the job experience related to design, manufacturing and procurement, testing and launch planning. Some of his on the job experience included participating in the assembly of the spacecraft bus to the imager payload. He helped to write a structural test plan and analyze results. He also participated in meetings with the launch provided and did structural analysis in response to changes in launch plans. This engineer served as a customer representative and played an oversight role to the Supplier, gaining experience in requirements and management at the level of independent implementation. After returning to Nation Delta from Nation Sigma, this engineer participated in the practical training and on the job experience to become certified to operate DeltaSat-R1. He participated in the independent implementation of the operations activity. He took on a technical leadership role among the subsystem specialists before moving to a new position in a commercial company that operates communication satellites in Nation Delta. In his new position, he worked especially in the areas of management and operations.

The three examples of engineers profiled from Nation Delta are all cases of team leaders within the Implementer Delta1 organizational structure. The group of visiting engineers was large relative to other case studies (about 20 engineers). They worked with a Supplier Organization that is extremely large. The Implementer Delta1 engineering team applied a team structure inspired by their Supplier. They separated the engineers focused on the spacecraft, ground segment and overall system into different subteams and assigned leaders to each smaller team. The three engineers profiled above held leadership roles in this subteam structure while at Supplier Sigma1 and they took on great responsibility when they returned to Nation Delta. There is not enough data available for a helpful team summary, but the three examples do start to imply a general progression toward autonomy. The ground segment lead engineer focused more on operations and has fewer examples broad coverage of the satellite subsystems. The other two engineers show both breadth of satellite lifecycle phase and several examples of independent implementation.

6.2.4 Research Question 4: What Capability Building Achievements do Organizations Have?

Two frameworks are introduced at the beginning of this section that address organizational capabilities. The frameworks capture organizational capabilities related to satellite engineering in the context of a single satellite project and in the context of operating a satellite development organization. As defined above, capability building may come through achievements that feature new topics areas in satellite engineering, new levels of autonomy or new levels of technical complexity. The frameworks include five levels of autonomy and a broad range of topics at the organizational level. The discussion below shows the performance of the case study countries as defined by these frameworks. The aspect of complexity is included by indicating the technical complexity of each satellite project. As shown in Figure 6-3 in the discussion on the technical characteristics of the seven satellites, four can be classified as more complex (AlphaSat-R2, BetaSat-R2, GammaSat-R1, DeltaSat-R2) and three are less complex (AlphaSat-R1, BetaSat-R1, BetaSat-R3). This is based on their mass and the spatial resolution their imager can achieve. A series of tables below (Table 6-88 to Table 6-94) shows the achievements of countries during specific projects. The more complex projects are shown in bolder, larger font in order to account for technical differences in the satellites. Further, the project names (i.e. AlphaSat-R1) indicate the order of the project for each country. By combining complexity, project order or timing, levels of autonomy and topics, these tables address four dimensions that describe the process of capability building.

Table 6-88: Satellite System Operation Achievements during Satellite Projects

Individual Satellite Project	Achieved during Training	Achieved with support in external facility	Achieved locally with external assistance	Achieved with mutual partner	Achieved Independently
Satellite System Operation: • Operation Management: Mission Planning, Anomaly Resolution, Information Management • Operation Engineering: Apply Subsystem Expertise to Mission Planning and Anomaly Resolution					AlphaSat-R1
					AlphaSat-R2
				BetaSat-R1	BetaSat-R1
				BetaSat-R2	**BetaSat-R2**
				BetaSat-R3	BetaSat-R3
					GammaSat-R1
					DeltaSat-R2

Table 6-88 describes the level of autonomy with which case study projects achieved satellite system operation. In this case all the countries ultimately achieved the same level. For all seven satellite projects, the Implementers eventually took over responsibility from the Suppliers for operations of their satellites. The Suppliers worked closely with the Implementers to operate the satellites during an initial check out phase for several months after launch. In most cases the Suppliers remained available for emergency assistance or long term maintenance. The contracts between the Implementers/Overseers and Suppliers specified the level of support that the Supplier was to provide in the operational phase. Each Implementer achieved day to day independence in operating their satellite system. The Implementers managed facilities that included transmitting and receiving antennas; computer systems that send commands and receive satellite status; computer systems that receive, archive and process satellite data; as well as support elements such as backup power supplies, connecting cables and mechanical equipment. As Table 6-88 specifies, the topic of satellite system operation includes operation management and operation engineering. As part of the mission planning aspect of operation management, the Implementers were at the interface between the satellite system and potential end users for the satellite data. They each defined a process by which other organizations, especially from within their government, could request images from the satellite. Operation engineering means using knowledge about the design of satellite subsystems to respond to anomalies or perform mission planning. The operation engineering team receives status updates about each satellite subsystem; together these updates describe the health of the satellite. The individuals who perform Operation Management may or may not be the same as those who perform Operation Engineering. For example, the operations team from Implementer Beta1, included one group that focused on converting requests for images into satellite schedules and another group that monitored the health of the satellite and responded to anomalous behavior. Implementer Gamma1 divided their ground station team between those focused on satellite operations and those focused on processing images.

Although the countries all achieved independent operations eventually, they reached this level in different ways. Nation Delta worked closely with Supplier Sigma1 during an extended period after the Implementer Delta1 engineers left Supplier Sigma1. Several representatives from Supplier Sigma1 spent about one year in Nation Delta providing training and ensuring that the computer systems and antenna were working properly. For the BetaSat-R2/R3 satellite projects, the ground station was provided by a subcontractor to Supplier Omega1 from a different country. Operations engineers from Supplier Omega1 and engineers from the subcontractor went to Nation Beta several times for shorter visits for launch. During these visits, they worked with the Implementer Beta1 engineers and did trouble shooting on the equipment. A joint team of engineers from Supplier Omega1 and Implementer Beta1 worked to monitor the satellites during launch and then to test and calibrate them for weeks after launch. Implementer Gamma1 pursued GammaSat-R1 with Supplier Tau1. The ground system was included in their contract with Supplier Tau1, but the Implementer worked closely with the subcontractor that provided their ground station. The ground station subcontractor was also from a different country than the Supplier in this project. Before the ground system arrived in Nation Gamma, about four engineers from Implementer Gamma1 visited the site of their ground station subcontractor to learn about their systems and receive initial training. Two engineers from the subcontractor went to Nation Gamma for the installation and start up of the ground systems at Implementer Gamma1. Those engineers from Nation Gamma that were working in Nation Tau returned home to participate in setting up the ground system. Implementer Gamma1 hired local worker to do the hands-on construction, but the engineers were also actively involved. Supplier Tau1 played the role of consultant as Implementer Gamma1 interacted with their ground system subcontractor. Implementer Gamma1 leased capacity from a company that operated a farm of satellite ground antennas near the North Pole. The company's business model is to offer ground station service to satellite operators in convenient geographic locations. Through this relationship, the Implementer Gamma1 ground station became a node in this company's global network of ground stations and generated revenue by supporting the satellites of other operators.

The Nation Beta satellite projects are shown in two columns because they had two strategies for satellite operation. At one level, they operated the satellite independently for data collection about Nation Beta and the surrounding region. The three satellites for Nation Beta were also part of a cooperative satellite constellation led by Supplier Omega1. This Supplier coordinated satellites owned by several customers to do joint imaging campaigns for commercial customers. Thus, the Supplier also had access to task and interact with Nation Beta's satellites when they were not being used to image over Nation Beta. With regard to autonomy, this arrangement is labeled in Table 6-88 as "Achieved with a mutual Partner." In this case, the complexity of the satellite and the time progression from a country's first to their second satellite did not differentiate between the performance of the Implementers.

Table 6-89: Satellite System Manufacturing, Assembly and Test Achievements during Satellite Projects

Individual Satellite Project	Achieved during Training	Achieved with support in external facility	Achieved locally with external assistance	Achieved with mutual partner	Achieved Independently
Satellite System Manufacture, Assembly, Test • Materials Selection and Procurement • Component Selection and Procurement • Manufacturer (external) selection and contracting • Manufacturing (internal) • Subsystem Functional Testing • Subsystem Environmental Testing • System Assembly and Integration • System Functional Testing • System Environmental Testing	AlphaSat-R1				
	AlphaSat-R2		**AlphaSat-R2**		
	BetaSat-R1				
	BetaSat-R2				
		BetaSat-R3			
	GammaSat-R1				
	DeltaSat-R2				

Table 6-89 shows the achievements of the Implementer Organizations with regard to Satellite System Manufacture, Assembly and Test. The table includes many examples of activities that are included in that broad category such as selecting and procuring materials and components; selecting and contracting with external manufacturers and so on. The satellite manufacturing process is a mix of internal and external effort. The tendency to manufacture within the Supplier's facility varies with both subsystem and with the nature of the Supplier. Some subsystem elements lend themselves to in-house manufacturing because their success is highly critical, which gives the Supplier incentive to control their production. They also require well defined infrastructure to manufacture. The electronics boards that are part of almost every subsystem fall into this category. Several of the Suppliers in these case studies maintain a staff of specially trained technicians who are certified to solder and implement electronics boards for spacecraft by hand. The facility for such work must be operated in a particular manner to avoid electro-static discharge that could damage the electronics. Once such a facility is established, it can be used for a wide variety of projects because the components are small and similar across satellites. A subsystem that lends itself to external manufacturing is the mechanical and structural area. One approach to satellite design is to house the electronic components for each subsystem in a box made aluminum or other strong and light material. The engineers design these boxes and their arrangement to withstand the rigors of launch and operation in space. It is often convenient and low risk to have such structural components manufactured externally. Other subsystems such as propulsion and electric power involved hazardous materials in the propellant and batteries. Suppliers must consider whether they have the safety protocols in place to manufacture with such materials; it is often advantageous to work with external vendors.

For most of the case study satellite projects, the Implementers achieved these activities at the level of autonomy labeled "Achieved during training." In each project, engineers from the Implementer teams participated in these activities, but they were generally done under the guidance and supervision of the Suppliers. During BetaSat-R3, the Implementer made specific arrangements to create an opportunity for the Nation Beta engineers to take on primary responsibility for this project activity. Thus, BetaSat-R3 is the lone project appearing in the column "Achieved with support in external facility." BetaSat-R3 was completely manufactured, assembled and tested in Nation Omega, but engineers from Nation Beta had leadership roles in the process. For the AlphaSat-R2 project, Implementer Alpha1 achieved two levels of organizational capability. They created an opportunity to work on assembly of the satellite in Nation Alpha. AlphaSat-R2 was built through a series of prototype models. The early models were manufactured, assembled and tested in Nation Tau at the Supplier Tau1 facility or with their subcontractors. During the project, Implementer Alpha1 was gradually developing facilities to assemble and test the final model of the satellite. The facilities included a clean room where satellite components could be handled without contamination as well as an electronics lab with the proper set up to avoid electrostatic discharge. Implementer Alpha1 also pursued opportunities to manufacture some components of AlphaSat-R2 in Nation Alpha. The found local subcontractors that could build several parts based on the designs generated by the Implementer Alpha1 and Supplier Tau1 teams. After assembly, AlphaSat-R2 was returned to Nation Tau for testing. This activity was achieved at a mix of levels for the AlphaSat-R2 project. Both Nation Alpha and Nation Beta created somewhat artificial opportunities to enhance their skills in satellite assembly, manufacture and test. Implementer Alpha1 invested the logistical effort and expense to ship the satellite internationally in the middle of its assembly and test process. Implementer Beta1 bought an extra satellite that was more helpful for training than for data.

The AlphaSat-R2 and BetaSat-R3 projects stand out in this area of performance. AlphaSat-R2 is more complex than BetaSat-R3, but the overall BetaSat-R2/R3 project was similar in scale to

AlphaSat-R2. With regard to time, they are both part of the second satellite project for the Implementer. Both Implementers specifically sought an opportunity to move beyond their level of autonomy in this activity as compared with their first project.

Table 6-90: Satellite Project Business Development or Approval Achievements

Individual Satellite Project	Achieved during Training	Achieved with support in external facility	Achieved locally with external assistance	Achieved with mutual partner	Achieved Independently
Satellite Project Business Development or Approval • Development of feasibility studies and funding proposals • Stakeholder needs evaluation and communication					AlphaSat-R1
					AlphaSat-R2
					BetaSat-R1
					BetaSat-R2
					BetaSat-R3
					GammaSat-R1
					DeltaSat-R2

The first two topic areas involved capabilities labeled as "production capabilities" on the level of a single satellite project. These are the steps required to implement and operate a system. The next two topic areas relate to "Investment Capabilities," which are required to initiate, conceive and design a system. The first Investment Capability is Satellite Project Business Development or Approval. These are the activities through which the Implementers secure funding and approval from funders to execute the satellite project. In this context, the capability refers to the interaction between the Implementer Organization, their Overseer Organizations and the funding organizations within their government. As part of winning funding and approval from their government, Implementers often create an initial proposal or feasibility study that begins to define the satellite project and explains the benefits it will bring. They may also work to define what stakeholders in the nation are impacted by the project. One major stakeholder category is the group of data end users, but there may be others such as current and potential employees and complementary firms. Before the AlphaSat-R1 and BetaSat-R1 projects, Implementer and Overseer Organizations formed committees to think through these early issues. The committees represented various stakeholder categories. Implementer Delta1 held workshops to bring together potential end users and other stakeholders of DeltaSat-R1 before starting the project formally.

All of the Implementer Organizations in the case studies achieved this capability at an independent level of autonomy. The amount of effort required to account for stakeholder needs and convince funding agencies to support project proposals varied according to the political context for each project. For the AlphaSat-R1 and GammaSat-R1 projects, there was high level political support for investment in science and technology at the national level. Key government leaders provided pivotal support to the project based more on the potential to enhance national technological capability than on the benefits of the data. For the BetaSat-R1 project, the process of evaluating stakeholder needs and developing funding proposals coincided with the process of formulating a national space policy, national space agency and long term space project road map. These high level activities are captured in the framework that describes organizational capabilities related to operating a satellite development organization rather than a single satellite project. They are discussed more below. Because business development for the BetaSat-R1 project was coupled with business development for the Nation Beta space program, there was a greater emphasis on describing the benefits that satellite data would bring to the country for stakeholders.

Table 6-91: Satellite Project Definition Achievements

Individual Satellite Project	**Achieved during Training**	**Achieved with support in external facility**	**Achieved locally with external assistance**	**Achieved with mutual partner**	**Achieved Independently**
<u>Satellite Project Definition</u> • Supplier elicitation, review and selection • Contracting with System Supplier • Development of project requirements and preliminary system concept					AlphaSat-R1
				AlphaSat-R2	
			BetaSat-R1	BetaSat-R1	
			BetaSat-R2		
			BetaSat-R3		
			GammaSat-R1		
					DeltaSat-R2

The Satellite Project Definition capability is also a part of the set of Investment Capabilities. Whereas the Business Development aspects describes how Implementers gain approval and funding from their overseers, the project definition capability focuses on forming and defining the relationship between the Implementer and Supplier. The steps include finding, reviewing and selecting a Supplier – perhaps from among a group of candidate suppliers. For the selected Supplier a contract is negotiated, reviewed and approved. Throughout this process, the system requirements and the preliminary concept for how the system will meet the requirements are defined. The seven satellite projects are ranked at three levels of autonomy for the Project Definition Capabilities. Nation Beta and Nation Gamma worked with external consultants as they pursued this process, thus their autonomy level is shown as "Achieved locally with external assistance." The consultants advised in area such as recommending suppliers to consider and reviewing supplier proposals. For several projects, the Supplier was highly involved in the

Project Definition activity because the project was seen as a collaboration between mutual partners. For the AlphaSat-R2 project, Implementer Alpha1 and Overseer Alpha1 were in dialog for years with representatives of Supplier Tau1 about the possibility of partnering on a satellite. For the BetaSat-R1 project, Implementer Beta1 did receive support from a consultant, but they also agreed to work with Supplier Omega1 and several of the Supplier's customers on a constellation with specific technical and operational characteristics. This highly influenced the project definition process. Although BetaSat-R2 and BetaSat-R3 were also designed to fly in constellation, their technical specifications were not completely determined by the collaboration. The AlphaSat-R1 and DeltaSat-R1 projects were defined with a more independent approach that did not involve such early collaboration with the Supplier. The complexity and timing of these satellite projects did not have a clear impact on the level of autonomy.

Table 6-92: Satellite System Design Achievements During Satellite Projects

Individual Satellite Project	Achieved during Training	Achieved with support in external facility	Achieved locally with external assistance	Achieved with mutual partner	Achieved Independently
<u>Satellite System Design</u> • System modeling • Functional and physical design • System analysis • Process Planning • Systems Budget Management • Application of system design software	AlphaSat-R1				
	AlphaSat-R2	**AlphaSat-R2**			
	BetaSat-R1				
	BetaSat-R2				
	BetaSat-R3	BetaSat-R3			
	GammaSat-R1				
	DeltaSat-R2				

The third capability in the set of Investment Capabilities is satellite system design. The tasks in this capability include highly technical physics-based modeling and analysis using specialized software that is dedicated to a particular satellite subsystem. The subsystems engineers define both the function and physical layout of their portion of the satellite. The design capability also includes technical management activities such as maintaining up to date documentation of various budgets such as system mass, volume and estimated cost. Process for assembly and operations are planned in preparation for production activities. The design process for each satellite is highly involved and relies heavily on the judgment of the engineers. This is true even if the design is based on previous satellites because each spacecraft is customized to fit the needs of the end users. The Implementer Organizations from the seven satellite projects generally contributed to design only at the level of training within the Supplier Organization. Two projects stand out. During the AlphaSat-R2 project, the engineers from Implementer Alpha1 were newly hired and unfamiliar with satellite technology. They spent their initial time at Supplier Tau1 gaining an orientation to the technology. Later, several of them contributed to design for certain satellite subsystems as part of the team led by Supplier Tau1. The imager and spacecraft were both new designs; there was no existing template from which to work. During the BetaSat-R2/R3 satellite projects, Implementer Beta1 arranged with Supplier Omega1 to give the Nation Beta engineers responsibility for designing and implementing BetaSat-R3. The design was based on an existing satellite platform, but each Nation Beta engineer had to update their portion of BetaSat-R3 for its new mission. These two projects stand out in terms of the level of autonomy achieved by the organization in the area of satellite system design. The projects are at different complexity levels but similar in terms of time. It was the second satellite procurement for both countries.

Table 6-93: Incremental or Major Product Invention Achievements during Satellite Project

<table>
<tr><th>Individual Satellite Project</th><th>Achieved during Training</th><th>Achieved with support in external facility</th><th>Achieved locally with external assistance</th><th>Achieved with mutual partner</th><th>Achieved Independently</th></tr>
<tr><td rowspan="7"><u>Incremental/Major Product invention (creation)</u>
• Application of scientific principles to technology development</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>AlphaSat-R2</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>BetaSat-R2</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table>

In addition to Production and Investment Capabilities, satellite projects may involve Innovation Capability. There are two steps to fielding a new product innovation. The invention step creates a new product; the innovation step implements the product in a non-controlled environment and applies the product to specific mission requirements. The new product may be an incremental or major departure from previous products. An incremental invention improves upon previous designs but does not change the architecture of the product. A major product invention proposes a fundamentally new architecture for a product. The creation of a new product invention involves the application of scientific principles to new technology development via experimentation or trial and error. The case study satellites are classified with respect to product invention achievement based on whether the spacecraft bus or imager payload were new or previously used designs. Only two satellites from the case studies had new designs for spacecraft and imager;

these were AlphaSat-R2 and BetaSat-R2. All the other satellites were based on heritage designs, which is an approach that is highly valued in the satellite community. New designs are risky for the customer and Supplier. Both AlphaSat-R2 and BetaSat-R2 were incremental product inventions. They were not architecturally different in a significant manner from previous optical remote sensing satellites. They did have slightly different internal structural arrangements and some new components compared to previously design satellites by the same teams. They featured higher technical performance, but they provided the same functions as previous satellites. For both Nation Alpha and Nation Beta, they sought this incremental invention for complex satellites in their second project.

Table 6-94: Incremental or Major Product Innovation Achievement during Satellite Project

<table>
<tr><th>Individual Satellite Project</th><th>Achieved during Training</th><th>Achieved with support in external facility</th><th>Achieved locally with external assistance</th><th>Achieved with mutual partner</th><th>Achieved Independently</th></tr>
<tr><td rowspan="7"><u>Incremental/Major Product innovation (implementation)</u>
• Application of technology to mission requirement
• Risk Management
• Evaluation of Technical Maturity</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>AlphaSat-R2</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>BetaSat-R2</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Table 6-94 addresses the implementation of the AlphaSat-R2 and BetaSat-R2 satellites as new products operated in a non-controlled environment. It confirms that the new satellite designs were not only invented but also implemented as part of a specific mission. Part of implementing a new product in a mission for an end user is evaluating and managing the risks of the unknown technology. Satellite developers sometimes address this by introducing redundancy in the design that combines old and new technology for the same function. If the new, unknown technology fails, the old reliable technology can replace it. The two tables tell a common story that these satellite projects were unique in pursuing an incremental product innovation. The desire to do so was driven by the customer. The Supplier in each case also had incentives to pursue an incrementally new design. Both Supplier Omega1 and Supplier Tau1 benefitted from working with a customer that was willing to accept the risk of new technology development. For the Suppliers, this meant a funding source to support new technology development that would benefit them in later projects. Both Suppliers used the platform from these two projects in later sales. In terms of capability, Nation Alpha and Nation Beta gained exposure to the development of a new satellite platform at the training level of autonomy. Although it is a low autonomy level, the exposure is still significant.

The discussion above considers capabilities at the level of a satellite project. There are also Production, Investment and Innovation Capabilities at the level of operating a satellite development organization. In this context, the concern is not just to define and execute a single satellite project but to execute a long term satellite program and maintain an organization with people and facilities to support the program. Production at the organizational level means operating and maintaining the infrastructure that supports satellite system. Investment includes business development, definition and infrastructure establishment for a satellite program made of multiple projects. Innovation at this level refers to new organizational or technical processes rather than products. The tables that describe these achievements gives credit to specific nations rather than projects; not all of the achievements can be observed in the context of a single project and some happen between projects. The achievements identified in the tables were valid at the time of data collection. Organizations may have developed further since that time.

Table 6-95: Satellite Infrastructure Operation and Maintenance by Organizations

Satellite Development Organizations	Achieved during Training	Achieved with support in external facility	Achieved locally with external assistance	Achieved with mutual partner	Achieved Indepen-dently
<u>Satellite Infrastructure Operation and Maintenance</u> • Test programming and execution using equipment • Repair and maintenance of physical capital required for satellite operation, assembly and test	Nation Alpha		Nation Alpha		Nation Alpha
	Nation Beta				Nation Beta
	Nation Gamma				Nation Gamma
	Nation Delta				Nation Delta

Table 6-95 presents the level of autonomy with which nations in the case studies achieved the capability of operating and maintaining satellite infrastructure. There are two major types of satellite infrastructure and countries had different levels of autonomy in each type. One type of satellite infrastructure is the equipment and facilities used to assemble and test satellites. This type can include clean room, machine shops, electronics laboratories, testing chambers and their associated equipment. The second type of satellite infrastructure is the ground system that supports operation of the spacecraft after launch and the reception and processing of the data. This infrastructure features antenna, computers, power systems, software and other supporting components. All of the four case study Nations eventually achieved local responsibility for operation and maintenance of their satellite ground support systems. This is shown in the far right column of Table 6-95. With regard to systems that allowed satellite assembly and testing, three of the four nations only achieved this as guests of the Supplier Organization (far left column of Table 6-95). Nation Alpha stands out on this table because they did operate local facilities for limited satellite assembly and functional testing. They started the operations with support from Supplier Tau1 and others but continued to operate it independently later on.

Table 6-96: Satellite Program Business Development and Satellite Program Definition by Organizations

Satellite Development Organizations	Achieved during Training	Achieved with support in external facility	Achieved locally with external assistance	Achieved with mutual partner	Achieved Independently
Satellite Program Business Development or Approval • Development of feasibility studies and proposals • Stakeholder needs evaluation and communication					Nation Alpha
					Nation Beta
					Nation Gamma
Satellite Development Organizations	**Achieved during Training**	**Achieved with support in external facility**	**Achieved locally with external assistance**	**Achieved with mutual partner**	**Achieved Independently**
Satellite Program (Multiple Projects) Definition • Development of program proposal and program architecture • Evaluating infrastructure and personnel needs for program					Nation Alpha
					Nation Beta
					Nation Gamma

Table 6-96 presents the performance of countries in pursuing business development and definition for a series of satellite projects that make up a long term program. As of the time of data collection three of the four countries had initiated at least two satellite projects with Suppliers. They are all credited with achieving this independently. There are two aspects to this achievement and the countries differ in the extent to which they achieve both aspects. One aspect is simply gaining approval and funding for a second project after completing the first. The first satellite project a nation pursues may bring a certain amount of political support due to their pioneering nature. A nation's first project transforms them from being a satellite service user to a satellite service provider. The second satellite project does not have the same air of pioneering transformation. There is a risk that stakeholders that are distant from the satellite activities may not understand the need for a second satellite project after an initial success. The countries are given credit in Table 6-96 for overcoming the potential inertia of the first satellite project and moving on to the second. A second aspect of business development for a satellite program is the capability to plan and gain support for a long term road map of satellite projects that moves the nation methodically toward a distant goal of technological capability. A nation may complete two consecutive satellite projects without having a long term program defined. Nations Alpha, Beta and Gamma all approached this activity differently. Nation Alpha did not start their first project with a clear long term goal for a national satellite program. The opportunity to launch a small national satellite was presented. The Overseer and Implementer Organizations responded to launch opportunity by gradually forming a vision for achieving national capability build satellites. Nation Alpha did not, however, work with high level government leadership to define a long term series of satellite projects with progressive goals. As they worked on operations for AlphaSat-R2, Implementer Alpha1 worked with Overseers Alpha1 and Alpha2 to define potential goals for the long term. They did feasibility studies for national satellite projects based on different types of technology – such as communications. As of the time of data collection Implementer Alpha1 had not achieved Overseer approval for a long term road map to serve as future project goals. They were planning and approving each project as an individual. Meanwhile, Nation Alpha was still in a long term process to define their national space policy. In contrast Nation Beta did define a long term road map with specific technical milestones and an ambitious long term vision. The central governing body in the executive branch of Nation Beta approved a multi-decade space program with several milestones that marked steps toward indigenizing space technology. The approval came near the beginning of the BetaSat-R2/R3 satellite project. Milestones on this long term plan included deadlines for building a satellite locally and for building and operating a launch vehicle locally. Nation Gamma started the process of defining and gaining approval for a long term series of projects with capability milestones. As they entered GammaSat-R2 with Supplier Tau1 they envisioned future strategies to combine enhanced technical performance of the satellite with organizational autonomy. They considered the possibility of following a path similar to Nation Beta by which they would buy multiple satellites during one project, with one focused on performance and the other on training. Time is an important factor to consider the presentation of data in Table 6-96. Nation Alpha had a history of a little more than 15 years for their satellite projects; for Nation Beta the timeline covered on the order of 10 years; and Nation Gamma's experience was about five years.

Table 6-97: Satellite Infrastructure Establishment by Organizations

Satellite Development Organizations	Achieved during Training	Achieved with support in external facility	Achieved locally with external assistance	Achieved with mutual partner	Achieved Independently
Satellite Infrastructure Establishment • Feasibility studies • Implementation project management • Procurement of equipment • Soliciting and selecting bids • Contracting and oversight • Hiring and training of personnel • Start up of Operations			Nation Alpha		Nation Alpha
			Nation Beta		
			Nation Gamma		
			Nation Delta		

Table 6-97 presents the achievement of a single nation in the area of satellite infrastructure establishment. As defined above, satellite infrastructure includes the ground system for operating the satellite as well as the equipment and facilities required to assemble and test satellites. Three of the four nations established new general workspace as part of the case study projects. Nation Alpha evolved their facilities for both the Implementer and Overseer several times. During the BetaSat-R2/R3 satellite project, Nation Beta set up a new space agency headquarters campus and opened several specialized campuses in other parts of the country. Nation Gamma rented and set up a new office facility for Implementer Gamma1 during GammaSat-R1. Nation Delta had well established facilities, but built new office space at the site of the new ground station that was built for DeltaSat-R1 away from Implementer Delta1 headquarters. The general facility implementation is not captured in Table 6-97. The table only presents achievements related to establishment of satellite ground systems and satellite assembly and test facilities. All four nations established new ground systems for satellite operation with support from Suppliers or ground system subcontractors. This places them in the middle column for autonomy. Nation Alpha also established facilities for satellite assembly and test. In terms of autonomy, they started with external assistance to define the specifications and standards for the clean room and electronics laboratory. Implementer Alpha1 and Overseer Alpha1 both set up specialized facilities and worked with local contractors for construction. Thus, Nation Alpha stands out in achieving satellite infrastructure establishment.

Table 6-98: Incremental/Major Process Invention and Innovations by Organizations

Satellite Development Organizations	Achieved during Training	Achieved with support in external facility	Achieved locally with external assistance	Achieved with mutual partner	Achieved Independently
Incremental/Major Process invention (creation) • Application of scientific, management or social science principles to define new satellite engineering process, testing techniques, or management approaches				Nation Alpha	Nation Alpha
Satellite Development Organizations	**Achieved during Training**	**Achieved with support in external facility**	**Achieved locally with external assistance**	**Achieved with mutual partner**	**Achieved Independently**
Incremental/Major Process innovation (implementation) • Implementation of new satellite engineering process, testing techniques, or management approaches				Nation Alpha	Nation Alpha

In Table 6-93 and Table 6-94, Nations Alpha and Beta were credited with achieving incremental product innovations during training because they procured satellites with new spacecraft and imager designs for their second projects. Table 6-98 considers invention and innovation again for an organization. In this context, new processes rather than new products signify invention and innovation. Nation Alpha achieved an incremental process innovation at an independent level of autonomy by developing steps for monitoring and operating AlphaSat-R2. They worked independently to define a set of potential anomalies and prepare procedures for countering them. Nation Alpha also achieved an incremental process innovation by sending their satellite to a rarely used orbit. This was done with a partner as they worked with Supplier Tau1. Nation Alpha did not claim to be first to propose using the orbit, but they were still pioneers in actually building a small remote sensing satellite for such a mission and operating it.

6.2.5 Reflections on Capability Building

Before continuing on to Research Question 5, this section considers the outcomes of the capability building analysis at the individual and organizational level.

6.2.5.1 Individual Capability Building

This section provides several points of reflection about the individual capability building analysis. The analysis approach provides a useful indication of individual opportunities for capability building. The analysis does not directly measure individual learning, but it does show progress over time in the level of application and topic areas that each individual covers. As someone moves from theoretical training to independent implementation in an area, it is likely that they are learning the knowledge. The evidence for the tables is based on interviews. It is possible that some examples for a given individual did not emerge in the interviews. In that sense, the tables show a conservative estimate for the capability building opportunities. The set of data presented above is highly gender biased. It primarily shows examples of male engineers. This does not fully reflect the gender breakdown of the engineering teams at the Implementer Organizations. Most of the Implementer engineering teams that went to work with the Supplier Organization did have several women members.

The stories of individual capability building relate to several theoretical concepts. The first is absorptive capacity. An individual organization has higher absorptive capacity when they have previous experiences that support their ability to learn new material. In these capability building profiles, several engineers had related practical experience or previous satellite experience before they went to visit the Supplier for training. Both spoke of how they used their previous knowledge in their work at the Supplier. Both felt some level of confidence based on their earlier experiences. In the case of one engineer from Nation Beta, he worked on large scale power systems and moved to small scale. His knowledge did not all transfer directly, but he felt confident in the working environment. Another Nation Beta engineer was trained as part of the communication satellite project. He felt he learned theory well during that training and it helped his hands on work when he arrived at Supplier Omega1. Absorptive capacity is not always technical. One engineer from Nation Delta felt more confident at Supplier Sigma1 because he had studied at a university in Nation Sigma before the training experience.

6.2.5.2 Organizational Capability Building

The capability building achievements of the organizations in these case studies takes place over years or decades. Nation Alpha has the longest history, so it is not surprising that they also have some impressive achievements compared to other nations. Note that the organizational autonomy scale used to capture achievements is focused on transitioning from a state of dependency on others for technology to independent understanding of a technology. In other words, the scale shows the process of mastering a technology. One scholar of technological capabilities in developing countries proposes that technology mastery is just the first step in a longer series of steps toward harnessing a new technology in a country. Lall proposes a series of steps including mastering a technology, adapting the technology to local conditions, improving the technology, diffusing the technology within the economy and exporting the technology.[1] The steps are proposed for a generic technology. In the case of a satellite, adapting a satellite system to local conditions may be done with both the data and the spacecraft. The steps to process satellite data depend on the nature of the geography. Nation Alpha took steps to adapt their entire system to local conditions by choosing an orbit that would give them more frequent coverage of their land. Improving the technology may be done through the incremental or major product and process innovations discussed above. As noted, the two new satellite platforms for the AlphaSat-R2 and BetaSat-R2 satellites are examples of improving the technology in partnership with a supplier. After mastering satellite technology, the Implementers could seek to improve it independently. Diffusing the technology into the economy could take several forms. Nation Alpha started this process by working with local firms for some fabrication of parts for AlphaSat-R2 and by using local firms to build their assembly and test facilities. In general, the satellite technology diffuses in the local economy when the satellite data is used to support decision making or geographical analysis. The final step is exporting the technology. None of the case study implementers reached that stage, but Supplier Tau1 did go through the entire process from technology mastery to technology export in a period of about two decades.

In order to highlight the importance of diffusing technology in the economy, Lall proposes an additional category of organizational capability called Linkages. This includes sharing information and business with local vendors, customers and researchers. Nation Alpha stands out in this area, but Nations Beta and Gamma also have vision for working on this. Nation Beta has investigated local manufacturing opportunities for satellite components. They also developed several technologies that they hoped to commercialize into the economy for non-space use.

---

[1] Lall, Sanjaya. "Technological Capabilities and Industrialization." *World Development.* Vol 20, No 2, p 165-186, 1992.

Nation Gamma had several relationships with local universities for research on satellite data use. As part of this relationship, they sometimes worked with local students on projects. These are all examples of linkages. If new nations pass through all of Lall's steps from mastery to technology exporting with small satellites, the potential financial impact may not be high. Lall's framework was built with a focus on mass produced goods that can be exported to many customers around the world. When a country achieves the capability to export satellites, it may not have a large impact on the overall economy. It does, however, have the potential for symbolic impact because the number of satellite exporters in the world is small compared to many other technology products. There is not room in any country for a large number of firms or organizations manufacturing satellites. In the more developed countries the well established aerospace companies are large, vertically integrated companies that grew by merger because the market was small. Thus, the goal for the Implementer nations in these countries may be different from Lall's proposed series of steps. Mastery, adaptation, improvement and diffusion of satellite hardware may be more important than exporting. On the other hand, several countries in these cases have the goal of exporting satellite data to a global market. The data market does have room for expansion by new players.

6.3 Research Question 5: What are potential relationships between architecture and capability building?

This section explores potential links between architecture and capability building in three stages. The first stage proposes three archetypal project types that provide unifying themes which are consistent in several projects. The second stage starts to consider how future projects can be architected to purposely create opportunities for capability building. The third stage considers factors outside of the architecture – including personal characteristics – that impact the training experience.

"What archetypal projects highlight the relationship between architecture and capability building?"

Research Question 5 considers the relationship between the architecture of collaborative satellite projects and the capability building opportunities that Nations achieve at the individual and organizational level. One answer to the research question proposes three archetypal project categories that show a link between key aspects of architecture and capability building experiences. Table 6-99 introduces three archetypal categories that capture several aspects of Context, Architecture and Capability Building. The three archetypes are driven by three types of political and leadership contexts. For each archetype, two or three of the case study satellite projects fit into the pattern for context, architecture and capability building. These archetypes provide an initial anchor into relevant processes that link the three areas. Each archetype is introduced in the following discussion.

Table 6-99: Three Archetypal Projects that Summarize Links between Context, Architecture and Capability Building

Summary of Archetypal Collaborative Satellite Projects			
	Structured Project	**Risk Taking Project**	**Political Pushed Project**
Context			
Political Support	Low political support	Medium Political Support; Need to Increase.	Strong political support
Leadership	Leader in space organization understands political and bureaucratic system	Key leader in space organization with vision and technical understanding	Key National Level Leader gives support and visibility to satellite activity.
Timing	2nd National RS Project	2nd or 3rd national RS project	1st remote sensing project
Architecture			
Funding Approach	Approval for funding is done through official bureaucratic process – no favoritism for space project. Proposal should demonstrate the benefits of the project.	Formal approval process for Implementers led by Overseers.	The high level leaders are interested in funding the project and the Implementers do not have to convince them.
Supplier Selection	Key is to use a formal, traceable **process** to choose supplier.	Choose based on personal relationship. The key is to work with someone that is **trusted.**	Choose supplier based on personal relationship or introduction. Key is to work with someone that has a similar **vision.**
Technical Approach	Complex and high performance	Mix of high and low complexity and performance	Less complex and low performance
Phase of Project Experienced	Phase A/B to Phase D	Phase A to Phase D	Phase C and D
Accountability in Mentor Relationship	Well defined mentor relationship	Mix of formal and informal	Flexible, informal mentor relationship
Capability Building Opportunities			
Level of Application of Training	Strong on theoretical and practical Training	Strong on practical and on the job training	Strong on practical training and medium on the job training

Areas of Organizational Accomplishment (Advances in autonomy, complexity, topics)	High in complexity, Low in autonomy, High in new topic coverage	Med in Complexity, High in Autonomy, High in new topic Coverage	Low in complexity, Low in autonomy, High in new topic coverage
Example Projects			
	BetaSat-R2 and DeltaSat-R2	AlphaSat-R2 and BetaSat-R3	AlphaSat-R1, BetaSat-R1, GammaSat-R1
	Structured Project	**Risk Taking Project**	**Political Pushed Project**

The Politically Pushed Project

Beginning on the far right with the politically pushed project, this archetype is a model that fits AlphaSat-R1, BetaSat-R1 and GammaSat-R1. For the politically pushed satellite project there is strong political support from a key national leader. This leader takes initiative and has enough influence to give the project visibility and political recognition. This reality was true for the three projects in the data set that were first national satellite projects. The political leader fostered excitement for the pioneering achievement. The architecture for a politically pushed project has several common aspects. The funding approach is flexible. Because high level leaders are interested in the project, the Implementer leaders to not have to spend time convincing them of the value of the project. They focus instead of defining the project activities and technology. When Implementers choose Suppliers for the politically pushed project, the key factor that drives them is finding a partner with whom they share a common vision. The Implementer may or may not use a rigorous selection process to find and compare potential suppliers. This depends on their familiarity with the space marketplace. The key issue is that they eventually form a personal relationship or receive an introduction to a Supplier team that supports the Implementer vision for their first national satellite project. The technical approach for the politically pushed project is conservative, seeking low complexity and tentative technical performance. The satellite does not need to be highly ambitious; it only needs to be successful to usher in the first national project. The Implementers in the politically pushed project are not deeply familiar with the process of satellite development. They are guided by the supplier as they define the technical characteristics of the satellite and training experience. The Implementers are not aware of the different stages of the satellite development lifecycle. The engineers mainly experience the later lifecycle stages that focus on manufacturing, assembly and testing. The Supplier engineers provide informal mentorship to the visiting Implementer engineers in a flexible manner that evolves naturally. The capability building opportunities that result from this combination of contextual factors and architectural choices are as follows. The level of application of the training for the Implementer engineers is strongest in the area of practical training where they work in a hands-on manner but they are mainly forming skills rather than contributing to the project. There is a medium level of experience with on the job training, especially at the end of visit to the Supplier. In terms of organizational advancement in the three axes of capability building, the Implements make a low advance in terms of complexity, and a low advance in autonomy. They experience many new topics, however, because the entire satellite development process is unfamiliar. All of this description applies to the AlphaSat-R1, BetaSat-R1 and GammaSat-R1 projects. They did not have all of their architectural dimensions in common, but this set overlaps.

The Structured Project

The first column of Table 6-99 shows the Structured Project Archetype. The Structured Project may follow the Politically Pushed Project as the second national satellite investment in remote sensing. The Structured Project faces low political support. The excitement of the first national satellite project in remote sensing has worn off. The project requires a leader at the level of the Implementer or Organizational level who understands how to survive in the political and bureaucratic system that does not necessarily favor their projects. As these leaders apply for funding from the government, they are no longer granted special status because of the novelty of space. In this case, they need to demonstrate clearly how the project will bring benefit to the country. Thus they emphasize the opportunity to generate useful data. As the Implementer selects a Supplier, they continue to follow a rigid, bureaucratic process in order to fit within official policy. They use a formal, traceable process to choose the supplier that indicates a rigor. They do not simply make a personal arrangement based on relationships, even if they know the Supplier already. The technical complexity of the Structured Project satellite is high and the performance is excellent. This ensures that the satellite performs a social service worthy of funding. Also, since the first project was successfully completed, the willingness to invest in advanced technology is increased. The Implementer is more aware of the satellite lifecycle. They work with the supplier to ensure that their engineers visit for a longer portion of the development process, including the design phase. They also seek well defined relationships between Supplier mentors and Implementer engineers that can be documented and tracked along with other project deliverables. The Capability Building Opportunities created through this combination of Context and Architecture are as follows. The training for individuals is highly theoretical and includes some practical training. The Implementers seek high quality academic experiences that give the engineers foundational knowledge to understand the design process. The organizational advances are thus high in terms of exposure to complex technology, low in terms of gaining new autonomy and high in terms of new topics covered at the theoretical level. This description is true for BetaSat-R2 and DeltaSat-R1.

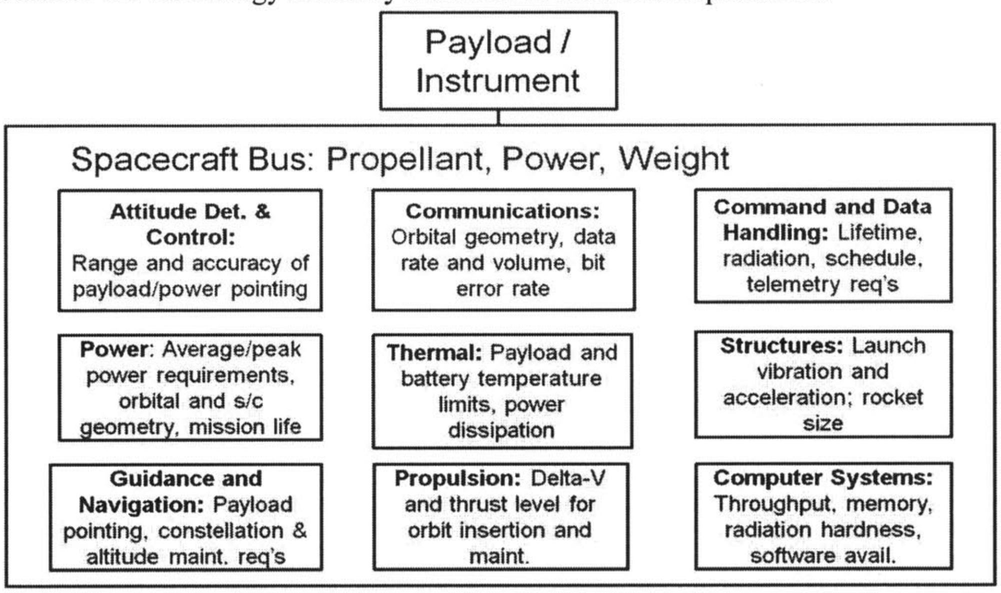
The Risk Taking Project

Another potential path that Nations take after early satellite projects is the Risk Taking Project. In this case the political climate is mediocre. There is a need to increase it by demonstrating the excitement of space in a fresh way. In this context, a strong leader in the Implementer or Overseer organization can play an important role by providing vision based on a sound technical understanding of satellite technology. As the leader pursues the funding process, they follow the formal guidelines as they might in the Structured Project. When the Implementer chooses a Supplier, they are concerned with working with someone that they trust. The trust is important because it allows the Implementer to consider taking a technical risk with the Supplier as their guide. The technical nature of the satellite may vary. The key is that in some way, the Implementer defines an opportunity to take a high risk for high rewards as part of the project. This may be by seeking exposure to new topics or more autonomy. The Implementer ensures that their engineers experience all the satellite lifecycle phases and participates fully. The mentor relationship may be formal or informal; this is driven by the Supplier culture. The Risk Taking Project provides opportunities for strong practical and on the job training because the Implementer leadership has clearly defined a new achievement goal for the organization – either in terms of new topics or autonomy. This summarizes key aspects of the AlphaSat-R2 and BetaSat-R3 projects. They took different risks. For AlphaSat-R2, they sought a new satellite design in an unusual orbit. For BetaSat-R3 the risk was to allow the Implementer Beta1 engineers to work more independently. The common thread was to take a risk that demonstrated the potential of the technology to advance the nation.

These three archetypal project categories bring together the analysis above. They show potential links that could start to explain how context leads to specific architectural choices and how these choices impact the range of capability building opportunities.

How can projects be architected to create best opportunities for capability building?

As future national space organizations pursue collaborative satellite projects that follow the model studied here, they have the opportunity to learn from the past experiences of others and create project architectures that are most likely to support their objectives. This section makes an analogy with a physical satellite to develop an approach to architecting satellite projects. Satellites are divided into two main sections: the payload or instrument and the spacecraft bus. The payload is the part of the satellite that provides a useful service to the customer or end user. The spacecraft bus includes all the subsystems that support the operation of the payload by supplying structure, thermal protection, radiation shielding, power, computation, navigation, pointing and communication, among others. For most satellites, payload is the part of the satellite that achieves the objectives of the customer. The decisions for how to design the subsystems are all based on the needs of the payload. Each subsystem has several major design characteristics that represent decision facing the subsystem engineer as they develop their part of the satellite. There are also key features of the payload and operational plans that impact how each subsystem is designed. These features are called design drivers. Figure 6-7 shows a conceptual model of a satellite and highlights nine subsystems with their design drivers. The figure emphasizes the concept that the design choices for each subsystem are based on the needs of the payload. The operation of the payload is the ultimate goal of the satellite. Some satellites have multiple payloads; this increases their complexity. If there are conflicts between the technical requirements to operate both payloads, the satellite design team needs to work with the customer to prioritize the payloads. Depending on the needs of the payloads, some satellites subsystems are more influential in the design than others. Some subsystems must meet a precise performance requirement in order for the payload to work; for other subsystems, the performance is not as critical. For example, if a satellite operates a camera as a payload, it may be the case that the attitude control subsystem is very important to point the camera accurate. This requirement may imply technical challenge. At the same time, the requirements on the communication system to send the data from the satellite to ground stations on earth may be less critical because the technology is readily available to meet that requirement.



(Wertz and Larson, SMAD, 1999)

Figure 6-7: Conceptual model of a satellite showing subsystems and design drivers[ccix]

The concepts illustrated in Figure 6-7 allow an analogy to defining the architecture of a satellite project. A satellite project can be conceptualized as a system with the equivalent of subsystems and payloads. For a project, the payloads are replaced with desired outcomes. In the case study projects, the desired outcomes included a particular technical performance by the satellite system and increased capability building. The subsystems of a satellite projects are not physical elements of the project. Instead they are the Architectural Views that define different aspects of the project. Examples of the Architectural Views defined in Research Questions 1 and 2 include Organization View, Supplier Selection View, Management and Contract View, Personnel Management View and Training View. Within each view is a series of dimensions. One dimension is the combination of a function and potential forms that can execute the function. Architecting a satellite project means assigning specific objects of form to execute functions for each dimension. For example, in the Organization View one function is Overseeing the project. This is executed generically by an Overseer. One architectural choice is to decide what organization executes the function of Overseeing. Figure 6-8 provides a conceptual model for the architecture of a satellite project that builds on Figure 6-7. As is the case with a satellite project, the architectural decisions of assigning forms to functions for each dimension should be driven by the desired outcomes. Ideally, the assignment of each form supports the technical performance requirements and capability building objectives. In addition, the context brings constraints that impact the set of options for what elements of form are available to be assigned to functions. In some cases, contextual constraints make it impossible to assign an ideal element of form to a particular function and the project must compensate for this deficiency.

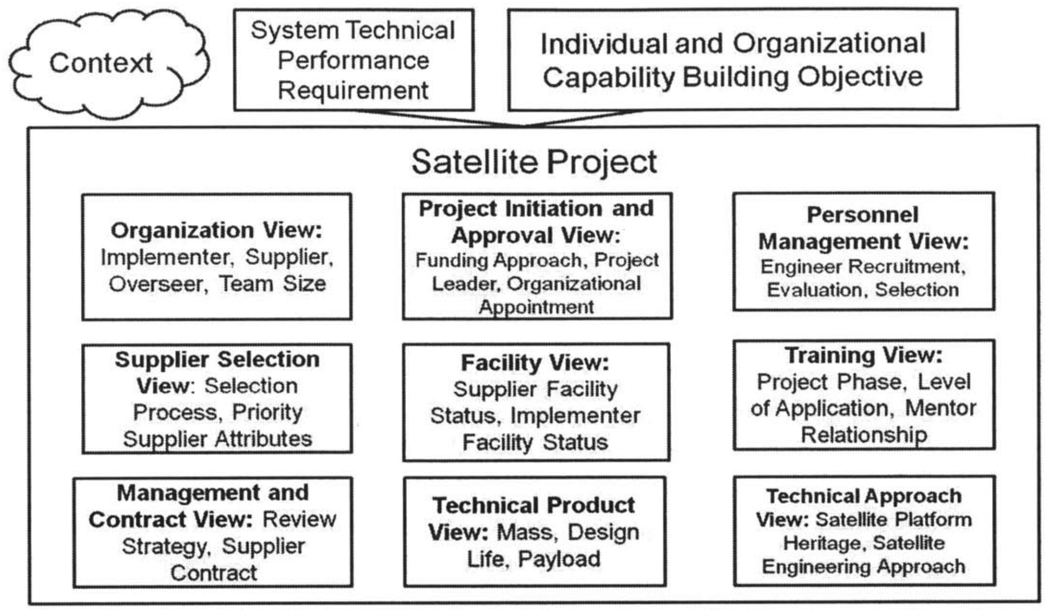


Figure 6-8: Conceptual model of satellite project architecture showing objectives, views and dimensions

How can decision makers who are involved with collaborative satellite projects determine what elements of form to assign to functions in order to best achieve technical requirements and capability building objectives? Such an approach will require three types of knowledge. The first type of knowledge is about the internal rules that govern each View. These rules define what functions are relevant, what elements of form are potentially relevant and the different characteristics of each element of form. The second type of knowledge is about the relationships between Views. Does a decision to assign one element of form in one View impact other Views? If Views are linked, a decision about one View may reduce the set of options for another View. Third, knowledge is needed about the relationship between Views and the requirements and objectives. How does the choice of each View impact the achievement of the project technical performance and capability building? The decisions for each View should be driven by these requirements and objectives.

In the case of a satellite design process, the knowledge about rules governing each subsystem, relationships between subsystems and the relationship between subsystems and payloads is generally well understood. These rules and relationships are based on physics; they can be quantified and modeled using software. It is much more difficult to define the relationships and rules governing Architectural Views of satellite project. For the rules governing each View, there is knowledge to be learned from literature. Each Architectural View is a specialty area that has its own set of knowledge beyond the scope of a specific satellite project. For most Architectural

Views, there is literature that provides general guidance on the governing rules. For example, the Supplier Selection View is linked to the larger project management and project delivery literature that addresses the process of evaluating and choosing a firm during procurement of a large-scale infrastructure project. The Personnel Management View is linked to a larger literature that addresses the general strategies for recruiting, evaluating, selecting and retaining engineers in a government or commercial setting. For all the Views there is some amount of literature or common practice in other disciplines that can start to elucidate the rules of the View. In some cases, concepts from the literature may not apply directly apply because they were developed based on different assumptions or in different concepts. As these situations are discovered, they will motivate future research.

The relationship between the Architectural Views of a satellite project is an area that will require further research and literature review to confirm. This is initially explored in the discussion on Research Question 2. More research and literature review is also needed to define the relationships between the Views and project outcomes. The evidence about these issues from this study is inconclusive, because of the exploratory nature of the work. Table 6-100 gives examples of project dimensions that showed either variation or similarity across projects. Projects tended to be similar in the type of organization that served as Overseer; most Overseers were relevant government ministries. Most Implementer Organizations played a similar role in the process of selecting engineers for training. During engineer recruitment, projects used similar sources of recruitment and similar evaluation processes. There were fewer examples of similarity than of variation. Projects varied in dimensions such as the type of Implementer Organization, the type of Supplier Organization, the Team Size and others. Some of this variation is expected to impact the project outcomes based on concepts from literature or experiences in other fields.

Table 6-100: Summary of Project Dimensions that show variation or similarity across projects

Examples of Architectural Dimensions with *Variation* Among Projects	**Examples of Architectural Dimensions with *Similarity* Across Projects**
1. Implementing Organization 2. Supplier Organization 3. Implementer Visiting Team Size At Supplier 4. Role Of Supplier As Engineer Selection Organization for Implementer Engineers 5. Implementer Engineer Recruitment Process 6. Supplier Selection Process 7. Training Project Phase (that visiting engineers experienced at supplier) 8. Theoretical training 9. Practical training 10. Mentor-trainee accountability system 11. Complexity of Technical Product 12. Satellite Platform Heritage 13. Satellite Engineering Approach	1. Overseer organization 2. Role of Implementer as Engineer Selection Organization 3. Engineer Recruitment source 4. Engineer evaluation process 5. Priority supplier attributes 6. Implementer facility status 7. Supplier facility status 8. On the Job Training Approach

14. Role of Implementer Engineers in Reviews 15. Educational Background of Implementer Engineers	

Table 6-101 gives further information about some of the architectural dimensions that varied across projects. The case studies reveal the nature of the variation for several dimensions. In some cases, variation can be observed in several ways. The types of Implementing Organizations can be divided as government versus private sector; operational versus research; or as focused on delivering satellite services versus satellite manufacturing. The Supplier firms fit into two groups that are different in several ways. Two of the Suppliers are smaller, younger organizations with non-traditional engineering and project management approaches. The third supplier is larger, more established and represents mainstream technology approaches. The Implementer organizations sent teams of different sizes to work with the Suppliers. The divisions between smaller and larger teams are labeled subjectively. Three teams were in the range of six to 15 people while three teams were in the range of sixteen to thirty people. Table 6-101 provides the source of variation for several other dimensions.

Table 6-101: Discussion of variation among architectural dimensions

Examples of Architectural Dimensions with *Variation* Among Projects	**Major Source of Variation**
Implementing Organization	Implementers can be split along several divisions: government versus private organizations; operational versus research organizations; or satellite service versus satellite manufacturing
Supplier Organization	The suppliers can be split into two groups where two suppliers are small in size and use non-traditional approaches; one supplier is large and uses traditional technology approaches
Implementer Visiting Team Size at Supplier	Three projects have teams in range of 6 to 15 people; three projects have teams in range of 16-30 people.
Role Of Supplier As Engineer Selection Organization for Implementer Engineers	In two out of six projects, the Supplier played a strong role in selecting Implementer engineers.
Implementer Engineer Recruitment Process	Four projects advertised broadly through public and private channels; two projects relied mainly on private

	channels.
Supplier Selection Process	Two projects used informal process; four used formal process with review of multiple proposals.
Training Project Phase (that visiting engineers experienced at supplier)	Four projects mainly exposed trainees to Phases C and D; Two projects exposed them to Phases A to D.

For each dimension that shows variation, the data inspires initial ideas about potential relationships within Architectural Dimensions, across Architectural Dimensions and between Dimensions and Project Outcomes (technical performance and capability building). Examples are given in Table 6-102. The Architectural Dimension of Implementer Organization seems to show a connection between the choice of Overseer and choice of Implementer because the Overseer Organization typically appoints the Implementer. The first observation is that while most Overseers were similar in nature (most were government ministries related to science and technology), they chose a variety of types of organizations to serve as Implementers. There is a plausible conjecture about the relationship between choice of Implementer Organization and the project outcomes. There were four types of Implementer Organizations, each with a different operational model. The four types were government linked company, national space agency, national remote sensing agency and national research agency. The conjecture is that these different types of agencies might choose different areas of technical focus within the field of satellite technology. This is not clearly seen. The national remote sensing agency does make a clear choice to be focused on operations, but it the other three types of agencies appear similar in their approaches. All three state a long term goal to establish internal capability to design and manufacture satellites. All three state a long term goal to set up physical infrastructure to support satellite assembly and testing. All three assign teams to the complete set of satellite subsystem specialties, including operations. Will it be the case that these three organizations (a company, space agency and research agency), will differentiate more in the future based on their category? Or are the labels unimportant because they share the same operational goals? It may be the case than in the early years of a country's activity in a new technology, specialization is less relevant because the organization is trying to learn the overall technology and has not yet determined a long term path.

Table 6-102: Examples of conjectures about relationships among Architectural Dimensions, between Architectural Dimensions and between Dimensions and Project Outcomes

Architectural Dimension that shows variation	Proposed Chain of Relationships	Potential Outcome

Implementer Organization	Overseer Organization → Implementer Organization	We might expect different types of implementers to have different areas of technical focus, but it is not clear. One difference is that the Remote Sensing Agency is more operations focused.
Supplier Organization	Supplier Organization → Satellite Engineering Approach	The Supplier Organizations can be divided into two categories. One emphasizes subsystem design; one emphasizes subsystem integration
Implementer Visiting Team Size At Supplier	Visiting Team Size → Role Assignment Philosophy	Teams of trainee engineers are assigned to different ranges of subsystem roles and learn different subsystem topics during on the job training

Table 6-102 also presents conjectures about relationships relating to the Architectural Dimension that assigns a Supplier Organization to the functions of producing satellite and training engineers. In these six case studies, the choice of Supplier inherently defines the Satellite Engineering Approach Dimension because each Supplier has a specific technology approach. That may not be the case with all Suppliers. In general, it could be possible for a Supplier to operate with multiple engineering approaches, although there is not much evidence of that in the aerospace community. The Satellite Engineering Approach Dimension is closely related to many other aspects of a Supplier Organization. The Engineering Approach defines the types of facilities a Supplier requires, their contractual preferences, their technical product and their training approach. It thus impacts the Views for Management and Contract, Facility, Technical Product, and Training. With regard to training, the conjecture is that the Supplier following a more traditional satellite engineering approach would emphasize satellite design via subsystem integration. This type of firm tends to outsource the design and fabrication of many subsystems to external vendors. Alternatively, the Supplier following a small satellite engineering approach emphasizes satellite subsystem design. This difference in training should impact the capability building outcomes, especially with regard to Individual Capability Building experiences. The data from this study is not designed to systematically compare the individuals along these lines. This is conjecture provides a starting point for further work.

A similar discussion applies to the Architectural View of Implementer Visiting Team Size at Supplier. The Team Size dimension impacts the Role Assignment Philosophy Dimension. The leadership within the Implementer and Supplier Organizations work together to assign Implementer engineers to technical positions during their training. Small teams used different philosophies than larger teams. The smaller teams either sought to cover many topics within satellite engineering by giving each person multiple roles or they choose a small set of topics on which to focus. Large teams tried to cover as many topics as possible by spreading their engineers across the disciplines. The difference between these approaches is expected to have long term impact on the organizational achievements. Perhaps these choices will influence the way the organization specializes later on. If a team trained a few people in strategically chosen areas, this choice may shape their future decisions about what aspects of satellite projects to outsource. Implementer Organizations that send large teams seeking to cover many topics also tend to model their satellite organizations after the organization of the Supplier firm. It is not clear that such an organizational structure is most effective for a new organization in the field from a different country. The Implementer Team size seems to be an important dimension whose impact needs to be explored both with more research and with longer observation of the case study countries.

This discussion has given a few examples to motivate the need to explore connections future that can inform the architecture of future satellite projects. Along with the potential to assign forms to functions strategically is the realization that contextual constraints may limit the freedom of decision makers. Furthermore, the case studies also show that there is not a centralized decision maker architecting the satellite projects. Decisions are made by a combination of the Overseer, Implementer, Supplier and other actors from the various nations such as regulators. This research proposes that key leaders from the Overseers and Implementers may benefit from thinking about the satellite projects as systems that can be architected. They may not be free to define Architectural Dimensions as they choose due to constraints or the actions of other stakeholders. They will be aware, however, of the set of options open to them and the potential impact of choosing one option over another. Further research will continue to explore the relationships between and among Architectural Dimensions and Outcomes.

What are alternative explanations beyond architecture for project outcomes?

This section considers alternative influences on project outcomes in order to explore the limits of architecture as a factor. As the relationship between project architecture and capability building is discussed, an important idea is that the architecture of a satellite project does not completely determine capability building. The definition of individual and organizational capability building distinguishes between **opportunities** for capability building and the actual learning and achievements of new capabilities. The architecture of a satellite project directly influences the opportunities that an individual or an organization has to build capability. Given the same opportunity, people and organizations respond different. This is based partly on their past experiences that determine their absorb capacity. It is also based on the level of initiative that drives the people or organizations to achieve even if the circumstances are not ideal. The potential benefit of a well architected satellite project is not a guaranteed path to capability building. It is the chance to reduce unnecessary barriers to learning. The appropriate architecture, however, does not guarantee learning. The circumstances that influence the engineers in these case studies include Architectural Dimensions that are defined by choices made by decision makers as well as contextual factors that are outside the Implementer's control. Some of the individuals who worked as Implementer engineers in these case studies demonstrated that they chose to not be limited when faced with circumstances that were not conducive to their capability building. These individuals had strong internal motivations to improve their capabilities. They also had an ability to connect the new work on satellite technology with previous experiences. They invested in their personal growth regardless of circumstances.

Several types of obstacles were faced by engineers from several Implementer Organizations in the case studies. The obstacles were in four categories: Timing, Culture, Architectural Dimension and Personal Characteristic. The Timing obstacles are a general category of unexpected delays or schedule changes that impacted the training or work experience of the Implementer Engineers. Culture obstacles are the issues that faced Implementer Engineers as they moved to a new country and new organization. Sometimes obstacles occurred as a result of Architectural Dimensions defined by project decision makers, such as the assignment of engineers to specific roles. Finally, some Implementer Engineers faced obstacles based on their own personal characteristics such as educational background, personality and time management skills. Table 6-103 gives some examples of Obstacles that faced one or more Implementer Engineers. For each obstacle, the middle column of the table defines the type. When possible, based on the available data, the far right column gives an example of engineers finding resolutions to overcome the obstacle.

Table 6-103: Engineers from Implementer Organizations Faced and Overcame Obstacles due to several sources

Examples of Implementer Engineers Overcoming Obstacles		
Obstacle	***Type of Obstacle*** *(Timing, Culture, Architectural Dimension, Personal Characteristic)*	***Example of Resolution***
An Implementer Engineer is uncomfortable with team role assignment for visit to Supplier Organization	Architectural Dimension: Role Assignment Philosophy	One engineer was assigned to a role that focused on management tasks. He also wanted to use his engineering skills and sought opportunities for additional technical assignments.
There is a delay in the schedule for the Implementer Engineers to travel to the Supplier Organization for training.	Timing Issue	Some engineers used the unexpected time at the Implementer Organization to practice new skills, review previous work by Implementer and learn from more experienced engineers.
An Implementer Engineer faces an overwhelming workload while working at Supplier and needs to decide how to manage their time.	Personal Characteristic	One engineer made a difficult decision to forgo some theoretical training in order to focus on responsibilities at Supplier Organization.
An Implementer Engineer is frustrated because their activities at the Supplier Organization do not meet their expectations regarding the topics they would	Architectural Dimension: Training Approaches	

cover or level of autonomy they would have.		
An Implementer Engineer unsatisfied with their relationship with their mentor at the Supplier Organization.	Architectural Dimension: Mentor Approach	
An Implementer Engineer encounters cultural differences that make it difficult to adjust to the Supplier country.	Cultural Issue	One engineer worked closely with their Supplier mentor during the early part of their visit to get assistance with practical tasks in the community.
An Implementer Engineer is uncomfortable with their assigned responsibilities in the home organization after training.	Architectural Dimension: Post-Training Assignment	Several engineers proposed new projects to the Implementer Leadership and took initiative to train new recruits to participate in the new projects.
The launch of the satellite is delayed and this causes uncertainly about responsibilities for the Implementer Engineers in the near term.	Timing Issue	
Due to the Temporary or Transitional Status of facilities, an Implementer Engineer faces challenges in executing assignments.	Architectural Dimension: Implementer or Supplier Facility Status	Some engineers did their best to work well despite minimal facilities.
An Implementer Engineer finds that they do not have an adequate educational background for the work they are assigned at the Supplier.	Personal Characteristic	One engineer faced this obstacle. He found that he was able to be more successful at hands on work than theoretical work. He and his mentor re-defined his responsibilities to focus more on implementation rather than design.

In each Implementer Team, some of the engineers stand out because they found resolutions to obstacles that challenged them. One example from Table 6-103 features an engineer that was uncomfortable with the role he was assigned during his visit to the Supplier. The role was mainly focused on management tasks; he preferred to work on technical analysis as well. He did not have the option of changing roles, so he actively sought out additional tasks that gave him technical experience. The table provides several other examples of engineers who resourcefully overcame obstacles that threatened their capability building progress. There are a few examples in the table that present obstacles but not resolution. These come from cases where an engineer shared a frustration but they did not pursue creative resolution. The Implement Engineers varied in their performance at addressing obstacles.

This reality that engineers respond differently to obstacles poses a question about the hiring strategies used by Implementer Leaders when selecting engineers. Can Implementer Leaders focus on hiring excellent engineers that overcome obstacles rather than focusing on making a series of decisions to define an architecture that facilitates capability building? Will these excellent engineers be able to function well even in a project that presents many obstacles? How much effort should Implementer Leaders invest in hiring the best engineers as compared to other Architectural Dimensions?

The data suggests that one major division in terms of hiring strategies is whether to hire people with more professional or academic experience or people who are less experienced. For six of the seven projects in these case studies, the Implementers primarily hired young professionals and recent graduates. The one project that only hired people with experience did not expect those engineers to remain as employees of the Implementer after the Supplier training. Within the teams that were primarily made of less experienced engineers, the more experienced engineers stand out as being effective at resolving obstacles. They are not alone, however; engineers that resolved obstacles well came from both more and less experienced groups. The "experience level" of the engineers has several aspects. Some of the more experienced engineers studied for graduate degrees, either in their home country or aboard. For those that studied internationally, they benefitted both from the experience of learning new technical topics but also practicing living outside their own country. Some of the more experienced engineers primarily had professional experience in related fields. They benefitted from a maturity in the generic aspects of professional life such as communication, time management and team work. Despite these benefits of hiring more experienced people, some of the Implementer leadership expressed a preference for hiring less experienced engineers. These leaders wanted to be the first to train the engineers and shape their professional values. If a leader follows such a philosophy, they may also adjust their training expectations to what a fresh graduate from their first university degree can accomplish during a training experience. In some cases, fresh graduates from a first degree were hired to the Implementer Organization and then immediately sent for training at the Supplier Organization. In this case, they did not have necessarily have time to be oriented as employees of the Implementer. Their first professional experience was in the Supplier Organization. This may impact their professional formation.

When Implementer leaders seek to hire new engineers as employees and as part of the team that will train at the Supplier Organization, they face several challenges. First, in the case study nations, there are not educational programs that specifically train for satellite engineering. Thus they are looking for people with related engineering degrees that have the potential to learn the specialty of satellites. This is a manageable challenge. All over the world, firms hire engineers with degrees in areas such as mechanical engineering, electrical engineering, computer science and physics to work as satellite engineers. The second challenge is that most Implementers are government organizations or acting on behalf of their national government. Some of the Implementers are restricted to hiring people that are national citizens. In some of the case study countries, this was a severe limitation as many non-citizens also lived in the country and held relevant qualifications. The third challenge is that the Implementers need to find engineers that are willing and able to spend long periods living abroad. In some situations this is difficult. For women in some of the case study countries, living abroad poses a particular barrier. If engineers are married or have children, they may not choose to live abroad for training. In these case studies, the engineers traveled to work with the Supplier as individuals. They did not move with their families. They often lived as a team in shared housing that was not conducive to families. The fourth challenge that some Implementers face is the need to compete for engineers with other organizations that offer comparable jobs. This issue varied across the case study countries. In some countries, unemployment was high and the jobs at the Implementer were precious and sought by many people. In other countries, the Implementer had to compete for engineers with other firms and government organizations that may offer better compensation. These competing employers included foreign and domestic actors. All the Implementers had to convince engineers to work domestically rather than seeking jobs abroad. Some of the implementers specifically recruited engineers that studied in foreign universities. These engineers may have been especially tempted to take a position abroad. Finally, the Implementers were faced with the challenge of defining a process to recruit, evaluate and select engineers. This is a classic problem of imperfect information. The problem is increased when Implementers choose to hire less experienced engineers in order to train them. When evaluating less experienced candidates, the goal is to identify the potential for professional achievement rather than actual achievement. This is inherently challenging. Most Implementers relied on applications and interviews to screen engineering candidates. Are there ways to improve their recruitment, evaluation and selection process?

After engineers are hired by the Implementers and trained at the Supplier Organization, another challenge emerges. In several cases, due to launch delays or time gaps between successive satellite programs, engineers who were trained by Suppliers chose to leave the Implementer Organization. This is a major loss to the Implementer who invested in their training. It is not necessarily a loss to the Nation, if the engineer pursues work in their country that builds on their training. This was the case in several examples. One Nation Delta engineer left the Implementer and worked in a domestic satellite communications company where he built on his knowledge. Some Implementers chose to use incentives or penalties to encourage engineers to remain after training. These issues of hiring and retention are not unique to the satellite Implementers. They are faced by many organizations. For these organizations, however, in some cases the retention tasks is made more difficult by circumstances beyond the Implementer's control. When the national government is slow to approve a satellite project for an organization that has a limited range of activities, morale sometimes decreases and engineers prefer to find new positions.

This section has discussed the fact that the architecture does not completely determine the capability building outcomes of the satellite projects. Much is determined by the personal characteristics of the engineers. This implies that the human resource approaches by the

Implementer to recruit, select and retain their engineers are highly important. In that sense, the human characteristics to circumstances are related to architecture because selecting team members is an architectural choice. Future work can consider what advice from human resource management literature might apply to these situations.

[cclix] Dahlman, Carl, Bruce Ross-Larson, Larry Westphal. "Managing Technological Development: Lessons from Newly Industrializing Countries." *World Development.* Vol. 15, No 6, p 759-775, 1987.
[cclx] Larson, W. and Wertz, R., ***Space Mission Analysis and Design.*** Microcosm, Hawthorne, CA, 1992.

7 Reflections on Literature

This section reflects on concepts from literature and the background discussion in order to explore whether assumptions and propositions are supported or questioned by the case study findings. The first area of literature is on Technological Learning. The four case study countries have all embraced the philosophy behind technological learning that encourages local effort to harness technology as part of the multi-faceted development process. Several concepts from the technological learning literature are compared to the study findings.

The first is the concept by Kim[cclxi] and Utterback[cclxii] that shows how latecomers may move through an innovation cycle. The proposal by Kim is that latecomers engage with a mature technology and initially focus on the process aspects. They later focus on product aspects once their level of technical sophistication increases. One of the issues with applying this model to the satellite projects is that the model assumes the product lifecycle of a mass produced commodity. As a Complex Product Systems, satellites do not have a clear transition into a mature phase during which product innovations diminish. Despite that caveat, the predictions are somewhat aligned with observations from the projects. The Architectural Dimension of Training Project Phase, captured the segment of the satellite lifecycle in which each Implementer team participated. The phases are defined based on NASA standards. Phases A and B focus on early design, while Phases C and D focus on detailed design, assembly, integration and testing. In a sense, Phases C and D are the process or production segments within the lifecycle of a satellite project. Phase A and B focus on the design of the product. A loose analogy can be made to the concepts proposed by Kim and Utterback, keeping in mind that they were focusing on the long term cycle of innovation for a product. They were not modeling the cycle of development for a single product. Despite that difference, Kim argues that latecomers can focus on learning production before learning product design. That is close to what happened for the six case study satellite projects. The AlphaSat-R1, BetaSat-R1 and GammaSat-R1 projects were all the first national projects for their country. In each of these projects, the Implementer engineers were present at the Supplier firm for the later satellite lifecycle phases. This was partially due to delays in their arrival and partially due to the fact that the satellites were based on previous designs. The training experience in these three projects provided more opportunities to learn about satellite manufacture, assembly, integration and test than about satellite design. The evidence suggests that this was not done intentionally by decision makers in the Implementer and Overseer Organizations. For second national projects – AlphaSat-R2 and BetaSat-R2 – two Nations made a deliberate plan to expose their engineers to the earlier lifecycle phases and learn about satellite design.

7-1: Outcomes for Training Project Phase Architectural Dimension

Training Project Phase	AlphaSat-R1	AlphaSat-R2	BetaSat-R1	BetaSat-R2/ BetaSat-R3	GammaSat-R1	DeltaSat-R2
NASA Phase A	No	Yes	No	Partial	No	No
NASA Phase B	No	Yes	No	Partial	Partial	No
NASA Phase C	Yes	Yes	Yes	Yes	Yes	Yes
NASA Phase D	Yes	Yes	Yes	Yes	Yes	Yes

This strategy of learning production processes first and product design later was not intentional, but what are the implications? In traditional satellite engineering firms, the production phases (Phases C and D) are overseen by engineers but executed by technicians that have different qualifications than the engineers. During the design (Phases A and B), the engineers are the main actors as they use specialized software tools to model and define the plans for the satellite. In the smaller, less traditional Supplier firms in these case studies, some engineers took a more hands-on role during Phases C and D, so the distinction was less clear cut. The manufacturing, assembly and integration of satellites require a series of skills that are challenging but do not necessarily require an engineering degree to execute. One set of tasks is to use the engineering designs and solder many electronics boards for various subsystems. The soldering must be done with specific techniques to achieve space quality. In many satellite firms, this soldering task is done by technicians who are not required to have a university degree. Other steps performed by technicians during assembly and integration include machining parts based on engineers' specifications in a machine shop, fitting and testing valves, assembling models of the satellite for ground testing and operating environmental testing equipment. These are the types of activities that Implementer engineers were exposed to if they arrived at the Supplier firm for NASA Phase C and D. Does it make sense for engineers without professional or satellite engineering experience to start with these activities or is it better for them to focus on the engineer tasks of using computer software to define designs? It certainly depends on the long term goals of the Implementer. Do they plan to become an organization that manufactures satellites or that oversees Suppliers who fabricate satellites? There are some advantages for a new engineer to start in a late lifecycle phase. It helps them build familiarity with the implementation process for satellites. Every designer needs to understand how their design will be implemented so they can make designs that are easy to manufacture. Also, an Implementer engineer that comes to a Supplier for training may have similar professional credentials to the technicians who solder, machine and test. In these case studies most Implementer engineers had university degrees, but little work experience. The technicians may lack university degrees, but they know the practical knowledge of their field. Perhaps the work of a technician is an appropriate starting point in the long term training process for an Implementer engineer. Ideally, an engineer could train as a technician and later apply that knowledge as they train on satellite design. This is not the case if Implementers choose to send engineers who are later in their careers and have already worked professionally. There are disadvantages to training that focuses first on production and later on design. If an Implementer engineer begins in Phases C and D, but they do not have the theoretical background to understand how satellite work, it may be difficult to absorb the practical steps. Some of the engineers interviewed for the case studies were in this situation. They worked only on Phases C and D. They were able to achieve tasks and projects while at the Supplier firm, but when they returned, they demonstrated a limited understanding of the theoretical implications of their work. A training progression that begins with theory, proceeds to focus on design and ends with implementation may be more comfortable for some engineers.

	Role of Foreign Technology Sources	
	Active	*Passive*
Market Mediated	Quadrant 1 • Foreign licensing • Turn-key purchase • Technical consultancy • Special-order capital	Quadrant 2 • Sale of standard capital good
Non-market Mediated	Quadrant 3 • Technical assistance from technology vendors • Political partnerships	Quadrant 4 • Imitation • Reverse engineering • Observation • Journals • Meetings

Figure 7-1: Adapted from Kim's framework on foreign sources of technology

Kim[cclxiii] also proposes a framework describing how latecomers may access new technology from a variety of foreign sources. The framework is repeated in Figure 7-1. In these case studies, the primary approach to harnessing foreign technology sources is through quadrant 1, which shows cases that are require an active role by foreign partners and use market mediation. The market mediation factor accounts for whether the latecomer directly pays for the technology. Overall, for these collaborative projects, Implementers paid for special-order capital and training; this fits into Quadrant 1. The interesting variation arises in how Implementer engineers used the other quadrants. Quadrant 4 captures the approaches that require the most initiative by the Implementers. There is little evidence of imitation or reverse engineering in these case studies. Since satellites are not commodities, it is not practical to obtain an example product and experiment on it to see how it works. On the other hand, the Implementers that worked with Supplier Tau1 did take models or components of their satellites to their home facilities to do independent work. Implementer Delta1 installed a functional model of GammaSat-R1 at their home facility. The model was not in the same shape of the actual satellite, but it had the functionality to interact with the ground station like the actual satellite. For satellites, perhaps working with models that have some characteristics of the full product is a feasible and helpful form reverse engineering. It is risky to experiment on a flight model, but earlier models can be used for learning. The Implementers that worked with Supplier Tau1 also attended conferences as part of their training. Implementer Gamma1 also sent their employees to conferences independently of Supplier Tau1. The team that worked on satellite data processing sought to write many conference papers early in their existence. It was a means of monitoring their progress and interacting with local universities and the international remote sensing community. How did the Implementers use Quadrant 3? Each worked with vendors who supplied ground stations. In some cases, the primary Supplier was a go-between, but Implementer Gamma1 and Implementer Beta1 both worked closely with representatives of their ground station vendors. They received technical assistance in the sense that vendor representatives came to their locations for days or weeks and helped them trouble shoot issues or install hardware. A satellite ground system is also a form of special-order capital, so this aspect is a blend of Quadrant 1 and 3. Implementer Alpha1 stands out as working with local technology vendors to manufacture some components for their satellite and install their satellite manufacturing infrastructure. For these relationships, there was mutual learning. Kim's framework is shown to be relevant to the case study satellite projects. The Implementers are relatively week in Quadrant 4, which requires the most initiative.

Table 7-2: Examples of Guidance from Technological Learning Literature

Level	Theoretical Guidance	Example of Actionable Project Implementation Approach	Source
Organizations	Crisis Construction can improve team performance	• Key Leadership should set high goals to produce an atmosphere of crisis and inspire team to productivity	Nonaka 1994 and Kim 1999
Groups and Individuals	Both Individual and organizational learning need to occur	• Provide a mechanism for more experienced engineers to teach less experience engineers • Spread knowledge through organization via strategic job rotation	Kim 1999, Nonaka 1994, Edmonson 2003
Individual Level	Learner initiative partly determines absorptive capacity	• Provide individuals with a variety of experiences to help them maintain creative thinking	Cohen & Leventhal 1991, Kim 1999, Nonaka 1994

Table 7-2 presents a summary of guidance on Theoretical Learning that is identified in the literature review. How were these ideas exhibited in the case studies? Nonaka and Kim, among others, point out the benefit of motivation by leaders. They advise that leaders harness externally generated crises or create artificial crises to give the Implementer Organization a sense of urgency. This is expected to add to absorptive capacity, which depends partly on the level of effort of an organization. To some extent all the projects had a sense of crisis because all the engineers knew that they represented their country. They saw that their work related to maintaining national pride. Beyond that aspect, three satellite projects stand out as examples of crisis construction for different reasons. For AlphaSat-R2, leaders created a crisis by setting an ambitious technical goal of launching into a unique orbit. The interesting dynamic here was that the project was delayed for about four years between the completion of the satellite and the launch. To what extent did the crisis mentality sustain over this long delay? The evidence that it was sustained is that the team found creative ways to use the time during the delay. They built small nano-satellites with local universities and increased their understanding of the calibration process for the instrument on the satellite. There was some dampening of the crisis effect, however. Key leadership at the Overseer Organization transitioned and some implementation goals were not met. For the BetaSat-R3 project, the Implementer and Supplier organizations came together to create a crisis when they decided to launch the satellite that was originally planned as a training model. This added pressure to the Implementer engineers who were charged with taking leadership to build the satellite. There was some conflict within this crisis. The Supplier was also concerned about how the satellite's performance would impact their reputation. This led to two competing crises. The Implementer engineers wanted to prove their ability to build the satellite; the Supplier engineers wanted to oversee to ensure to errors. The two goals were sometimes incompatible. GammaSat-R1 was also built with a sense of crisis because high level political leadership wanted to see a successful project in a short time scale. This example is primarily positive because the political leaders gave both pressure and the resources to execute the project successfully. Crisis construction is not always straightforward to manage, and it can be difficult to sustain when external delays are imposed. Note that AlphaSat-R2 and BetaSat-R3 were in the category of "risk taking project" with the analysis of archetypal projects for Research Question 5.

The next line on Table 7-2 talks about strategies to encourage both organizational and individual learning. Several Implementers made efforts to create a mechanism for more experienced engineers within their teams to train less experienced engineers. This was particularly relevant between the first and second projects for Implementers Alpha1, Beta1 and Gamma1. When a first generation team had been trained and a new team was hired, there were both formal and information approaches to passing on knowledge. Some of the approaches included the following: having senior engineers give lectures to junior engineers; assigning individual mentors between senior and junior engineers; assigning senior engineers as supervisors to small teams of junior engineers; giving junior engineers access to documentation produced in earlier satellite projects. All of these efforts were helpful. There was generally less effective effort to use similar strategies when engineers were returning from the Supplier training experience. For some Implementer teams, engineers needed guidance about how to transition into their role. This was particularly true for the cases in which Implementers hired recent graduates and sent them immediately to the Supplier firm before they spent much time working at the Implementer facility. There were not many examples of strategic job rotation programs designed to give engineers a broad grasp of different aspects of the Implementer's work. Some savvy engineers created these experiences for themselves. Some Implementers did not have a well defined structure that would enable a clear plan for how to rotate someone. This advice overlaps somewhat with the idea of giving individuals a variety of experiences. The variety may come from strategic job rotations or from other avenues. Most of the Implementers organize their work on a project-basis. Engineers are assigned to a particular team, but they work on projects with different groups as needed. This is a similar structure to all the Supplier firms. Whereas almost all engineers within Implementer Delta1 and Implementer Gamma1 were very focused on the case study satellites explored in this study, Implementer Alpha1 and Implementer Beta1 had more projects and people who did not work at all on the case study projects. In these settings, individuals did have the opportunity to gain a variety of experience. The variety included different stages in the satellite lifecycle and combinations of engineering and management activities. Implementer Alpha1 also worked on non-satellite projects as a separate line of business. Some engineers worked on both satellites and these terrestrial projects.

The literature review summarized characteristics of Complex Product Systems (CoPS) as defined by Hobday and Rush.[cclxiv] Which of these characteristics were evident in the case study satellite projects? The projects did exhibit the typical ambiguous, competing management objectives of CoPS. This was partly due to the goal of supplying both a spacecraft and training. Meanwhile, customers frequently wanted work done both quickly and effectively. Suppliers sought to achieve this while also addressing schedule delays caused by regulation and launch issues which were beyond their control. CoPS have design-intensive lifecycles and typically focus on a primary supplier integration many subsystems developed by a variety of suppliers. This aspect was somewhat different for the satellite projects led by Supplier Omega1 and Supplier Tau1. Both are vertically integrated, although they do outsource specific manufacturing tasks and some subsystems. CoPS are often developed by project-based organizations, which was true in these cases. And like other CoPS the organization followed consensus based decision making, meaning that people throughout the team had the opportunity to give feedback. This was especially true during reviews at key milestones. Hobday and Rush expect the management tools to be limited and unproven in CoPS project with limited information technology tools. This was not completely true. The smaller Supplier firms were transitioning into a more structured approach to track project information, but they used information technology constantly. Supplier Omega1, for example, used many software management tools to enable team communication about physical aspects of the satellites and anomalies in the development process that needed to be resolved. Risk in CoPS projects is described as hard to control, hidden, and unpredictable. This was true to some extent. The Suppliers were aware of some risks that consistently hamper satellite projects. These include the potential for regulatory delay related to export or immigration issues, launch delays and delays due to technology development. The Suppliers could not predict exactly when these delays would appear, but they knew that such risks were common. Hobday and Rush expect customers procuring CoPS to be highly involved, to negotiate prices and requirements, and to address interests of multiple stakeholders. All of these elements were true, except the customers in these projects were less experienced in the technology than the customers assumed by this literature. Finally, Hansen and Rush noted in another study that CoPS projects are often hampered when they overlapped with organizational changes such as acquisitions and mergers.[cclxv] The explanation is that these changes can impact organizational processes and interrupt project progress. In one of the satellite case studies, Supplier Omega1 acquired a small company at the beginning of one project and was acquired by a larger company near the end of the same project. There is no evidence that these acquisitions disrupted the project due to changes in processes. This is because the acquisitions had well defined interfaces. The new owners allowed the acquired firms to continue operations without much change. The other mechanism by which acquisitions may disrupt projects is by distracting key project personnel or high level decision makers. The evidence is not clear on the impact of such distraction. Overall, this discussion does confirm that the satellite projects have many characteristics of CoPS as defined by Hobday and Rush. The projects escaped some of the challenges of CoPS when their technology was less complex, Suppliers were more vertically integrated and the teams smaller than other complex products.

Reflecting on the technology transfer literature, the barriers found by Ofori that hinder transfer in the construction industry did appear relevant in these case study projects to some extent. Ofori found the following barriers: 1) The foreign firms with advanced technology are hesitant to provide assistance that would make local firms more competitive against them in the future; 2) Incorporating technology transfer into a project bring the risk of increased cost, schedule delay and complexity; and 3) Each construction project is unique and learners may not be able to apply knowledge across projects.[cclxvi] Regarding the first barrier, the Suppliers in the satellite project case studies choose to transfer to technology to national satellite organizations while they understand that these teams may compete with them in the future. Some Suppliers have seen their former trainees become competitors. The Suppliers hoped to turn this from a liability into an asset in two ways. First, they hoped to stay slightly more technically advanced than these potential competitors by developing more capable technology. Second, they hoped to maintain positive relationships with these competitors that could lead to synergy. As the Implementer Organizations became more technical advanced, the Suppliers hoped to partner with them in different ways that would allow the Implementers to specialize. They envisioned dividing the work on future projects – perhaps the Implementer would build instruments and the Supplier could build buses, for example. Regarding the second barrier, some Suppliers seemed to find that technology transfer or training did increase, schedule and complexity. These were the Suppliers that had more structured training and gave the trainees fewer project duties and more learning tasks. Suppliers seemed to reduce this second barrier by integrating the Implementer engineers more tightly into their team, so that their work contributed to improving the project. For all Suppliers, this was the goal to some extent. The capabilities of the Implementer engineer influenced the ability to do this integration. The third barrier refers to the uniqueness of projects that limits applicability of knowledge over different experiences. This is less true in this set of case studies because the Implementers that bought more than one satellite bought similar types of satellites.

Table 7-3: Summary of Country Characteristics According to Hofstede's Cultural Dimensions

	Implementers	Suppliers

Cultural Dimensions	*Nation Alpha*	*Nation Beta*	*Nation Gamma*	*Nation Delta*	*Nation Omega*	*Nation Tau*	*Nation Sigma*
Individualism	Low	Low	Medium	Low	High	Low	High
Power Distance	High	High	High	Medium	Low	Medium	High
Uncertainty Avoidance	Medium	Medium	High	Medium	Low	High	High
Masculinity	Medium	Medium	Medium	Low	High	Medium	Medium

Within the Technology Transfer literature, some scholars emphasize the role of culture. These satellite project case studies all brought together Implementers and Suppliers from distinct countries and cultures. Hofstede defined cultural dimensions that are exhibited in the workplace. The study has data relevant to the seven countries that were home to Implementers and Suppliers.[cclxvii] The four cultural dimensions are as follows: "power distance, uncertainty avoidance, individualism vs. collectivism, and masculinity vs. femininity."[cclxviii] Table 7-3 shows how the seven case study Nations compare in terms of the four cultural dimensions. The scores are shown as low, medium and high for convenience. They are adapted from Hofstede's scale, which gave each country a score between zero and one hundred. For this analysis, a score of 1 to 35 is Low; 36-65 is Medium; and 66 to 100 is High. A score of Medium reflects a balance between two extreme characteristics which likely mixes aspects of both. Also note that these scores are from a study in the early 1980s. National culture changes slowly, so most scores are still relevant, but they can be taken with caution. Also, these are the scores for the countries, not the Implementers and Suppliers. The organizations may foster culture that is different from the predominant national culture. For example, leadership at Implementer Alpha1 talked about how their country had high power distance. He did not want that to dominate within his firm and he tried to develop approaches to reduce the power distance. He noted that it took time to make such changes, but he saw progress through almost two decades as leader of the organization. A similar case might apply for Nation Gamma. Implementer Gamma1 had a low power distance within the satellite team because the political leadership had created an unusual organization and empowered young people with great responsibility. Their situation did not seem to reflect the overall culture.

Table 7-4: Cultural Dimensions in Project Alphasat-R1

Satellite Project AlphaSat-R1		
Cultural Dimensions	*Nation Alpha Implementer*	*Nation Omega Supplier*
Individualism	**Low**	**High**
Power Distance	**High**	**Low**

Uncertainty Avoidance	Medium	Low
Masculinity	Medium	High

Table 7-4 gives the matching of Implementer and Supplier for the AlphaSat-R1 project. Note that Implementer Alpha1 and Supplier Omega1 are from Nations that have opposite tendencies in terms of Individualism and Power Distance. Bhagat et al classify Nation Alpha in the category of vertical collectivism, while Nation Omega has horizontal individualism.[cclxix] Bhagat et al predict that if two organizations differ in terms of both power distance and individualism, their partnership for technology transfer is expected to be less effective than the partnership of organizations with similar orientations. As seen in Table 7-5, Implementer Alpha1 went from partnering with Supplier Omega1 to Supplier Tau1. The Nation Alpha is much closer in scores for individualism and power distance with Nation Tau than Nation Omega. Thus, we would expect that their partnership with Supplier Tau1 would be stronger. The evidence seems to support that expectation, but the conclusion must be considered cautiously. Implementer Alpha1 did transition to working with Supplier Tau1 instead of continuing to work with Supplier Omega1. The second satellite project (AlphaSat-R2) did give the Nation Alpha engineers a more integrated connection to the Supplier team. Thus the evidence is strong that the teams blended well when cultural dimensions were aligned, but the impact of this blending on technical performance of the satellite or capability building outcomes is not clear.

Table 7-5: Cultural Dimensions in Project AlphaSat-R2

Satellite Project AlphaSat-R2		
Cultural Dimensions	*Nation Alpha Implementer*	*Nation Tau Supplier*
Individualism	**Low**	**Low**
Power Distance	**High**	**Medium**
Uncertainty Avoidance	Medium	High
Masculinity	Medium	Medium

Table 7-6 shows the pairing of cultural dimensions between Implementer Beta1 and Supplier Omega1. Nation Beta has the similar scores on cultural dimensions with Nation Alpha. Once again, this is a project in which two organizations come together but are not well matched in culture. Why did Implementer Alpha1 work with Nation Omega for two consecutive projects if they did not have cultural characteristics that are considered compatible? How did this impact the capability building? The story is complex. Nation Beta is scored as Low on Individualism and High on collectivism. This may be true of the country, but evidence from the case showed that engineers from both Implementer Alpha1 and Supplier Omega1 found that the visiting Implementer team needed to learn to work together during the BetaSat-R2 project. They were a newly formed team; they did not have bonds built by common experiences. The individual engineers were more concerned about completing their work than ensuring that the whole team met their goals. This was exhibited during the project reviews. Early on the reviews demonstrated a lack of communication among the team; later the team showed more cooperation. At least in the area of team work, collectivism did not seem to dominate. Collectivism was clear in the interactions between representatives of Implementer Alpha1; there was a sense of expectation that friends and relatives will support each other and be loyal. Power distance seemed to impact the activities of engineers from Nation Alpha while working at Supplier Omega1. Both Nation Omega and Supplier Omega1 have low power distance while Nation Alpha has high power distance. "People in large power distance societies accept a hierarchical order in which everybody has a place."[cclxx] The team of Implementer engineers from Nation Beta had a hierarchical order based on seniority. At times, team members who had specialized technical insight into a problem with the satellite felt it was inappropriate to correct a misconception held by someone who had a higher position. The Supplier Omega1 team would take this kind of correction as a normal approach to problem solving. The power distance dynamic may have also impacted the relationships between Supplier Omega1 mentors and Nation Beta visiting engineers. Based on culture, the Supplier Omega1 mentors would expect a causal, non-hierarchical relationship. The Nation Beta engineers would look at the mentors as authority figures if they applied their cultural bias. There is evidence that individual engineers from Nation Beta reacted differently to this situation. Some became close friends with their mentors and related very casually; others maintained more distance.

The experiences of Supplier Omega1 show an interesting variation in how Implementers reacted to potential mismatches of cultural dimensions. Supplier Omega1 did have some cultural differences with both Implementer Alpha1 and Implementer Beta1. In one case the Implementer found a new Supplier with a closer cultural profile; in the second case the Implementer continued to partner with Supplier Omega1.

Table 7-6: Cultural Dimensions in Projects BetaSat-R1 and BetaSat-R2/R3

Satellite Project BetaSat-R1 and BetaSat-R2/R3		
Cultural Dimensions	*Nation Beta Implementer*	*Nation Omega Supplier*
Individualism	**Low**	**High**
Power Distance	**High**	**Low**
Uncertainty Avoidance	Medium	Low
Masculinity	Medium	High

Table 7-7 and

Table 7-8 show that during the GammaSat-R1 and DeltaSat-R1 projects, the cultural differences were not as extreme as those described above. The language barrier was likely a larger cultural factor than these dimensions for the GammaSat-R1 and DeltaSat-R2 projects. All the engineers (Implementer and Supplier) worked together in English as a second language.

Table 7-7: Cultural Dimensions in Project GammaSat-R1

Satellite Project GammaSat-R1		
Cultural Dimensions	*Nation Gamma Implementer*	*Nation Tau Supplier*
Individualism	Medium	Low
Power Distance	High	Medium
Uncertainty Avoidance	High	High
Masculinity	Medium	Medium

Table 7-8: Cultural Dimensions in Project DeltaSat-R2

Satellite Project DeltaSat-R2		
Cultural Dimensions	*Nation Delta Implementer*	*Nation Sigma Supplier*
Individualism	**Low**	**High**
Power Distance	Medium	High
Uncertainty Avoidance	Medium	High
Masculinity	Low	Medium

[cclxi] Kim, Linsu. *Imitation to Innovation: The Dynamics of Korea's Technological Learning*. Boston: Harvard Business School Press, 1997.
[cclxii] Utterback, James, *Mastering the Dynamics of Innovation,* Harvard Business School Press, Cambridge, 1994.
[cclxiii] Kim, Linsu. "Building Technological Capabilities for Industrialization: Analytical Frameworks and Korea's Experience." *Industrial and Corporate Change*. Vol 8, No 1, 1999.
[cclxiv] Hobday, M., Rush, H., "Technology Management in complex product systems (CoPS) – ten questions answered." *International Journal of Technology Management.* Vol. 17, No. 6, 1999.
[cclxv] Hansen, K., Rush, H., "Hotspots in complex product systems: emerging issues in innovation management." *Technovation,* Vol 18, No. 8/9, 1998, p. 555-561.
[cclxvi] Ofori, G., "Construction Industry Development: role of technology transfer," *Construction Management and Economics,* Vol. 12, 1994, p. 379-392.
[cclxvii] Hofstede, G., "Cultural Dimensions in Management and Planning." *Asia Pacific Journal of Management*, January 1984, p. 81.
[cclxviii] Hofstede, G., "National cultures in four dimensions: A research-based theory of cultural differences among nations." *International Studies of Management and Organizations,* Vol. 13, No. 1-2, 1983, p. 46-74.
[cclxix] Bhagat, R., Kedia, B., Harveston, P., Triandis, H., "Cultural Variations in the Cross-Border Transfer of Organizational Knowledge: An Integrative Framework." *The Academy of Management Review,* Vol. 27, No. 2, April 2002, p. 204-221.
[cclxx] Hofstede, G., "Cultural Dimensions in Management and Planning." *Asia Pacific Journal of Management*, January 1984, p. 81.

8 Conclusion

This section offers a summary of findings, contributions, and proposals for future work.

8.1 Summary of Findings

This dissertation uses exploratory, inductive research to describe and model the process by which developing countries pursue international collaboration as part of the process to master complex technology. The study is motivated by the potential for satellite technology to contribute useful services and technology applications in developing countries. A second motivation is the activity among new countries in Africa, Latin America and Asia to establish local capability to design and build satellites. The dissertation specifically considers case studies of satellite projects that follow a collaborative satellite development model. In this model, national space organizations from developing countries contract with foreign firms to supply a satellite and training for local engineers. Detailed case studies of six satellite projects executed by four developing countries are analyzed using original frameworks. The research questions consider the implementation approaches of the projects using the concepts from the Theory of Systems Architecture. The analysis further compares projects regarding capability building at the individual and organizational level. To summarize this study, this section presents the key findings from each research question.

Research Question 1: What are the Architectures of Collaborative Satellite Projects?

The response to Research Question 1 includes adapting an Architectural Framework from the Theory of Systems Architecture that parses project aspects into categories. The satellite projects are described using twelve Architectural Views that each account for a different perspective on implementation issues. Within each view are multiple Dimensions. Each Dimension includes a function, a generic form that implements this function and the set of specific, alternative forms that potentially implement the function. The descriptive analysis for this research question inductively defines the set of Architectural Views, Dimensions, Functions and Forms that are relevant across all six collaborative satellite projects. The Dimensions are defined based on the range of approaches pursued by four Implementer Organizations and three Supplier Firms. The complete answer to Research Question 1 is the full enumeration of Dimensions, Forms and Functions. This complete description shows the range of implementation options used by the four Implementer countries. The twelve Architectural Views are as follows: Organization, Project Initiation, Personnel Management, Supplier Selection, Facility, Training, Contract, Technical Product, Technical Approach, Management, Policy, Culture and Social Issues.

Research Question 2: How are the Architectures of Collaborative Projects Similar and Different?

The Architectural analysis reveals the diversity of approaches among the six collaborative satellite development projects. All the case study Nations are similar in that they choose to use a collaborative project with a foreign firm to start their domestic satellite program. They may have taken other routes such as starting with university satellite projects, buying a satellite without training or building the satellite locally with foreign consultants. Even though all four nations pursue similar high level project architecture, Research Questions 1 and 2 revealed diversity in the specific elements of form. There are more Architectural Dimensions in which the case study projects vary than Dimensions in which the projects are similar. Using a synthetic procedure of pattern matching and process tracing, four of the Architectural Views emerge as key to defining three Archetypal Project Architectures that capture major aspects of the case study evidence. The four Architectural Views are Project Initiation, Supplier Selection, Training and Technical Product. The Project Initiation Architectural View describes how Implementer and Overseer Organizations worked within their national context to demonstrate the value of the project to their government funding agencies. It also considers the nature of the bureaucratic steps required to secure funding for the satellite project. The six satellite projects can be classified into two broad categories regarding their Project Initiation process. Some projects required high effort to achieve funding, while others moved forward with low effort. The level of effort depended on the political climate. When a strong national leader supported the satellite program, the fundraising effort was low. The Supplier Selection Architectural View includes Dimensions describing the process to select a satellite Supplier firm, the priority attributes Implementers considered, and the range of competing Suppliers that Implementers considered. By combining all of these Dimensions, projects can be summarized as pursuing more formal or more informal Supplier Selection processes. The formal processes are traceable and transparent within a bureaucratic system. Examples of formal selection processes include calls for proposals, hiring a consultant to review the selection process or visiting a series of Suppliers. The informal processes are often based on personal relationships or connections between Implementers and Suppliers on the basis of a common goal. Examples of informal processes include choosing a personal acquaintance, responding to an invitation for a collaborative project and selecting a Supplier based on a referral from an acquaintance. The Technical Product Architectural View groups all the satellites developed in the case studies into two groups based on complexity. The more complex satellites had higher mass, longer design life and higher technical performance than the less complex satellites. Finally, the Training Architectural View considers Dimensions that describe the training provided to the Implementer engineers by the Supplier Firm. The training activities can be classified as Theoretical, Practical or On the Job. Projects also differed in terms of the project phase that trainees experienced and the level of formality in the relationship between Implementer trainees and their mentors from the Supplier Firm. Given all of these Dimensions, the Training View can be summarized with three categories. Based on the training approach and the project phase, three satellites exhibited an emphasis on Practical training activities; these projects also had informal accountability in the mentoring relationships. Two satellites emphasized Theoretical training and formal mentoring relationships. The remaining two satellites emphasized On the Job training and used mentoring as required to achieve project objectives. The four Architectural Views summarized here captured key differences across the satellite projects that align with three Archetypal Projects, as defined in the summary of Research Question 5.

Research Question 3: What Capability Building Opportunities do Individuals Have?

This analysis assesses the opportunities that individual Implementer engineers have for capability building in several time periods – before, during and after training with the Supplier. The original analysis approach accounts for the nature of technical knowledge and the nature of learning. The knowledge may vary in terms of codification, topic and application. The learning may vary in terms of topic, autonomy and complexity. During the interaction with the Supplier, Implementer engineers had some combination of theoretical training, practical on-the-job training and supervised experience. At the Supplier Firm, Implementer engineers varied in terms of which satellite topics they covered within the satellite lifecycle – from Project Definition and Requirements Management to Operations. Five scenarios describe different types of training experiences for engineers based on the range of topics they emphasized. Subsystem focused engineers worked primarily on middle project phases; they received requirements, generated a design and worked through implementation and test for one part of the satellite or ground system. System focused engineers worked more in the early and late satellite life cycle activities that consider interactions between subsystems and project management activities. Operations focused engineers had extensive operations training while at the Supplier Firm. Management focused engineers had leadership responsibility over their peers and served as a bridge between the Implementer and Supplier Firm. Local Facility focused engineers did not travel to the Supplier Firm; they worked independently at the Implementer local to build up new infrastructure. Most individuals had no experience or limited experience with satellite engineering before working with the Supplier. Many were recent graduates whose main experience was theoretical training related to some discipline with satellites such as Mechanical Engineering, Electrical Engineering or Computer Science. When the Individual Capability Building profiles are combined for each Implementer, it provides a visual confirmation that the group of individuals was progressing in level of autonomy and application over time.

Research Question 4: What Capability Building Achievements do Organizations Have?

This analysis defines an approach to observe organizational capability building by adapting well accepted frameworks to suit the specific case of satellite projects. The challenge for this adaptation is to deal with the dual nature of satellites as both products and capital goods that produce data products. The resulting framework offers an example that distinguishes between the capabilities to develop one complex product and the capabilities required to operate an organization with a series of such projects. This analysis categorizes the achievements of the Implementer Organizations. The framework credits each Implementer with their achievements of specific capabilities at the appropriate level of autonomy (ranging from an achievement during training to an independent achievement). All the Nations achieved high autonomy on satellite operation and satellite project definition and approval, but they were more dependent for satellite design, manufacture and test. Nations Alpha and Beta stand out in this analysis for achieving higher autonomy in satellite manufacture, assembly and test. Also, these Nations were involved with product and process innovations as part of their training experiences. In the long term, Nations also differed in the extent to which they moved beyond mastery of satellite engineering to local adaptation, diffusion and innovation activity. Nations Alpha's efforts to set up a local assembly and integration facility and to manufacture several components of AlphaSat-R2 locally show progress in this area.

Research Question 5: What are potential relationships between architecture and capability building?

This analysis uses a pattern matching, process-tracing approach to identify three Archetypal Project Architectures based on different combinations in the four key Architectural Views (Project Initiation, Supplier Selection, Training and Technical Product). Three Nations start their satellite programs with Politically Pushed Projects. These projects are driven by high level political support. They partner with Suppliers based on vision. Their technical achievements are modest in terms of complexity and autonomy, but they expose the Nations to many new concepts in satellite engineering. Later some Nations pursue Structured Projects. Political support has declined and these projects follow formal, bureaucratic policies to gain approval, select suppliers and organize training. These projects pursue higher complexity satellites in order to bring obvious benefit from a highly capable system. This does not increase the autonomy of the Implementer, but satisfies stakeholders that want to see short term value. Other Nations pursue the Risk Taking Project for a second or third in a series. This project sees a need to increase political support by doing something technically impressive. The Supplier is chosen based on trust and the training is driven by the needs of the technical achievement. This project can enhance the Nation's autonomy, the level of technical complexity they can manage and new topics. The actual outcomes depend on the type of risk they pursue. These project types may lay a foundation for patterns both within projects and across longer term satellite programs. This study also proposes that the analogy of designing a satellite can be applied to architecting a satellite project. If further research and literature review reveals the relationships within and across Project Dimensions, the decision makers can define project architectures that are aligned with their requirements and objectives.

8.2 Contributions

This section summarizes the theoretical, methodological, and practical contributions of the research. On a theoretical level, this exploratory work provides detailed descriptions of an activity that was poorly observed by researchers of Technological Learning. The activity – collaborative satellite development projects – has the potential to impact national capability building in developing countries. The research identifies twelve Architectural Views that demonstrate both the commonality and diversity among implementation approaches in collaborative satellite projects. Synthesis of the Architectural Views leads to the definition of three Archetypal Project Architectures that provide a process-based explanation for differences in implementation and capability building approaches. The dissertation also identifies four theoretical propositions that can be pursued through deductive research in order to build theory about collaborative satellite development projects, technological learning and system architecture.

In the area of methodology, the dissertation demonstrates the application of the Theory of Systems Architecture to a study of Technological Learning, which has not been done frequently, if at all. The Architectural Analysis allows issues from several areas of literature to be considered within a common framework. The Capability Building Analysis adapts a general set of capabilities (Production, Investment and Innovation) for the specific case of satellites. This leads to a detailed definition of the activities required to implement satellite projects and programs. The dissertation also defines several templates for profiles of capability building that capture both short and long progress.

On a practical level, this body of work is directed specifically to the decision makers in Implementer, Overseer and Supplier organizations that execute such collaborative satellite projects or similar efforts. For this audience, the research provides valuable information about the opportunities and challenges of collaborative satellite projects. Specifically, the response to Research Question 1 enumerates a large set of alternatives for how projects can be implemented. The work begins the process of defining how choices related to Technology, Training, Personnel Management and other Architectural Views impact projects outcomes desired by the Implementers and Overseers.

8.3 Future Work

This study used an exploratory perspective to gather large amounts of information and organize it into a systematic description of collaborative satellite development projects. The research reveals unknowns about the projects and the decisions facing Implementers in areas such as training approaches, team structure and supplier relationships. The inductive research for this dissertation lays a foundation for future deductive research that can refine and test the conclusions developed here. This section presents these conclusions in the form of four theoretical propositions.

Proposition 1: The set of 12 Architectural Views applies to satellite projects that follow the collaborative satellite development model examined in these case studies.

The Views can be considered relevant to a satellite project if at least one function within each View is executed as part of the project.

Proposition 2: Collaborative satellite development projects can be categorized as one or a combination of the three Archetypal Architectures: Politically Pushed, Structured and Risk Taking.

The Archetypal Architectures are defined by the four key views, as mentioned above.

Proposition 3: Nations tend to start in Politically Pushed Projects and later transition to Structured Projects, Risk Taking Projects or a hybrid of several Archetypes. The type of Archetype for later projects is driven by the nature of leadership in the Implementer Nation.
The case study projects present specific characteristics of Implementer leadership that appear to drive the type of Archetype pursued. When there is a Bureaucratically Savvy Implementer Leader that is confident about working through the official system to achieve funding, the Implementer pursues a Structured Project. A Risk Taking Project is pursued by a Technically Savvy Implementer Leader with a vision for how their country can achieve a new technical milestone. Leaders may exercise both types of skills and implement a Hybrid project.

Proposition 4: The Archetypal Architectures facilitate different types of capability building outcomes at the Individual and Organizational level during the timeframe of the project.
Politically Pushed projects emphasize Practical training with informal mentoring; and the main organization achievement is covering new topics. Risk Taking projects emphasize On the Job training and advancement in organizational autonomy; the mentoring approach is driven by project requirements. Structured projects emphasize Theoretical training, advancement in the complexity of technology pursued by the organization and formal mentoring.

In order to test and refine these propositions as part of the theory building process, future deductive work can draw on the global population of collaborative satellite development projects. There are at least 24 examples of early satellite projects in which nations used the same collaboration model to purchase training and a satellite from a foreign firm. Some of the relevant satellite projects include the following: AlgeriaSat-1, 2a & 2b; NigeriaSat-1,2 & X; EgyptSat-1; KitSat-1, 2 & 3; TiungSat; RazakSat; DubaiSat-1&2; THEOS; ThaiPhat; FaSat-Alpha & Bravo; PoSat; Tsinghua-1; BilSat; Maroc-TUBSat; LAPAN-TUBSat; FormoSat-1&2. Through additional field work that builds on the data collection methods used in this dissertation, the Architectural Views can be explored for more projects. The set of Architectural Views and variations on the Archetypal projects may also be relevant to studying collaborative projects in other areas of technology. A defining aspect of satellite technology that makes it important to learn through collaboration is the presence of tacit knowledge that is best learned through mentored experience. Other technology areas that may share this feature include the following: other aerospace systems, other Complex Product Systems, university collaborations, health care, civil construction, information systems and nuclear systems. In order to apply the Views and Archetypes to other technology types, it may be necessary to redefine them at a higher level of abstraction and generality. This direction of research will further the process of describing and modeling the processes by which learning countries acquire new technologies.

Another stream of future work will pursue prescriptive recommendations for decision makers in collaborative satellite development projects. This requires a body of research that further explores relationships within project dimensions, across project dimensions and between project dimensions and project outcomes. Whereas the current study uses inductive methods to collect broad data about the implementation of several collaborative satellite projects, future progress will be made using deductive approaches. For some of the Project Dimensions, existing knowledge from literature will supply helpful insights about the rules governing that aspect of the project. For other Dimensions, new empirical work will be needed. This empirical work will test hypotheses about the key dimensions of collaborative satellite projects that potentially influence technological learning – such as training methods, supplier-customer relationships, and program design.

Looking more broadly, future work can also explore the challenges and opportunities from other phases of satellite programs. After a satellite is launched, Implementers and their local partners need to ensure that the data or service is used effectively. The potential benefit of satellite services often goes unmet because of systems level challenges and poor Technology Management.[cclxxi] The application of satellite earth observation data, for example, requires effective coordination across several technical systems located in a wide range of organizations - including multilateral agencies, space organizations, foreign firms, local and regional governments, national ministries and communities. This stream of research can describe, model and prescribe the architectures of the complex systems that deliver satellites services. Potential data collection approaches include field interviews and observation and analyze may involve a combination of tools, such as Network Analysis, Design Structure Matrices and Stakeholder Analysis.

This work gives initial consideration to different types of satellite engineering. Satellite systems require extensive investments in personnel, facilities, equipment and technical processes. New countries are pursuing local satellite programs, but the scale and rigor of traditional satellite engineering do not fit their needs or capabilities. Traditional satellite systems engineering seeks to reduce risk by using specialized technology and complex management structures with high overhead costs. Meanwhile, a new wave of satellite engineering techniques is emerging from the community that develops spacecraft according to the "small satellite" philosophy.[cclxxii] They seek to decrease the cost of satellite systems by reducing performance requirements, increasing risk tolerance, using technology that is not space qualified, and building satellites with low mass and volume. In the face of these competing approaches, future work can redefine the standards for satellite systems engineering for new players. The research will describe, model and evaluate the relationship between satellite systems engineering and the value that is delivered to end users. Initially, this research will use technical modeling and practitioner interviews to compare the traditional and small satellite engineering approaches. The long term goal is to propose and validate new satellite systems engineering techniques that match the needs of developing countries. Emerging satellite programs need to develop strategies for long term activity. This means finding a path to gradually building capability despite contextual changes in politics, requirements and constraints.

[cclxxi] Mennecke, B. & L. West, "Geographic Information Systems in Developing Coutnries: Issues in Data Collection, Implementation and Management." Chapter 4 in *Information technology management in developing countries.* Dadashzadeh, M. Ed, Hershey, PA: IRM Press, 2002.

[cclxxii] Fleeter, R. *The Logic of Microspace.* Microcosm Press, El Segundo, 2000.

9 Appendix A: Detailed Summaries of Case Study Projects

Appendix A provides detailed summaries of the six satellite projects executed by four nations with three suppliers. The detailed summaries are written as Analytical Narratives that present information about each satellite project using an organization scheme based on Architectural Dimensions that were deductively defined during data analysis. The same set of Architectural Dimensions provides the foundation to answer Research Questions 1 and 2.

This section first explains the codes used to describe the actors, locations and satellites for each project. Within each nation that participates in the projects there may be various types of organizations – Suppliers, Implementers, Overseers and Universities. Suppliers sell satellites and training services on a commercial basis. Implementers are executing satellite projects and they seek services from the suppliers. Overseers are from the same nation as the Implementers. They provide some combination of funding, government policy guidance and oversight. Universities are academic institutions engaged in teaching and research. Within each organization, there may be various types of personnel – Engineers, Managers, Political Leaders and Professors. Engineers are directly engaged in technical activities of satellite projects. Managers are supervisors of engineers and they are engaged in other activities that may include, project management, quality assurance, administrative activity, business development, compliance with regulatory guidelines and interaction between organizations. Political Leaders are working at high levels of government and defining policy strategy. The Professors category includes personnel in academic positions in universities with duties of teaching and research. These categories are summarized in Table 9-1.

Table 9-1: Guide to Dissertation Naming Convention

Generic Objects in Case Studies	
Geographic Reference	Nation
Organizations	Supplier
	Implementer
	Overseer
	University
Personnel	Engineer
	Manager
	Political Leader
	Professor
Satellites	Remote Sensing
	Communication

In order to protect the identity of the participants in the case studies, codes are used to describe the nations, organizations, personnel and satellites. Table 9-2 introduces the foundational codes that are used for each of these elements. Each Nation is identified by a Greek Letter, such as Alpha, Beta, Gamma, etc. The Organizations, Personnel and Satellites are associated with specific countries and indexed with numbers. The italicized letters in Table 9-2 represent the numerical indices. For example, the first Nation is Nation Alpha. The first Implementer from Nation Alpha is Implementer Alpha1. The first engineer from Nation Alpha is Engineer Alpha1; and the first remote sensing satellite from Nation Alpha is AlphaSat-R1.

Table 9-2: Guide to Dissertation Naming Convention

Code for Specific Objects from Nation Alpha	
Specific Organizations	
Supplier Alpha,*i*	Supplier,*i* from Nation Alpha
Implementer Alpha,*k*	Implementer,*k* from Nation Alpha
Overseer Alpha,*m*	Overseer,*m* from Nation Alpha
University Alpha,*n*	University,*n* from Nation Alpha
Specific Personnel	
Engineer Alpha,*p*	Engineer,*p* from Nation Alpha
Manager Alpha,*q*	Manager,*q* from Nation Alpha
Leader Alpha,*r*	Political Leader,*r* from Nation Alpha
Professor Alpha,*s*	Professor,*s* from Nation Alpha
Specific Satellites	
AlphaSat-R,*t*	Remote Sensing Satellite,*t* from Nation Alpha
AlphaSat-C,*u*	Communication Satellite,*u* from Nation Alpha

9.1 Nation Alpha

This section summarizes Nation Alpha's two remote sensing satellite projects.

9.1.1 The AlphaSat-R1 Project

Nation Alpha's first satellite remote sensing satellite project was a partnership with Supplier Omega1.

Initiation and Approval of Satellite Project

The first Nation Alpha small satellite project was officially inaugurated at an event hosted by Leader Alpha1 in Project Year 2. In addition, the Nation Alpha cabinet approved the plan to build a small satellite and provided a budget. It soon became clear that AlphaSat-R1 would not be completed in time to be launched for free with the AlphaSat-C1 and AlphaSat-C2 communication satellites. The project had enough momentum at this time, however, to continue.

The Project Team
This section describes the role of organizations and personnel within the satellite project.

Which Organizations were involved with the project?
The primary Implementer for Nation Alpha was the government-owned firm Implementer Alpha1. Implementer Alpha1 served as an institutional home for the engineers that were hired to work on the AlphaSat-R1 project. Implementer Alpha1 received its direction from the Nation Alpha government, with specific leadership from Overseer Alpha1, the space research organization. During this time Overseer Alpha1 was moved from the central government to the related government ministry (Overseer Alpha3). Implementer Alpha1 contracted with Supplier Omega1 (a satellite manufacturing firm) to both build the small satellite and train a cohort of Nation Alpha engineers. Another organization that eventually played a key role in the project was the launch provider. More distant project participants include the owners of satellites that were launched simultaneously with AlphaSat-R1.

How were local engineers selected to join the project?
Two types of engineers were selected to participate in the AlphaSat-R1 project. One set was hired as a core team to go to the location of Supplier Omega1 and participate in the development of AlphaSat-R1. A second set was hired to build up the new Implementer Alpha1 firm and prepare for operations of AlphaSat-R1. The two teams of engineers differed in terms of background, selection process and activities. About seven engineers formed a core team of trainee engineers that went to Supplier Omega1. These 7 trainees were selected from universities, industry and military branches and seconded to Implementer Alpha1 for this project. This core team of trainees spent nine months in Nation Omega working at Supplier Omega1 – from Project Year 4 to Project Year 5. The AlphaSat-R1 team invited universities, the military and the Implementer Alpha2 communication satellite firm to propose candidates for the core team of the satellite project. The core team was then selected via an interview process. Both Leader Alpha2 (Leader of Overseer Alpha1) and the leader of Supplier Omega1 participated in interviewing the candidate engineers. The Supplier Omega1 team also contributed to the selection process by proposing the types of backgrounds that would be appropriate for the project. For this group, the hiring process targeted experienced professionals who were early in their careers. The Overseer Alpha1 and Implementer Alpha1 leadership sought people with strong interest in the area of space technology. Most of the engineers did not have experience with space, beyond educational exposure. One exception was an engineer who participated in the six months of international training activities for the AlphaSat-C1 and AlphaSat-C2 communication satellites. He also joined the AlphaSat-R1 project. The plan for this core team of engineers was that they would be temporarily seconded from their home organizations as professors, military officers and industry professionals. After training at Supplier Omega1 there were expected to return to their original positions.

The second team of engineers was hired directly to Implementer Alpha1. They primarily worked in Nation Alpha, although some of them spent short periods at Supplier Omega1. This second team was less experienced; they were primarily recent university graduates. They were hired by Manager Alpha1 who managed the AlphaSat-R1 project and led Implementer Alpha1.

How was a firm selected as the supplier for the satellite system and training?
As the leaders of Implementer Alpha1 and Overseer Alpha1, both Manager Alpha1 and Leader Alpha2 played a key role in selecting the primary supplier for the AlphaSat-R1 project. These leaders reviewed proposals from a variety of potential suppliers that spanned both government and commercial entities. The two leaders did not have previous experience with space technology projects, so they were learning the space marketplace for the first time. As they compared the proposals, the key attributes they considered were good technical performance of the product, extensive training options, long-term experience with small satellites, low price and a strong relationship to a university. The Nation Alpha team selected Supplier Omega1 because they fit these criteria. Supplier Omega1 offered a low cost, small satellite for earth observation. The satellite had strong performance (in terms of spatial resolution) relative to its weight Supplier class. Supplier Omega1 had flight heritage from multiple missions. Supplier Omega1 also stood out for what they could offer in terms of training. They were willing to host Nation Alpha engineers during the satellite manufacturing process and license technology for future use by the Nation Alpha team. Furthermore, Supplier Omega1 was a company that spun out of a university and still retained close ties. The Nation Alpha trainee team could receive teaching and mentoring from faculty and staff at the university as well as the company. None of the other prospective partners seemed to offer all of these benefits.

How was the launch provider selected?
The AlphaSat-R1 team went through several stages of seeking an opportunity to launch the satellite into space. In the first stage, they expected a free launch as part of the AlphaSat-C1 and AlphaSat-C2 communication project. This opportunity is what actually spurred the AlphaSat-R1 project. Ultimately, the timing did not allow AlphaSat-R1 to share the communication launch. There was a two year window between the signing of the communication launch contract and their actual launch. The procurement of the AlphaSat-R1 small satellite was not complete in that timeframe. In the second stage, Implementer Alpha1 and Overseer Alpha1 planned to purchase launch services via their satellite system provider, Supplier Omega1. Although Supplier Omega1 was not a launch provider, they offered the service of negotiating a launch on behalf of Nation Alpha. A launch vehicle and approximate time period were initially proposed by Supplier Omega1 for Project Year 4. This opportunity did not materialize, however. Thus, the AlphaSat-R1 team entered a third stage in which they took on responsibility for finding their own launch opportunity. They went through a process of meeting and negotiating with launch providers from many countries in three continents – Asia, Europe and North America. Their broad search

included a variety of launch approaches, some of which were non-traditional. The attributes they were primarily searching for were affordable price and strong technical performance. They ultimately selected launch Supplier Rho1.

What were the roles of the trainee engineers while at the supplier location and after training?
The technical roles for the Nation Alpha engineers who trained at Supplier Omega1 were determined jointly by both the Nation Alpha and supplier team. As an overall division of labor, the team at Supplier Omega1 focused primarily on satellite engineering and the team of engineers based at Implementer Alpha1 focused more on operations. Within the team of seven Nation Alpha engineers that worked at Supplier Omega1, six worked on specific satellite specialties and one served as team leader with a more general technical focus. The six specialists were each assigned to train one primary area of satellite engineering. Because the team was too small to cover all the subsystems, each of the six also took on a secondary technical area.

After the seven Nation Alpha engineers completed training at Supplier Omega1 and the satellite was delivered to Nation Alpha, this core team of engineers had to work with their original organizations to decide what to do next. They had not been hired permanently to Implementer Alpha1; they were seconded from their respective organizations for the purpose of the training. As leader of Overseer Alpha1, Leader Alpha2 had originally envisioned that if influential people from various organizations were trained in satellites, they could take their skills back to their home organizations and spread the knowledge. So it was natural for the representatives from the military and universities to return to their original jobs. Only one engineer from this core team transferred from a university position to working full time at Implementer Alpha1.

Facilities
During the AlphaSat-R1 project, the Implementer Alpha1 firm worked in a temporary facility with office space that was not custom designed for their use. As part of the AlphaSat-R1 project, Supplier Omega1 installed a mission operations and satellite control station in a major city of Nation Alpha. The Nation Alpha team also leveraged the Overseer Alpha1 facilities as needed. Supplier Omega1 was based in temporary facilities as well. Supplier Omega1 spun out of a university research center. During its early years, the firm shared office and laboratory space with the university. Supplier Omega1 employees were integrated with university employees. Thus the engineers from Nation Alpha that trained at Supplier Omega1 were also based in the university facilities. The supplier firm rented externally owned facilities for some steps of the satellite testing process which require large scale infrastructure.

Training
During the nine months that the core team of Nation Alpha engineers worked at Supplier Omega1, they experienced a set of training activities which included academic courses, technical lectures, group projects and on-the-job training under the mentorship of Supplier Omega1

engineers. When the Nation Alpha engineers arrived at Supplier Omega1, the first stage of training was a series of lectures in the form of a short course. The course was given by staff from the space research department at the university affiliated with Supplier Omega1. The lectures provided an overview of spacecraft engineering. Later engineers from Supplier Omega1 gave more detailed lectures about specific specializations within satellite engineering. Every Nation Alpha engineer attended all the lectures, even lectures for specialties outside of their own. Some Nation Alpha engineers enrolled in formal degree programs at the university, but it was not feasible to complete the degrees in the short timescale of the AlphaSat-R1 project. As a group project, the Supplier Omega1 team led the Nation Alpha engineers through a design exercise to deepen their understanding of satellite engineering and the applications of satellite to national needs within Nation Alpha. After the initial short courses and lectures, each Nation Alpha engineer was assigned to work on a particular aspect of the satellite project under a mentor from Supplier Omega1. The vision was for the Nation Alpha engineers to share responsibilities with their Supplier Omega1 mentors and to contribute to the satellite project. In addition to working directly on AlphaSat-R1, the Nation Alpha engineers worked on individual projects. The projects varied in terms of application – some were immediately applicable to AlphaSat-R1. Others had a long term purpose.

The hands on training activities of the Nation Alpha engineers were impacted by the project schedule and technical heritage of the mission. The Nation Alpha engineers were delayed in their arrival to Nation Omega due to bureaucratic problems. Due to this delay, they arrived later than expected. The Supplier Omega1 team had already begun working on the satellite with a fast paced schedule designed to meet the original Project Year 4 launch goal. The satellite development process was in a late stage. The phases of design and manufacturing were complete; what remained was integration and testing of the system. Thus the Nation Alpha engineers primarily participated in integration and testing aspects of AlphaSat-R1. Later, however, it became clear that there was more time to work on the satellite because the launch was delayed. Due to this, the Nation Alpha engineers were able to work with the Supplier Omega1 engineers to plan and implement an additional instrument as payload to the satellite.

Policy, Cultural, Social Issues

The policy issues that impacted the AlphaSat-R1 project came from three sources –Nation Alpha, Nation Omega and the international community. In the context of Nation Alpha, support of a key government leader helped initiate the project. Later, there was a danger that political support would wane due to the three years of launch delay. The minister from Overseer Alpha3 played a role in maintaining communication and support for AlphaSat-R1 within the central government. In the context of Nation Omega, there were export control regulations. AlphaSat-R1 was a technology transfer project in which an organization in Nation Omega was transferring knowledge and technical documents to an organization in Nation Alpha. This transfer was governed by the export control laws and processes of Nation Omega and concluded successfully.

At the international level, the AlphaSat-R1 project needed to work within the requirements for frequency allocation and filing. The International Telecommunication Union manages these issues. The process designates how a satellite will use portions of the radio frequency spectrum to communicate; this must be coordinated to avoid conflicts. AlphaSat-R1 operated within the amateur radio bands; this limited the complexity and effort required to secure permission for frequency allocation.

9.1.2 The AlphaSat-R2 Project

Nation Alpha's second remote sensing satellite project was a partnership with Supplier Tau1.

The Project Team
This section describes the role of organizations and personnel within the satellite project.

Which Organizations were involved with the project and how were they related?
Implementer Alpha1 was the main organization with responsibility to implement the AlphaSat-R2 project under the authority of Overseer Alpha1 (which transitioned to become Overseer Alpha2 in the middle of the project). The relationship between Implementer Alpha1 and the Overseers evolved during the AlphaSat-R2 project as the national space agency became more formalized. Overseer Alpha2 was the owner of the AlphaSat-R2 program that provided oversight and Implementer Alpha1 was the Implementer firm. Overseer Alpha2 participated in setting high level requirements for AlphaSat-R2. The other role of Overseer Alpha2 was to be the public face of the project by interfacing with government and the press. Implementer Alpha1 worked closely with the Supplier Tau1 to implement AlphaSat-R2. The satellite and payload programs were a collaboration between the two firms. Implementer Alpha1 and Overseer Alpha2 hired a company from Nation Lambda (Supplier Lambda1) to provide launch services. A more distant stakeholder is the national geospatial data agency of Nation Alpha. They did not have any contractual responsibility or role in the AlphaSat-R2 project. They did have the role, however, of receiving data from both domestic and foreign satellite data and distributing it to users in Nation Alpha. Thus, they are part of the AlphaSat-R2 value chain.

How were local engineers selected to join the project?
The process of choosing engineers to participate in the AlphaSat-R2 project was also a process of hiring long term employees into Implementer Alpha1. Thus there were two levels of selection. The Implementer Alpha1 management hired new employees and choose a subset of these to travel to Nation Tau to work directly with Supplier Tau1 engineers on AlphaSat-R2. Implementer Alpha1 leadership sought candidates both domestically and abroad because many Nation Alpha students traveled overseas for their studies. Manager Alpha1 in particular would often travel abroad for events. During these trips he worked with Nation Alpha embassies in major cities to find Nation Alpha students. If possible he interviewed them or invited them to do internships at Implementer Alpha1. In the context of the partnership with Supplier Tau1, the leadership from the supplier had the opportunity to specify what type of academic background

they expected in the visiting engineers. Beyond that, Manager Alpha1 looked for people who seemed prepared and eager to learn new technology. Most of the Nation Alpha engineers that worked on AlphaSat-R2 were recent graduates that were hired specifically to participate in the new satellite project. No one from the core team of trainees that went to Supplier Omega1 for training was part of the Implementer Alpha1 team sent to Nation Tau. One engineer, however, was sent to Supplier Omega1 during the AlphaSat-R1 project and continued with Implementer Alpha1 during the AlphaSat-R2 project. He was based in Nation Alpha rather than Nation Tau during the second project.

How was a firm selected as the supplier for the satellite system and training?
The process of choosing Supplier Tau1 as a partner was based on a long term, personal relationship between the leaders of the key organizations. Leader Alpha2, as founder of Overseer Alpha1, became friends with Professor Tau1, a pioneer in Nation Tau's space community. As the Nation Alpha team considered a second satellite project, they sought specific technical and management aspects. On the technical side, they wanted a satellite that would be larger and have greater performance than AlphaSat-R1. From a project management standpoint, they wanted a process that would allow them to collaborate equally with a partner. They needed a partner that would share technical and financial risk and allow Nation Alpha engineers to contribute to the technology development process. A new satellite manufacturing firm had spun out of Professor Tau1's university; the firm was Supplier Tau1. Because Supplier Tau1 showed a willingness to work with Nation Alpha in joint development of a new spacecraft bus platform and to train engineers, Nation Alpha chose this small, nascent firm as their partner.

How was the launch provider selected?
The Nation Alpha team (Implementer Alpha1 and Overseer Alpha2) took responsibility for finding a launch for AlphaSat-R2. The satellite was designed to operate at a unique orbit in space. Few launch providers were accustomed to offer this specific service. As with the AlphaSat-R1 project, Nation Alpha considered many potential plans when arranging a launch for AlphaSat-R2. Early on, Nation Alpha made an agreement with one country to launch AlphaSat-R2. They later learned that this would not be possible due to international trade restrictions. Implementer Alpha1 and Overseer Alpha2 considered other launch options, some of which were highly creative. Nation Alpha ultimately chose to work with Supplier Lambda1, which was a new start up that had not yet proven their capability to build a functional rocket. On the other hand, Supplier Lambda1 was able to offer a low price and find a launch site that was not limited by trade restrictions from which to send AlphaSat-R2 directly to its intended orbit. Implementer Alpha1 was the first customer for Supplier Lambda1. At the time that they choose to work together, Supplier Lambda1 was a small start up. The Nation Alpha team found Supplier Lambda1 to be innovative and price competitive. Nation Alpha saw that the two teams could help each other: Supplier Lambda1 provided a low cost launch to a unique orbit and Nation Alpha's patronage allowed Supplier Lambda1 to start building a reputation.

Where was the team located and how did they transition?

The AlphaSat-R2 team was often split geographically between Supplier Tau1 and Implementer Alpha1. The Implementer Alpha1 company leadership stayed in Nation Alpha while an Implementer Project Manager led teams in Nation Tau. Teams of Implementer Alpha1 engineers went to Nation Tau in several waves over a four year period. About eighteen Nation Alpha engineers lived in Nation Tau; they stayed for different lengths of time. Some stayed as long as 2 years, while others had shorter stints of less than one year. A total of about 30 people from Implementer Alpha1 spent some time in Nation Tau. The first team from Implementer Alpha1 went to Supplier Tau1 to begin work on the satellite payload. During this early phase, Nation Alpha had two partnerships going – with Supplier Tau1 and a second supplier in a different country. There were Implementer Alpha1 employees stationed with both partners simultaneously. Some Implementer Alpha1 engineers continued to visit Nation Tau after their main shift was completed. There was also a team of Implementer Alpha1 engineers that did not spend long periods in Nation Tau. Their focus was to gradually build up AIT (Assembly, Integration and Test) facilities in Nation Alpha to enable them to integrate and test some subsystems of AlphaSat-R2. After the flight model of AlphaSat-R2 was delivered from Supplier Tau1 to Implementer Alpha1, the relationship with Supplier Tau1 did not stop. The Supplier Tau1 Project Manager traveled frequently to Nation Alpha to provide support.

What were the roles of the trainee engineers while at the supplier location and after returning home?

The roles for individual engineers were assigned by joint agreement between Implementer Alpha1 and Supplier Tau1. The Nation Alpha engineers that worked in Nation Tau focused on specialties within satellite engineering, including the payload aspects. The team was large enough to cover many of the satellite engineering specialties. Each person focused on one specific area. When the Nation Alpha engineers returned from Nation Tau they continued to work in the specialty area as the project continued in the testing and calibration stage.

Facilities

During the AlphaSat-R2 project, Implementer Alpha1 transitioned from temporary, generic office facilities to purpose-built facilities that included hardware laboratory space. At the start of the project, Implementer Alpha1 was based in small office space within a technology park in Nation Alpha. The park was designed to incubate new firms. In this office, there were no facilities to do hardware work and there was no laboratory space. Next Implementer Alpha1 moved to a different location in the same technology park. This new space was larger and it allowed Implementer Alpha1 to set up initial laboratory space for hardware work. By the end of AlphaSat-R2, Implementer Alpha1 had moved out of the incubating technology park and taken space in an industrial park. Over time, Implementer Alpha1 established several types of hardware workspace in the industrial park location that facilitated satellite integration, electronics fabrication, and optical testing. Together all of these made up an Assembly, Integration and Test facility for AlphaSat-R2. Implementer Alpha1 did what they could with the facilities they had at each stage. In the small lab at the technology park, several subsystem components were manufactured. Before the full AIT facility was completed at the industrial park location, Implementer Alpha1 engineers started on some hardware work to build structures to protect electronic components for the satellite. Implementer Alpha1 used the AIT facility to do the final assembly and functionality testing of the flight model of AlphaSat-R2 in Nation Alpha. Implementer Alpha1 did not have facilities for environmental testing of the assembled satellite. AlphaSat-R2 was shipped back to Nation Tau after assembly so it could go through environmental tests at a government facility in Nation Tau. In parallel with Implementer Alpha1's facility expansion, Overseer Alpha2 had facility projects as well. Overseer Alpha2 took leadership in helping to prepare AlphaSat-R2 to be operational. This involved ensuring optical calibration and establishing a workflow for satellite operations. Overseer Alpha2 developed a facility to do optical calibration of AlphaSat-R2, and they established a facility for monitoring and sending commands to the satellite. A mirror facility for satellite control was set up at Implementer Alpha1 to support them. The primary Image Receiving and Processing Station was operated by the National Remote Sensing Center in Nation Alpha.

Training

This section discusses training preparation and activities at the Supplier firm.

What preparation did trainees have in home country before leaving for supplier location?

Before groups of Nation Alpha engineers went to Nation Tau, Implementer Alpha1 made some efforts to prepare them and transfer knowledge that the organization had gained during the AlphaSat-R1 project. Most new engineers spent several weeks or months in Nation Alpha before transitioning to Nation Tau. During this time, a few team members that had experienced AlphaSat-R1 gave lectures about satellite technology or provided informal teaching. Implementer Alpha1 also introduced some of these new engineers to project management methods. Another effort to transfer AlphaSat-R1 knowledge was to assign more experienced Nation Alpha engineers as mentors to the new team members.

What happened during the transition to the supplier location?

Each Implementer Alpha1 engineer that went to Nation Tau had a unique transition experience. They were hired at different times and sent to Nation Tau in small groups or as individuals. Supplier Tau1 generally provided a technical orientation to new arrivals by hosting a week or two of theoretical lectures about satellite technology and subsystem design. The Nation Alpha engineers found this to be new information. As new Nation Alpha engineers arrived in Nation Tau, they sought support from the veterans who arrive earlier in learning how to live in the new country.

What training approaches were used?

The training experience for Nation Alpha engineers with Supplier Tau1 included technical lectures, on the job training under a mentor, access to technical documentation about the project, attendance at conferences and language classes for the local Nation Tau language. Supplier Tau1's approach to training the Implementer Alpha1 engineers was to give them project-oriented tasks to achieve and to focus primarily on their specific subsystem. After the introductory lectures, engineers often needed to learn to use an important tool such as a software package for design. Once they were able to use the design, analysis or testing tool, the Implementer Alpha1 engineers were given specific tasks that were part of the overall team responsibilities and the satellite development life cycle. The Implementer Alpha1 engineers did not spend much time doing extra learning assignments that were outside the scope of the project. The Implementer Alpha1 engineers had an informal relationship with their Supplier Tau1 mentors. They often shared office space or sat in close proximity. They met regularly for informal discussions.

Policy, Cultural, Social Issues

In the domestic policy context of Nation Alpha, one issue that influenced the AlphaSat-R2 project was the status of the government infrastructure with regard to space. The primary Overseer (Overseer Alpha2) worked under a government ministry (Overseer Alpha3). Implementer Alpha1 and Overseer Alpha2 work with teams from Overseer Alpha3 to propose long term road maps for national satellite projects. During the time of AlphaSat-R2, Nation Alpha did not have some of the national policy infrastructure that facilitates satellite projects. For example, they did not have a national space policy, a space act to define responsibilities in the space arena, or ratification of some international space treaties. The space policy document was under preparation during AlphaSat-R2 and was meant to serve as a foundation for a national space act. The AlphaSat-R2 project was also impacted by international trade regulations that made it infeasible to pursue certain launch options and certain communication with launch providers. Language was an issue in the collaboration between the Implementer Alpha1 and Supplier Tau1. The two teams spoke different first languages and communicated in an international second language. It was important for engineers from Nation Alpha to learn the local language of Nation Tau in order to interact in the society.

9.2 Nation Beta

This section summarizes the first two remote sensing projects for Nation Beta.

9.2.1 The BetaSat-R1 Project

Nation Beta's first remote sensing satellite projects was a partnership with Supplier Omega1.

Initiation and Approval of Satellite Project

Before starting the BetaSat-R1 project, the Nation Beta head of state convened a committee of five experts to provide advice and help define the satellite project. This was happening in parallel with the formation of the national space agency of Nation Beta. The committee members were to evaluate strategic questions about how to begin the new space program. They considered whether to buy a satellite and various types of satellites to procure. The committee played a role in deciding that Nation Beta would buy a remote sensing satellite and invest in training of personnel. They supported the proposal to make a contract with Supplier Omega1. In addition to the work of the committee, the newly formed Implementer Beta1 held stakeholder meetings before starting the BetaSat-R1 project. The project to procure BetaSat-R1 was formally approved by the central Nation Beta government. About one year later Nation Beta signed the contract with Supplier Omega1 which covered the remote sensing satellite and training of Nation Beta engineers. The relevant government minister signed on behalf of Nation Beta. Funding was provided by the Nation Beta government to cover the project. While Implementer Beta1 negotiated the contract with Supplier Omega1, they worked with a consultant for technical guidance. The satellite project was also shaped by the vision of Supplier Omega1 to coordinate a collaborative constellation of satellites that would work together to enhance each other's capacity. The BetaSat-R1 project joined this constellation.

The Project Team

This section describes the role of organizations and personnel within the satellite project.

Which Organizations were involved with the project and how were they related?

Implementer Beta1 contracted with Supplier Omega1 to execute the BetaSat-R1 project. They also hired consultants to review their technical decisions. Within Nation Beta, several government organizations were directly involved with the project, including the relevant ministry Overseer Beta1; a government advisory committee for space science and technology; and the office of the President. Each of these stakeholders was represented at the launch of BetaSat-R1. While the Nation Beta trainee engineers were in the Nation Omega, they had limited exposure to other emerging satellite teams that worked with Supplier Omega1. Because Supplier Omega1 was located on the University Omega1 campus during that time, Nation Beta engineers would sometimes share office space with doctoral students from the university. BetaSat-R1 shared a launch with satellites for several other countries.

How were local engineers selected to join the project?

Implementer Beta1 pursued a wide-reaching approach to choose the fifteen trainee engineers that would go to Supplier Omega1. Aptitude tests were held to find engineers and scientists with strong performance. Tests were held in several regions of Nation Beta. A selection panel also held a next level of review. The panel included representatives from Implementer Beta1, the Nation Beta government and Supplier Omega1. The selection process sought engineers that were relatively early in their careers and had skills in relevant areas such as electronics, communication and computer science. The selected team of Nation Beta trainee engineers was a mix of fresh graduates and engineers who had some work experience.

How was the launch provider selected?
Supplier Omega1 selected the launch provider for BetaSat-R1 after considering many firms and comparing them based on cost and reliability. The BetaSat-R1 was built to operate as part of a collaborative constellation; several members of the satellite constellation shared the launch.

How was a firm selected as the supplier for the satellite system and training?
When Nation Beta considered the proposal from Supplier Omega1, they evaluated it in terms of cost, technical performance and training potential. They selected Supplier Omega1 because they found the cost to be low and the technical performance to be acceptable. They also found Supplier Omega1's offers for training to fit their interests.

Where was the team located and how did they transition?
Implementer Beta1 was based in the capital of Nation Beta. For the BetaSat-R1 project, the Nation Beta trainee team lived and worked in Nation Omega from the end of Project Year 3 until the middle of Project Year 5. The whole group of trainees moved from Nation Beta to Nation Omega together after their selection process and a send off ceremony.

What were the roles of the trainee engineers?
During the BetaSat-R1 project, Supplier Omega1 defined the team roles and responsibilities for their engineers and the visiting engineers from Implementer Beta1. As was their standard practice, Supplier Omega1 set up a project team built around a core group of engineers that took responsibility for each section of the satellite. The Nation Beta trainees were assigned to be mentored by specific members of the Supplier Omega1 team. The Supplier Omega1 core team was led by a Project Manager and System Engineer. The Nation Beta engineers worked with their mentors as well as other Supplier Omega1 engineers on their subsystem teams. The specific assignments for each Nation Beta engineer were focused primarily on satellite engineering with a few engineers placed in the ground station operations area. The team of Nation Beta engineers was relatively small. They were scattered throughout the satellite project team. Each was given a primary assignment, but some were also encouraged to learn a secondary topic. This allowed the team to cover more disciplines.

Facilities
During the BetaSat-R1 project, facilities for both Supplier Omega1 and Implementer Beta1 were in an early stage of development. Supplier Omega1 was temporarily sharing facilities with a research center in University Omega1. Personnel from Supplier Omega1 and University Omega1 shared office and laboratory space. Supplier Omega1 did not have facilities for the environmental testing of the full BetaSat-R1 system. They rented such facilities from other laboratories in Nation Omega. Implementer Beta1, having opened in Project Year 1, was also in temporary facilities throughout the BetaSat-R1 project. Implementer Beta1 rented office space in the capital city of Nation Beta. This space housed the early management team. A separate site was used for the first BetaSat-R1 ground station in a different section of the capital city. The

construction of the BetaSat-R1 ground station was executed in about two weeks during Project Year 5, just before the launch of the BetaSat-R1. The imagery data from the BetaSat-R1 was downloaded and process by Implementer Beta1. Supplier Omega1 also had the capability to download data and perform satellite control activities from their facility in Nation Omega. In Project Year 5, the Nation Beta government approved funding to establish a permanent Implementer Beta1 campus outside the capital city with a new ground station, headquarters office buildings and a section focused on satellite technology.

Training

This section describes training preparation and activities at the Supplier firm.

What preparation did trainees have in home country before leaving for supplier location?

The Implementer Beta1 engineers that were sent as trainees to Supplier Omega1 were all newly hired for the purpose of the BetaSat-R1 project. They traveled as one group to Supplier Omega1. In the few weeks before they were sent to Supplier Omega1, they had an orientation process that included presentations from the Implementer Beta1 team.

What happened during the transition to the supplier location?

As the visiting engineers from Nation Beta arrived in Nation Omega during the BetaSat-R1 project, Supplier Omega1 provided support for arranging logistics and orienting the visitors to the new environment.

What training approaches were used?

During the BetaSat-R1 project, the training provided by Supplier Omega1 to the visiting Nation Beta engineers was not highly formalized or structured. The core approach was to integrate the engineers into a Supplier Omega1 engineering team and give them assignments for on the job training. In addition, the training included technical lectures about theoretical and practical aspects of satellite technology and a group design project. The Implementer Beta1 engineers did not pursue formal academic degrees. As part of the on the job training some Implementer Beta1 engineers were exposed to external processes, such as the manufacturing activity of a subcontractor. For the group design project, the Implementer Beta1 team was asked to design a complete satellite. They were given a week to develop a design based on given constraints. The deliverable was a presentation to Supplier Omega1.

How did trainee engineers interact with mentors?

During the BetaSat-R1 project, each visiting engineer from Implementer Beta1 was assigned to work under a mentor from Supplier Omega1. These mentors were engineers who also had responsibilities for design and engineering tasks to complete BetaSat-R1 and other satellites. The visiting Implementer Beta1 engineers met regularly with their Supplier Omega1 mentors for both formal and informal discussions. Most Implementer Beta1 engineers shared an office with their mentor or sat nearby. As a firm, Supplier Omega1 did not give highly structured guidance to the mentor engineers about how to train the visiting engineers. For some of the Supplier Omega1 team, BetaSat-R1 was their first training experience, although Supplier Omega1 had gone through multiple training projects. The mentor engineers varied in their training approaches and levels of formality. There were both formal and informal work plans and accountability systems for the Implementer Beta1 engineers. Some mentors focused on using their routine work as a learning opportunity to explain concepts and techniques to the Implementer Beta1 engineers. Some created training activities once they understood the strengths and interests of the visiting engineers. Some gradually developed a structured work plan for their trainees that included a series of assignments with both theoretical and applied aspects. Much of the work for these training assignments did not contribute to the development of the BetaSat-R1; it was purely for learning purposes. Overall, the Supplier Omega1 mentor engineers adapted to the capabilities and interests of the visiting Implementer Beta1 engineers and tried to give them as many opportunities as possible to participate in the BetaSat-R1 development.

Policy, Cultural, Social Issues

This section describes domestic and international policy issues.

Were there domestic policy concerns for supplier or implementer?

During the BetaSat-R1 project, Implementer Beta1 had strong support from the Nation Beta central government. The national space policy document was approved near the beginning of the BetaSat-R1 project; this created a support policy environment for Implementer Beta1 as they developed the satellite. The central government provided practical support by engaging with Supplier Omega1 via the oversight ministry and by easing customs concerns when the ground station equipment was imported into Nation Beta. The Nation Beta government also settled a dispute over frequency allocation that could have hindered the operation of BetaSat-R1. In middle of the BetaSat-R1 project, the electoral cycle caused some uncertainty and delay during a time of government transition.

Were there international policy concerns?

For BetaSat-R1, Supplier Omega1 had to pursue licenses from export control office of Nation Omega sell the satellites, provide technical training and send the satellites to launch site in a third party country.

9.2.2 The BetaSat-R2 & BetaSat-R3 Project

Nation Beta's second satellite project was a partnership with Supplier Omega1 to purchase two satellites.

Initiation and Approval of Satellite Project

From the point of view of Supplier Omega1, the business development effort to win the BetaSat-R2 project contract began several years before the formal negations. The negotiation process involved Supplier Omega1, Implementer Beta1 and a team of consultants supporting the

Implementer. Supplier Omega1 interacted closely with the consultant team. The key players in the negotiation process were the project managers from Implementer Beta1 and Supplier Omega1. They had responsibility for most of the process, but they would defer to the authority of their organizational leaders when necessary. The official ceremony to recognize the contract was held in the capital of Nation Beta. The contract scope included the BetaSat-R2 spacecraft, the ground infrastructure for the new spacecraft and training for the Nation Beta engineers. The Nation Beta government continued its involvement and oversight of the BetaSat-R2 project after the contract was signed. Both the president and relevant minister within Nation Beta reviewed the project.

The Project Team

This section describes the role of organizations and personnel within the satellite project.

Which Organizations were involved with the project and how were they related?

For the BetaSat-R2 & BetaSat-R3 satellite projects, Implementer Beta1 continued as the implementer while the same Ministry provided funding and oversight (Overseer Beta1). Although the Ministry did not generally get involved in the day to day issues of the BetaSat-R2 project, they were kept aware of the overall progress of the project. Implementer Beta1 worked with the same external consultant for both the BetaSat-R1 and BetaSat-R2 projects. The relationship between Implementer Beta1 and the firm was mainly handled by the Nation Beta program manager and the Supplier Omega1 project manager. There were also other secondary players that contributed to the communication. One Nation Beta engineer served Implementer Beta1 as the customer representative that worked on-site with Supplier Omega1.

How were local engineers selected to join the project?

The Nation Beta engineers that worked on BetaSat-R2 were a mix of people that had already worked at Implementer Beta1 on previous projects (the BetaSat-R1 and BetaSat-C1 satellite) as well as new hires for BetaSat-R2. The BetaSat-R1 project included 15 engineers while the communication satellite (BetaSat-C1) was a large team of fifty people. There were four categories of hiring experiences for the BetaSat-R2 engineers. About 5 or 6 engineers that worked on BetaSat-R2 were hired into Implementer Beta1 at the start of the BetaSat-R1 project. Another group of engineers was involved with the BetaSat-C1 communication satellite project. A third category of engineers was hired from outside Implementer Beta1 just before the BetaSat-R2 project started; they were sent to Supplier Omega1 with the first Cohort of trainees. The fourth category is made of engineers hired around during the BetaSat-R2 project for the purpose of joining the second training cohort at Supplier Omega1. Among the trainee engineers that were hired specifically for BetaSat-R2, there were some commonalities to their stories. They became aware of the job opportunity generally via a newspaper advertisement, a website or advice from a friend. After applying they were invited to take a test or do an interview – or both. The test covered writing and math. The math portion was at the secondary school level such as algebra and geometry. In Nation Beta, such exams are common as part of the job application process. The applicants differed in their level of familiarity with Implementer Beta1. Some had seen coverage of the BetaSat-R1 launch a few years earlier. Others had not heard of Implementer Beta1 at all. Several of the engineers hired by Implementer Beta1 were recent graduates, however, even recent graduates had some work experience because they were required to complete a year of volunteer service. This was a national requirement in Nation Beta. Some engineers had full time positions with the government or a company before joining Implementer Beta1. The engineers hired to do the training generally did not have previous experience with space technology before coming to Implementer Beta1. A few had theoretical or academic introductions to space technology and satellite services. Supplier Omega1 had limited input on a customer's selection process of the engineers for both BetaSat-R1 and BetaSat-R2. They did not evaluate or approve the selected engineers that were chosen by Implementer Beta1.

How was a firm selected as the supplier for the satellite system and training?
For BetaSat-R2, Nation Beta's selection process was to use selective tendering, meaning they did not hold an open call for bids. Instead Implementer Beta1 and their consultant met with potential suppliers to learn about their offerings. They invited only specific satellite suppliers to submit bids. The consultant reviewed the submissions in terms of technical quality and price. From the supplier perspective, the BetaSat-R2 project fit into Supplier Omega1's core market area. Supplier Omega1 was competing with several other potential suppliers, some of which were located in their region and others which were in different parts of the world. Supplier Omega1 sought to win the bid by offering unique training options and a competitive price.

How was the launch provider selected?
The BetaSat-R1, BetaSat-R2 and BetaSat-R3 satellites were all launched from the same country (Nation Rho). Supplier Omega1 worked frequently with this country to procure launch services. Supplier Omega1 also took on the role of selecting a launcher for BetaSat-R2 & R3 to be launched together. The launch agreement was initially signed before BetaSat-R2 and BetaSat-R3 completed development in Project Year 5. There was a delay, however, and the two satellites waited about two years to launch in Project Year 7.

Where was the team located and how did they transition?
For the BetaSat-R2 & R3 project, the team of engineers from Implementer Beta1 transitioned to Supplier Omega1 in two major groups. The first cohort included 11 engineers, and the Customer Representative. They went to Supplier Omega1 in Project Year 2. The second cohort arrived as a group of fourteen in Project Year 4. That brought the number up to 27 in the Nation Beta team. During the training, most of the trainees worked at Supplier Omega1's main location in one city, but some were assigned to a secondary location in nearby city. The second location had a focus on satellite imaging systems. Some of the Cohort 1 engineers studied for a Master of Science

Degree during their time in Supplier Omega1. A number of them continued to study for a PhD in Nation Omega after the BetaSat-R2 training was over.

What were the roles of the trainee engineers?

For the BetaSat-R2 & R3 project, Supplier Omega1 again played a key role in assigning the visiting engineers into subsystem or discipline team. Each trainee was assigned to specialize in a specific area of satellite missions. The high level approach was to consider the trainee's background and interests in order to match them to the appropriate subsystem. The team was large enough to allow each visiting engineer to focus on one area. Both Cohort 1 and Cohort 2 received tests when they first arrived to establish their math and science, to test their familiarity with space concepts and to find their area of strength in a subsystem. In addition to the test, Supplier Omega1 also considered the information about the trainees from interviews, CVs and their expressed interest. The majority of the visiting Nation Beta engineers worked on satellite or payload engineering, but about five people focused on ground system operations. There were several leadership roles within the visiting Nation Beta team – Customer Representatives, Project Manager and Systems Engineer. The customer representative's job was to coordinate issues between the Project Manager, Training Manager, and CEO from Supplier Omega and the Program Manager from Implementer Beta1. The Nation Beta System Engineer also played a coordinating role, but focused more narrowly on technical matters. The Nation Beta Project Manager worked to ensure that all deliverables for the team were completed at the expected cost and schedule. He was also concerned with the welfare of the team members. Once all the Implementer Beta1 trainee engineers completed their stay in Nation Omega and most were back in Nation Beta, some roles changed. The trainees that spent time in Nation Omega were re-integrated back into several teams at Implementer Beta1, along with new hires from Nation Beta who had not trained abroad. The Ground Station team evolved to be three groups with five people working on maintenance of the station hardware, six people working on satellite operations and three people working on image processing. There were also organizational changes. One particular section within Implementer Beta1 was leading the satellite development activities; most of the Implementer Beta1 engineers that trained at Supplier Omega1 were from this section. A new leader was chosen for this satellite development section. When he entered the position, he reorganized this section and reassigned positions. His team included engineers trained during abroad as well as new recruits. The roles of returning trainees were redefined with this organizational change. The new organization was based around divisions focused on specific engineering disciplines. Most people did not change activities, but their team structure changed.

Facilities

During the BetaSat-R2 & R3 project, both Supplier Omega1 and Implementer Beta1 transitioned into facilities that were specifically designed to address their organizational needs and allow them to grow in terms of personnel. As described above, Supplier Omega1 started by sharing office and laboratory facilities with University Omega1. In Project Year 2 of BetaSat-R2, Supplier Omega1 moved into a larger, dedicated building with office space and satellite control facilities. This new building was a short drive away from University Omega1. They continued to use the university for laboratory and hardware integration facilities throughout the BetaSat-R2 & BetaSat-R3 project. Supplier Omega1 also expanded by acquiring a company in a nearby town that focused on satellite payloads. Supplier Omega1 continued to rent access to external facilities for environmental testing of the BetaSat-R2 and R3 satellites. Implementer Beta1 opened a new campus outside the capital city of Nation Beta. The campus included the headquarters for Implementer Beta1, a section dedicated to the satellite technology team, new ground stations for Nation Beta's remote sensing satellites, as well as office space and ground stations for Nation Beta's communication satellite project. As was true with the BetaSat-R1, the primary ground station for control and image collection from the BetaSat-R2 & R3 satellites was located at Implementer Beta1, but Supplier Omega1 also had the capability to serve as a back up ground station. During the BetaSat-R2 & R3 project, Implementer Beta1 initiated a process to build the first facilities within its campus for working on the design, manufacture and testing of satellites.

Training

This section describes preparation for training and training activities at the Supplier firm.

What preparation did trainees have in home country before leaving for supplier location?

For the BetaSat-R2 & R3 project, two cohorts of Implementer Beta1 engineers were sent to Supplier Omega1. Both cohorts had several months or years at Implementer Beta1 before departing for Supplier Omega1. The first cohort was a mix of engineers that had already worked at Implementer Beta1 for several years as well as new hires. Some of the veterans prepared for departure to Supplier Omega1 by working on tasks in satellite operations or design. The second cohort was a team specifically hired for the BetaSat-R2 & R3 project. They had several months at Implementer Beta1 to prepare. During this time, some veteran Implementer Beta1 engineers gave lectures on satellite technology. Implementer Beta1 also brought in teachers to provide training in computer skills and programming. There was also time for the trainees to study relevant material from Implementer Beta1's satellite projects.

What happened during the transition to the supplier location?

During the BetaSat-R2 & R3 project, the Supplier Omega1 team included a full time training manager that addressed the personal, social, educational and mentorship needs of the visiting Nation Beta engineers. This role included helping the visitors find housing, learn about the local culture and integrate into the Supplier Omega1 community via social events. The Nation Alpha engineers arrived in two cohorts, so the veterans could help the later arrivals adjust to Nation Omega. For the first cohort of Nation Alpha engineers, the transition was both into Supplier Omega1 and University Omega1. Most of the first cohort entered a Masters degree in satellite engineering at University Omega1. They lived as students on campus during their first two years in Nation Omega. The second cohort did not have this academic experience.

What training approaches were used?

The training for the BetaSat-R2 & R3 project was highly structured. The training included technical lectures about satellite technology, a group design project, skill-based courses, technical demonstrations, on-the-job experience under a mentor, and contributing to the manufacture and testing of a training satellite (BetaSat-R3). A subset of the Implementer Beta1 engineers completed university degrees through a Master of Science in Satellite Engineering at University Omega1. The training also included a license to the technical documentation for the BetaSat-R3 training satellite. These aspects are explained in more detail here. Each of the two cohorts of visiting Implementer Beta1 engineers received technical lectures about satellite technology when they arrived. The lectures were given by staff from both Supplier Omega1 and University Omega1. The group design project was similar to that of the BetaSat-R1 team. The Implementer Beta1 engineers were given constraints and requirements for a satellite mission and they created a design solution by mimicking the team structure and analysis process of Supplier Omega1. The skill-based courses provided focused, practical training in hardware techniques and the use of software tools. The technical demonstrations taught about techniques for operating satellite engineering facilities and manufacturing approaches. The on-the-job experience was especially relevant for Cohort 1. They shadowed mentors in specific subsystem teams during the design of the BetaSat-R2. Both Cohort 1 and Cohort 2 engineers participated in aspects of the design, manufacture and test for the BetaSat-R3 training satellite. The objective was to give the Implementer Beta1 engineers as much responsibility as possible for this satellite, under the supervision of Supplier Omega1. Twelve Implementer Beta1 engineers enrolled in Master of Science degrees at University Omega1. For this group, about two years of the training was spent in part time study and part time work at Supplier Omega1. The degree requirements included two semesters of classes and a two semesters of working on a research project. During each semester, students took two classes. The Implementer Beta1 engineers spent a two per week at University Omega1 and the remaining days at Supplier Omega1. The research projects for the team were contributions toward a larger effort to build a very small satellite. Supplier Omega1 defined multiple approaches to monitoring and evaluating trainee performance during the BetaSat-R2 & R3 project. At a high level these included the following: 1) assigning the trainees to areas of specialized responsibility; 2) assigning Supplier Omega1 personnel to serve in support and mentorship roles; 3) using the project review process to assess work; 4) subjecting BetaSat-R3 to flight quality standards; and 5) enforcing deadlines for deliverables in each project phase. In addition to these approaches that were built into the project, the Supplier Omega1 training manager executed direct evaluations. She gave the trainees tests based on the technical lectures and tests on computer proficiency.

How did trainee engineers interact with mentors?

During the BetaSat-R2 & R3 project, the Implementer Beta1 engineers that visited Supplier Omega1 were once again assigned to work under mentors, especially during the On-the-Job experience and the work on the BetaSat-R3 training satellite. For this project, mentorship could come from people in multiple positions depending on the activity, but each Implementer Beta1 engineer had a primary mentor. The intent was for each Implementer Beta1 engineer to affiliate with a specific subsystem or discipline team and sit at a desk in that team's area within Supplier Omega1. The newly appointed training manager for Supplier Omega1 created a more structured accountability system for mentor engineers during this project. More mentors developed work plans for their trainee engineers. The plans included a series of learning tasks and milestones. The visiting engineers had regular meetings with their mentors and with the training manager to review their progress in the work plan. For the BetaSat-R2 project, the Implementer Beta1 engineers mostly shadowed and did theoretical assignments. For the BetaSat-R3 project, the Implementer Beta1 engineers had more direct responsibility and opportunities for hands on work. During the on the job training, the mentor engineers wrote weekly reports evaluating the activity and performance of the engineer under their supervision. Those reports were submitted to CMA02. CMA02 wrote monthly reports to deliver to the customer about training progress, using material from the mentor reports.

Policy, Cultural, Social Issues

This section describes domestic policy concerns, international policy concerns and cultural issues.

Were there domestic policy concerns for supplier or implementer?

During the BetaSat-R2 & R3 project the support from the central Nation Beta government continued to be strong, but the process of funding the new project was slower. Ideally, the second generation satellites would have launched before the first generation satellites reached the end of their design life. A delayed in funding made it difficult to reach that goal.

Were there international policy concerns?

For both BetaSat-R1 and the BetaSat-R2 & R3 satellite projects, Supplier Omega1 had to pursue licenses from export control office of Nation Omega sell the satellites, provide technical training and send the satellites to launch site in a third party country. Supplier Omega1 was also impacted by international export and trade regimes. The need to secure export licenses placed a general schedule risk on the projects. Also, for both satellite projects, the visiting Implementer Beta1 engineers required visas to stay in Nation Omega during their training. At times, there were delays in processing the visas, causing adjustments to the training schedules.

How did cultural issues impact the project?

As the Nation Beta engineers transitioned into Nation Omega to work with Supplier Omega1, they faced several cultural differences. Overall, they had to adjust to the new country, which featured a different climate, unfamiliar food and different social customs. The dominant languages of Nation Beta and Nation Omega were the same; therefore this was not a major change. Specifically within Supplier Omega1, the Nation Beta engineers found several dimensions in which the work culture was different than their previous experiences. In Supplier Omega1, the Nation Beta engineers found unfamiliar cultures toward authority, team dynamics, time management, gender roles and work ethic. The educational systems in Nation Omega and Nation Beta also had different areas of emphasis; this impacted the relationship between the two teams.

9.3 Nation Gamma

This section summarizes the GammaSat-R1 project, which was purchased as part of a partnership with Supplier Tau1.

The Project Team

This section describes the role of organizations and personnel within the satellite project.

Which Organizations were involved with the project and how were they related?

The major organizations that were directly involved with the GammaSat-R1 project included Implementer Gamma1 (customer), Supplier Tau1 (primary supplier of the satellite, ground station and training), Supplier Rho1 (launch provider), and Supplier Lambda2 (ground station supplier). There were also stakeholders within Nation Gamma government that oversaw Implementer Gamma1. The GammaSat-R1 spacecraft was "designed and developed by Supplier Tau1....with strong participation from Nation Gamma engineers." While the Implementer Gamma1 engineers were in Nation Tau, they were exposed to some other organizations from Nation Tau. During the launch campaign, the Implementer Gamma1 team was exposed to new organizations. The launch provider was Supplier Rho1. Implementer Gamma1 also signed a Memorandum of Understanding with the government of Nation Rho. The launch was shared by several other customers including a Supplier from Nation Omega. The Nation Gamma team had contact with the other customers as they all prepared their satellites just prior to launch.

How were local engineers selected to join the project?

Implementer Gamma1 was established at the beginning of the GammaSat-R1 project, so choosing engineers for the project was also a process of choosing new employees. Some of the key factors Implementer Gamma1 considered were the applicant's majors – which need to be relevant some satellite discipline – and their interest in the topic. In addition, at least some of the new hires needed to be willing and able to work in Nation Tau for long periods. Implementer Gamma1 specifically chose to work with "fresh people" that were not already proven as experts. They hired recent graduates in order to "develop them from the start." Implementer Gamma1 only hired people from Nation Gamma in order to develop local knowledge. Leaders at Supplier Tau1 shared the Implementer Gamma1 philosophy of hiring young, less experienced engineers. In hiring for Supplier Tau1, leadership targeted less experienced engineers that were recently graduated and assumed that it would take 1 to 2 years to help them become effective engineers. "I prefer less experienced people, especially newly graduated people...We can train them. Even if they study deeper or they have experience in a specific field, we have to train them. Unless they have experience in a satellite development company, we have to train them." As Implementer Gamma1 recruited new engineers to join for the GammaSat-R1 project, the leadership used word of mouth to let possible candidates know about the opportunity. The primary way that engineers learned they could apply to Implementer Gamma1 was from a friend that was affiliated with the organization or knew someone there. Some Implementer Gamma1 engineers sent in an application or CV to show their interest and were interviewed by phone or in person.

What was the background of the engineers that joined the project?

True to their philosophy, Implementer Gamma1 hired many engineers directly as they graduated from university for the GammaSat-R1 project. For most, Implementer Gamma1 was their first full time job, although some had short term experiences in other organizations. Many of the new Implementer Gamma1 engineers studied at local universities; some universities located in Nation Gamma have strong international ties. Most of the new hires to Implementer Gamma1 for GammaSat-R1 did not have substantial work experience, but some had training that was particularly suited to some aspect of their work on the satellite. The hiring policy of Implementer Gamma1 was purposefully narrow because of their vision to benefit the technological capability of the local people. They only hired Nation Gamma nationals, which made up a minority of the population. From this perspective, the hiring pool for qualified engineers that were also Nation Gamma nationals was small.

How was a firm selected as the supplier for the satellite system and training? How was the launch provider selected?

Implementer Gamma1 considered a variety of suppliers for their satellite and training project. Some of these suppliers made visits to Implementer Gamma1 for dialog during the selection process. The key attributes that caused them to choose Supplier Tau1 were their flexibility with the technical product they were willing to sell and their level of depth with the technology transfer. Supplier Tau1 distinguished themselves from other suppliers that had less flexibility in the specifications they would offer in their satellites. Supplier Tau1 also was willing to provide "in-depth" technology transfer. In addition to the technology requirements, Implementer Gamma1 sought a competitive price and a timeline that fit their needs. The experience of the Nation Alpha team with Supplier Tau1 also helped that firm win the contract. The Implementer Gamma1 decision makers liked the fact that Nation Alpha engineers were able to participate directly in the project work and contribute to the design of AlphaSat-R2. Implementer Gamma1 sought a partner that they could work with over multiple projects in a long term partnership. They also appreciated that the offer by Supplier Tau1 included an effort to help them adjust to the new society in Nation Tau. Implementer Gamma1 selected the launch provider directly - this was not done by Supplier Tau1 on their behalf. A professor with ties to Nation Gamma, but based in a different country served as a consultant and helped Implementer Gamma1 make the launch provider and satellite supplier selections. The Implementer Gamma1 team contacted all the potential launch providers that they saw as relevant to small satellites. This included about six to ten companies and governments from around the world. As Implementer Gamma1 compared the proposals of these companies, they compared them in terms of price, the technical reliability of the launch vehicle and the launch schedule. They ultimately selected a service provider that operated shared launches of a group of small satellites. The launch was shared with five other satellites owned by organizations from four countries.

Where was the team located and how did they transition?

During the GammaSat-R1 project, the Implementer Gamma1 project team was generally split. Part of the team was based in Nation Gamma to work on the terrestrial aspects of the GammaSat-R1 system, including the ground station to communicate with the satellite and the system for processing information from the satellite. The team that worked on satellite engineering was nominally based in Nation Tau from project Year 2 through Project Year 5. These engineers traveled back and forth between Nation Gamma and Nation Tau as needed. At times, they attended to organizational meetings or family commitments in Nation Gamma, but they spent the majority of their time in Nation Tau. As one engineer summarized, "We go [to Nation Tau] for three to four months and come back [to Nation Gamma]. We try to finish most of the work there and meet the schedule for each milestone. We don't want to miss any milestones there. When we are here we communicate with [Supplier Tau1] over email. It is convenient for us to do that. We do not want to miss any phase." Implementer Gamma1 engineers were hired at different times and made their initial trips to Nation Tau on individual schedules. Some of the early hires started working at Implementer Gamma1 in Project Year 1 and moved to Nation Tau for the first time in Project Year 2. Another set of engineers was hired in Project Year 2 and moved to Nation Tau later in the same year. Other individuals were hired in Project Year 4 and moved to Nation Tau for a long term stay in Project Year 5. These are just some examples of the individual hiring and moving schedules; engineers were hired in throughout the project.

What were the roles of the engineers based at the supplier location and the engineers based at the home location?

Implementer Gamma1 took the primary responsibility to make assignments of Nation Gamma engineers to specific discipline areas. Supplier Tau1 provided recommendations about the minimum requirements in terms of degrees. The training from Supplier Tau1 focused on satellite design rather than manufacturing of items such as electronics boards. Implementer Gamma1 felt that it would be feasible to outsource those types of tasks and find technicians in Nation Gamma to execute them. Implementer Gamma1 considered the limitations on what they could learn given their finite schedule and personnel resources. Implementer Gamma1 acknowledged that they would need a larger team of engineers working on a longer program to get more in-depth technology training. Implementer Gamma1 chose, however, to do more frequent, shorter projects in order to have more launching events. This approach satisfied stakeholders that wanted to see frequent results. With regard to personnel limitations, Supplier Tau1 encouraged Implementer Gamma1 to choose their training areas strategically. Supplier Tau1 suggested that Implementer Gamma1 assign the engineers to focus on areas that are less available on the world market. The pioneering team of Implementer Gamma1 engineers was assigned to roles in the areas of optics, mechanical engineering, electrical engineering and computer science.

The roles held by each engineer from Implementer Gamma1 were influenced by hiring date. The veterans that were hired in Project Year 1 and Project Year 2 had more substantial opportunities to contribute to GammaSat-R1 and take on leadership positions. For example, one engineer was hired in Project Year 1. He first worked as a trainee in the area of optical payload and was based in Nation Tau. In Project Year 3, he was asked to lead the space activities within Implementer Gamma1. He transitioned to being based at Implementer Gamma1 in Nation Gamma and focused on management. A second engineer was also a veteran that helped define Implementer Gamma1 in Project Year 1 and 2. He initially served as a software engineer focused on attitude control for GammaSat-R1. He was later invited to serve as deputy under the lead for the space activities. He continued his technical work and still spent time in Nation Tau. He also became the Team Leader for the Implementer Gamma1 Software Team. A third veteran that was hired in Project Year 1 to help establish Implementer Gamma1, focused his technical work on software engineering for the onboard software within the satellite. One engineer was hired in Project Year 3 and took on leadership of the ground-based systems for GammaSat-R1. He pioneered and led a small team that prepared to operate the satellite once it was launched. This team also had the role to receive, process and distribute imagery that was taken by the satellite. This team's job included participation in the installation of the antenna system to communicate with the satellite on the Implementer Gamma1 property.

What roles did engineers play upon return to home location?

When GammaSat-R1 launched in Project Year 5, the Implementer Gamma1 team had already agreed with Supplier Tau1 to work together on a second collaborative project to build GammaSat-R2. Thus, the overall schedule continued of some Implementer Gamma1 engineers working primarily at Supplier Tau1 and spending the majority of their time in Nation Tau.

Facilities

The Implementer Gamma1 team was based in a small office building of several stories just outside a major city in Nation Gamma. This was the first building for the new organization and did not yet have all of characteristics that the team would eventually require. During the GammaSat-R1 project, Implementer Gamma1 had limited laboratory facilities for hardware work within their location in Nation Gamma. They did not have laboratories for manufacturing satellite components or assembling satellite systems. During the GammaSat-R1 project, they did set up a ground station for satellite operations and to receive and process the satellite images. They also worked with Supplier Tau1 to transfer a model of GammaSat-R1 from Nation Tau to

Nation Gamma. This model had the functionality of the real satellite. They set up the functional satellite model within their offices at Implementer Gamma1 and connected it to the ground station system. This allowed them to check the operation of the ground system before launch the launch of the satellite. The primary ground station for GammaSat-R1 was in Nation Gamma at the Implementer Gamma1 facility. It included the antenna system, Mission Control Station and Image Receiving and Processing. The Implementer Gamma1 team spent about one month installing and testing it. Two engineers from Supplier Lambda2 and eight Engineers from Implementer Gamma1 worked together to install the ground station and perform Onsite Acceptance Testing. Also, four Implementer Gamma1 engineers went to Supplier Lambda2 for orientation and training for their ground systems. Those Implementer Gamma1 engineers who were based in Nation Tau at the time came to Nation Gamma to help install the ground station. The engineers from Supplier Tau1 were not as involved, although a manager of Supplier Tau1 went to Nation Gamma for the installation of the ground station at Implementer Gamma1. The steps to set up the ground station included site surveys, defining power requirements, checking for obstacles to signal quality, building the foundation, laying cables in a trench, setting up a backup generator, choosing a location for indoor equipment. The team worked long days (6am to 6pm) to complete the project (instead of their normal schedule of ending at 2pm). The Implementer Gamma1 team learned the equipment during the installation process so well that they could address many of the maintenance issues themselves, although they called Supplier Lambda2 when needed.

In addition to the ground station in Nation Gamma, Implementer Gamma1 worked with a company from Nation Kappa (Supplier Kappa1) that operated an antenna farm in North and South Poles. Implementer Gamma1 bought access to some of these antenna and they had spare capacity so they have resold some of that access to a customer. They provide satellite operations service for that customer.

GammaSat-R1 was taken through environmental testing in Nation Tau using facilities owned by the Nation Tau government. Supplier Tau1 did not have these facilities internally.

Training

This section describes preparation for training and training activities at the Supplier firm.

What preparation did trainees have in home country before leaving for supplier location?

The Implementer Gamma1 engineers transitioned to work at Supplier Tau1 at unique times. There was not a specific training program in Implementer Gamma1 to prepare them for the work at Supplier Tau1. The veterans that were hired in Project Year 1 had the formative experience of helping define the technology transfer goals and select the satellite supplier for departing for training. They did some independent study about space as part of this process. Engineers that were hired later had weeks or months to work at Implementer Gamma1 before departing for

Nation Tau. Most did not have previous exposure to space technology. They worked independently to review material about the Implementer Gamma1 project or read related books. Sometimes more experienced Implementer Gamma1 engineers provided informal explanations or tutoring.

What happened during the transition to the supplier location (logistics, orientation)?

The Implementer Gamma1 engineers moved from Nation Gamma to Nation Tau as individuals or in small groups throughout the GammaSat-R1 project. When Implementer Gamma1 engineers arrived in Nation Tau to work with Supplier Tau1, the company helped them arrange housing and logistics. The housing was in a group of apartments located near each other; each apartment was shared by three to four engineers. Supplier Tau1 hired a specific person to the visiting engineers and make logistical arrangements for them. The visiting Nation Gamma engineers had access to cars that they shared – one for each apartment.

What training approaches were used?

The training aspects of the GammaSat-R1 project included technical lectures, non-technical training sessions, mentor assignments, access to learning resources (i.e. books, paper and conference events), hands on training tasks, and on the job training as part of developing GammaSat-R1. These were the general approaches; they were slightly varied in some cases. For the engineers that were hired near the end of GammaSat-R1 with a focus on contributing to GammaSat-R2, the training was less structured. Supplier Tau1 provided many of the Nation Gamma engineers with training lectures and technical presentations. They also had them do activities in mathematics and physics. The lectures were about space technology and space activity in Nation Tau. The lectures were not highly academic, but they contained new information. The lectures covered topics such the company profile of Supplier Tau1, information about the space environment, and the various types of satellites and missions. They included an overview of satellites and how they work and some information about the subsystems. The lecture portion of the training was for less than a month. It was introductory material that helped the Nation Gamma engineers learn about what satellites are, what they can do and what the different sections of satellite are. In addition to the technology-oriented lectures, Supplier Tau1 provided some of the Implementer Gamma1 engineers with training in non-technical subjects including leadership, time management and communication. "These things are also involved in space – how to manage and deal with people, how to know how to communicate in conferences. This is also important. We are trying to maximize the way we work," said one Nation Gamma engineer. Supplier Tau1 invited professors from Nation Tau and international universities to give presentations and training on leadership, communication and team work. The training also included cultural sensitivity and how to communicate with people from different parts of the world. The training facilitator put people in small teams and had them elect a leader and execute a task. The Nation Gamma engineers found it to be unique training that they had not seen before. Several types of resources were available to facilitate independent learning on the part of the

Nation Gamma engineers – such as books, papers and conference events. Textbooks and industry reference books for the various specialties within satellite engineering were provided by both Implementer Gamma1 and Supplier Tau1. The Nation Gamma engineers found it helpful to refer to both books and the internet to learn theoretical information. They also found guidance on techniques for using software languages. The Nation Gamma engineers could access technical papers easily as well. A number of the Nation Gamma engineers attended conferences during the GammaSat-R1 project. Different engineers attended general space conferences as well as specialized meetings on specific aspects of satellite engineering. Most of the conferences were international meetings outside of Nation Tau. Some of the Nation Gamma engineers were able to present papers at these meetings. The ground station team based at Implementer Gamma1 worked hard to present many papers at the meetings of a relevant international society during the GammaSat-R1 project years. The training lectures, readings and conference events provided a foundation for more hands on learning by the Implementer Gamma1 engineers in Nation Tau. They worked on technical training tasks and worked under their Supplier Tau1 mentors to do on-the-job training while contributing to GammaSat-R1. Each engineer was assigned to particular subsystem team within Supplier Tau1. In the beginning the Nation Gamma engineers worked on simplified tasks to help them learn about satellite technology. During this phase, they also used independent reading and studying to learn the basic methods of their subsystem team. This was preparation for getting directly involved with their subsystem work. Overtime, the Nation Tau and Nation Gamma engineers worked more directly together and shared tasks for the GammaSat-R1 project.

How did trainee engineers interact with mentors?

Supplier Tau1 engineers were assigned as mentors for the Implementer Gamma1 engineers, as part of the training experience. Each mentor was chosen because they were highly qualified by experience or education. The Nation Gamma engineers were invited to work closely with these Nation Tau colleagues. One Supplier Tau1 engineer described his approach to mentoring as trying to involve the trainees in the tasks he was doing and to explain the types of challenges he faced. He would also explain the proposed solutions they were trying. He gave the trainee some specific responsibility, such as for the completion of one segment of the satellite subsystem. Another engineer from Supplier Tau1 was a mentor for several engineers from Implementer Gamma1 during GammaSat-R1. In his approach to mentoring, he first tried to understand what the trainee was interested in and then he directed the trainee to focus on some specific part of the system. The Implementer Gamma1 engineers found the Nation Tau team at Supplier Tau1 to be open with sharing information; they made themselves available as mentors. Sometimes Implementer Gamma1 engineers were mentored by multiple Supplier Tau1 engineers. As one example, a Nation Gamma engineer was assigned an official mentor, but he worked with and received support from at least three people regularly – a supervisor, an advisor and an engineer he partnered with. Some mentors helped the Nation Gamma engineers outside of work with issues such as communication, activities and purchases. The Nation Gamma engineers generally shared office space with their mentors from Supplier Tau1 in the small supplier facility. Depending on the personal style and project needs, they had both formal and informal meeting schedules between mentors and mentees. The work assignments and accountability system for the Nation Gamma engineers was informal and driven by the project activities.

Policy, Social and Cultural Issues

Implementer Gamma1 dealt with both national and international policy issues during the GammaSat-R1 project. The national issues related to establishing Implementer Gamma1 as a government organization and receiving government approval and funding for the program in space. At a high level, the Nation Gamma policy makers recognized that some of the value for the satellite projects came from the technology training experience during the project. They did not wait to see if GammaSat-R1 launched successfully before funding the next generation GammaSat-R2. Even though Implementer Gamma1 was officially under a regional government, the team saw it as a national program. Internationally, Implementer Gamma1 addressed issues such as ITAR and ITU requirements. Implementer Gamma1 learned how to do the ITU frequency registration and they worked with the national regulatory body for telecommunications that handles such issues. Implementer Gamma1 did not go directly to ITU, but worked through the national telecommunication regulatory. This regulator had experience because they did registration for other satellites owned by operators in Nation Gamma. There were international trade restrictions that influenced the parts sourced for GammaSat-R1. This was not a major barrier, but did affect some aspects of the design.

Implementer Gamma1 was a nationally defined team that was committed to execute GammaSat-R1 and other projects for the benefit of Nation Gamma. The engineers expressed a sense of pride to contribute to their country. Because Implementer Gamma1 chose to primarily hire recent graduates for the GammaSat-R1 project, the characteristics of the Nation Gamma education system were influential on the program. The Implementer Gamma1 engineers had a variety of experiences for their primary, secondary and tertiary education. The national system of primary education in the Nation Gamma has a common curriculum for all students. The language of instruction is the local language, but an international language is taught as a second language. Several of the Implementer Gamma1 engineers attended such national primary schools. There are also international primary schools where international languages are the primary medium. For secondary schools in the Nation Gamma system, students are taught in the local language and they have the opportunity to choose whether to focus on arts or science. There are also international secondary schools based on various systems. There are both local and internationally affiliated universities in the Nation Gamma; both tend to teach primarily in an international language. The Nation Gamma government also offered scholarships for some students to study abroad in advanced countries. The engineers that went to work in Implementer Gamma1 represented all of these different educational paths. It was common for university students to do short internships during school breaks in the Nation Gamma. The universities in the Nation Gamma did not specifically train in space technology, although there were majors in aerospace engineering and remote sensing. There were Bachelor and Masters programs in Remote Sensing and GIS, but they are stronger in GIS than remote sensing. So people are more trained in how to use data than in how to generate it.

The Implementer Gamma1 engineers moved to Nation Tau and some lived there for several years during the GammaSat-R1 project. The Implementer Gamma1 engineers had a variety of initial impressions to life in Nation Tau. Some found that they adapted well to life in Nation Tau and enjoyed living there. Others felt that they experienced culture shock, but also looked forward to the challenge of learning about an unfamiliar place. Some of the major differences that the Implementer Gamma1 engineers faced in Nation Tau were moving to a smaller city, eating new food, dealing with a language barrier and facing a culture where the Nation Gamma religion was not common. In Implementer Gamma1, the working language was flexible. People wrote documents in both local and international languages, according to their preference. In Supplier Tau1, the Nation Tau engineers use their national language among themselves and they initially relied on an international language to speak to the engineers from Nation Gamma. They also offered Nation Tau language classes to help the Implementer Gamma1 engineers adapt to life in Nation Tau. In terms of work culture Supplier Tau1 was not very hierarchical or formal, although they did have useful, systematic methods. The Implementer Gamma1 engineers did need to adjust to a very different work schedule. At Supplier Tau1, they worked longer hours and had different days off. The Nation Gamma and Nation Tau teams sometimes interacted socially outside of work. They may have meals together or play sports.

9.4 Nation Delta

This section summarizes the DeltaSat-R2 project, which was a partnership with Supplier Sigma1.

Initiation and Approval of Satellite Project

In preparation for the DeltaSat-R2 project, Nation Delta investigated both the needs of the data user community and the potential sources from which to buy a satellite. Starting three years before signing the contract with Supplier Sigma1, Implementer Delta1 held a series of workshops for the user community. The documents produced through the workshops contained mission requirements for the data which the satellite should produce to address the needs of potential users. In order to understand the options for procurement of the satellite, Nation Delta conducted a survey, during which government officials traveled to visit space related organizations in other countries. Ultimately, Supplier Sigma1 was selected as the prime contractor, and a contract was signed between Implementer Delta1 and Supplier Sigma1.

The Project Team

This section describes the roles of organizations and personnel in the project.

Which Organizations were involved with the project and how were they related?

Implementer Delta1 played a leadership role within Nation Delta on matters pertaining to geospatial information, including satellite data. For example, Implementer Delta1 was the secretariat for the Nation Delta government's national committee on Geographic Information Systems. For the DeltaSat-R2 project, Implementer Delta1 worked with Supplier Sigma1 as the prime contractor. Supplier Sigma1's role was to manage the official interactions with subcontractors for satellite hardware, ground systems and for launch. While the Nation Delta trainee engineers were in Nation Sigma, they sometimes interacted with subcontracting companies as part of their training experience. The Nation Delta engineers were not the only trainee team at Supplier Sigma1 at the time; there were also engineers from several other customer countries. The Nation Delta engineers did not have much interaction with these fellow trainees. They did not have social activities in common and they were kept separate in their work stations. Once satellite was launched, the DeltaSat-R2 team worked closely with the section within Implementer Delta1 that process data. These groups provided an interface between the DeltaSat-R2 operation team and the end users of DeltaSat-R2 data.

How were local engineers selected to join the project?

When Implementer Delta1 embarked on the DeltaSat-R2 project, it did not have personnel with a background in satellite technology. As discussed above, only one university in Nation Delta had a program focused on satellite technology. There were related degrees available at some Nation Delta universities, covering topics such as aerospace engineering (with a focus on aeronautics), telecommunication and satellite data applications. Implementer Delta1 chose to hire a new team of engineers to experience the training at Supplier Sigma1 and work as the core satellite operation team. The hiring experiences of the twenty Nation Delta trainees were all slightly different. From the leadership perspective, the approach was to recruit broadly using internet and other mass media. They asked applicants to submit applications and they conducted a series of interviews. Representatives from Implementer Delta1, Supplier Sigma1 and the Nation Sigma Embassy participated in the interviews. The applicants were not given exams; they were evaluated based on their educational backgrounds and majors. The three engineers that represented the Nation Delta military were selected through a unique process. They had to take a test to be selected. Eighteen of the twenty engineers for the DeltaSat-R2 team did not work for Implementer Delta1 before the satellite project. They came from a variety of previous experiences, but they generally had limited exposure to space technology. Some had recently completed graduate school abroad; some were in military organizations; and some were working in domestic industry. Implementer Delta1 leadership sought to hire engineers with work experience or with graduate study, rather than graduates fresh from their first degrees.

How was a firm selected as the supplier for the satellite system and training?

A committee representing several organizations in Nation Delta worked to select the supplier for DeltaSat-R2. Nation Delta representatives considered other potential suppliers and visited international space facilities as part of the selection process and feasibility studies. Supplier Sigma1 was found to be a trustworthy supplier because of their experience with previous high resolution earth observation satellites.

How was the launch provider selected?

As Prime Contractor, Supplier Sigma1 provided launch services and managed the relationship with the launch service provider on behalf of Implementer Delta1. During the project, there was a need to change from one launch vehicle to another due to challenges faced by the launch vehicle manufacturer. There was no major impact on the satellite from this change as DeltaSat-R2 was initially designed to be compatible with both launch vehicles.

Where was the team located and how did they transition?

Twenty engineers from Nation Delta spent almost two years in Nation Sigma at Supplier Sigma1 between Project Year 2 and Project Year 4. The team of 20 arrived in Nation Sigma two batches because of their hiring times. They left Nation Sigma in several batches, according to their role in operations. Personnel from Supplier Sigma1 also visited Nation Delta. During the year between the return of the Nation Delta trainees and launch, a Supplier Sigma1 team worked in Nation Delta to set up and commission the satellite operation system.

What were the roles of the trainee engineers while at the supplier location?

While the 20 engineers from Nation Delta were in Nation Sigma, they were assigned to specific roles within a technical team. These roles would eventually form the basis for their responsibilities as operators back in Nation Delta. The specific roles were chosen based on Supplier Sigma1's conventional team structure. The Nation Delta engineers were placed in their positions based on their educational background and experience, with some input from the engineer where possible. It included positions such as satellite manager, system engineer and subsystem specialists such as Mechanical, AOCS (Attitude and Orbit Control System), Power, Thermal, Software and Payload. A satellite manager has the job of coordinating and monitoring the work of all the satellite subsystem engineers. The Systems engineer is concerned with the interfaces in the whole system, including the spacecraft and the ground station. As the two year training period came to an end, the team roles were re-defined to focus on operations. Another responsibility of the trainee engineers was to be the monitoring team on behalf of Implementer Delta1 to ensure that Supplier Sigma1 provided a strong product. There was a committee of engineers that advised Implementer Delta1 management.

What roles did engineers play upon return to home location?

During Launch and Early Operations, Supplier Sigma1 personnel led the technical activities and the Implementer Delta1 team supported them. After about 2 months, the spacecraft was handed over to Implementer Delta1 and the core engineers began practicing their new operational roles independently.

Facilities

Supplier Sigma1 owned and operated all the fabrication and testing facilities used for DeltaSat-R2. Supplier Sigma1 installed several new facilities in Nation Delta as part of the DeltaSat-R2 project. While the trainee engineers were still in Nation Sigma, Supplier Sigma1 started building up the satellite control rooms and receiving dishes. When the Implementer Delta1 engineers returned from Nation Sigma, much of the ground system infrastructure was already in place. Implementer Delta1 initially intended to put the DeltaSat-R2 Ground Control Station in its facility in a major Nation Delta city. Later it was found that another location was needed in order to avoid communication frequency interference with the nearby airport. The Ground Control Station and antenna were installed in a small Nation Delta city about 150 km from the main Implementer Delta1 facility. A secondary Implementer Delta1 facility was established in this smaller city to host the Ground Control Station. The antenna for receiving imagery was installed at Implementer Delta1's primary facility. Nation Delta also bought access to a polar antenna farm in the far north that provided additional access to the satellite.

Training

This section describes the preparation for training and the training activities at the Supplier Firm.

What preparation did trainees have in home country before leaving for supplier location?

Some of the new hires for the DeltaSat-R2 training team had several months after they started working for Implementer Delta1 before they moved to Nation Sigma. A few were hired later and went to Nation Sigma immediately. Before leaving for Nation Sigma, most engineers prepared by reviewing technical documents and taking an introductory Nation Delta language course.

What training approaches were used?

During their time in Nation Sigma working at Supplier Sigma1, the Nation Delta trainee engineers experienced various phases of training activities, each with a different emphasis. The first phase focused on lecture-based courses; next the whole team worked on a group project. In the third phase, each engineer worked with a mentor for On-the-Job Training (OJT) which included observation of integration work or subcontractor facilities in some cases. The last phase of the training focused on operations. Throughout the project, some of the engineers also had oversight responsibility for Supplier Sigma1 on behalf of Implementer Delta1.

The first phase of training used lecture-based courses to introduce the Nation Delta engineers to satellite technology. These courses were offered as part of an academic curriculum regularly presented by Supplier Sigma1. The team arrived in the middle of Project Year 2, and the coursework extended for 9 months. The first 3 months included basic courses on satellite engineering and the space environment. Then there were 6 months of advanced courses on specific satellite subsystems. Everyone attended all the courses, even though they would later be specializing on particular subsystem or team roles. The Nation Delta engineers took exams on the course material. The format and difficulty level of the exams varied.

The Nation Delta engineers completed the basic and advanced courses around the end of 2005. They next entered into a four month group design project. For the group project, Supplier Sigma1 gave the trainee team the assignment to do an initial design for a remote sensing satellite that was based on the DeltaSat-R2 design. Supplier Sigma1 acted as the customer in this scenario and provided requirements to the Nation Delta team. Supplier Sigma1 also provided technical assistance. The Nation Delta trainees organized themselves into a team based on their disciplinary assignments On-the-Job Training. The outcomes of the project were a presentation and design document. During the project, the group applied part of the project review cycle utilized by Supplier Sigma1. They presented for three design reviews. At the last review the team delivered a final report including a data package and presentation. The scope of the design work included selecting an orbit, choosing the satellite architecture, designing a ground segment and choosing a launcher. The DeltaSat-R2 design was used as a baseline but the payloads were slightly different. The team focused first on understanding the DeltaSat-R2 design and proposed modifications to fit the new requirements.

After the group design project, the Nation Delta trainees started the On-the-Job Training phase at Supplier Sigma1. Each Nation Delta trainee was assigned to one or more mentors from a particular subsystem team or specialty role. During this phase, each engineer had a unique experience based on the type of work they were assigned by their mentor. Overall, the Nation Delta team was seen as a customer needing training, not as a joint engineering partner. Most mentors assigned their trainees to do specific hardware or software tasks, but these tasks were primarily training assignments that did not contribute directly to completing the satellite projects. Some Nation Delta engineers had the opportunity to participate in Assembly, Integration and Testing for DeltaSat-R2, such as the thermal, vibration and shock tests. The OJT experience was a mix of hands on work and observation. In some cases Nation Delta trainees visited clean rooms, toured labs, observe how Supplier Sigma1 interacted with external manufacturers, or visited subcontractor facilities.

The final phase of the training in Nation Sigma was focused on operations. The operational training continued when the Nation Delta trainee team returned to Nation Delta. For a few months before leaving Nation Sigma, Supplier Sigma1 team helped the Nation Delta trainees transition into an operations team. They taught the Nation Delta engineers how to use the Supplier Sigma1 operations hardware and software. A key part of the training focused on responding to unexpected behavior by the satellite. The Supplier Sigma1 engineers taught the Nation Delta team to carefully assess any problem on the satellite before taking action. They also introduced the standard procedures for responding to common problems. To test the learning of the Nation Delta team, they used a simulation system that mimicked the satellite. For about one year after the trainee team returned to Nation Delta, the training continued. Two Supplier Sigma1 employees stayed in Nation Delta for that year and provided the Operation Qualification, which certified the Nation Delta engineers to operate DeltaSat-R2.

Throughout the time in Nation Sigma, the trainee team had an additional responsibility that influenced their workload. They were the on-sight representatives of Implementer Delta1 as a customer to Supplier Sigma1. They were tasked to provide technical oversight of the DeltaSat-R2 project and to provide recommendations to Implementer Delta1 management about concerns. Specifically, the trainee team reviewed documents produced by Supplier Sigma1 for project milestones and reviews. There were also documents to review regarding the launch provider. The trainees assisted the Implementer Delta1 Inspection Committee by reviewing these technical documents and issuing formal questions for Supplier Sigma1 with requests for clarification or further actions.

The Nation Delta trainee team received support from Supplier Sigma1 in social and cultural activities. Supplier Sigma1 arranged for them to be offered classes in the Nation Sigma language and to participate in several tourist trips. These activities and the whole training package were organized by a specific person designated as the Supplier Sigma1 Training Manager. In some cases the Nation Delta engineers also spent time socially with their mentors from the Supplier Sigma1 team. Throughout the two year training experience, Implementer Delta1 management monitored the progress of the Nation Delta trainees via weekly and monthly reports. The Nation Delta leadership also attended some of the presentations and reviews in both Nation Sigma and Nation Delta.

How did trainee engineers interact with mentors?

A central aspect of the OJT experience was the relationship between the Nation Delta trainees and their Supplier Sigma1 mentors. Each Nation Delta trainee was assigned to work one or more mentors. This assignment reflected the area of specialty that they were learning. Mentors had flexibility in how they assigned tasks; mentors also defined the expectations for how work was achieved.

Policy, Cultural, Social Issues

This section describes domestic and international policy concerns and cultural or social issues during the project.

Where there domestic policy concerns for supplier or implementer?

In terms of trade policy, the Nation Delta government sought to achieve a balance of trade as they procured the satellite. They made an agreement that Nation Sigma would purchase agricultural products throughout the project period. The purchases from Nation Sigma were intended to off-set the cost of the satellite project. Once DeltaSat-R2 was launched, the

Implementer Delta1 team felt an urgency to demonstrate the usefulness of the project in order to ensure government support for future projects. The cost of the DeltaSat-R2 project was high relative to Implementer Delta1's traditional budget.

Where there international policy concerns?
International policy issues led to a launch delay. Two countries that were involved with the launch had a disagreement about range safety for the launch operations. The dispute was happening while DeltaSat-R2 was loaded into the launch vehicle. Supplier Sigma1 took the lead in managing this problem, with support from the Nation Delta and Nation Sigma governments.

How did cultural, social and regional issues impact project?
The Nation Delta trainee engineers faced social and cultural transitions when they were brought together and hired to work on DeltaSat-R2. The project involved three languages – the local language of Nation Delta, the local language of Nation Sigma and the international language in which the Implementer Delta1 and Supplier Sigma1 teams worked together. Most Nation Delta engineers spoke the international language secondarily and had little or no experience with the local language of Nation Sigma. The working language of Supplier Sigma1 was officially an international language, but the setting around the company was dominated by the local Nation Sigma language. The Nation Delta engineers studied the Nation Sigma language for a few months, but the course only provided an introduction to the language. The trainees did not use the Nation Sigma language for advanced conversation or engineering work. The Nation Delta engineers had different levels of skill in speaking the international working language. Those that were less confident struggled initially. Some of the Nation Delta engineers had already lived and studied abroad; for them the transition was easier. Overall, there were some language challenges because both teams had to operate in a second language in order to collaborate.

The team of Nation Delta engineers was newly formed for the DeltaSat-R2 project. As they entered the foreign setting of Supplier Sigma1, they did not yet have a rapport for working together effectively. This caused challenges in their team dynamics. The Nation Delta team sometimes asked the Supplier Sigma1 team to intervene and help address team relationship challenges.

10 Appendix B: Interview Material

This Appendix provides the interview questions used for Implementer and Supplier Representatives. The questions shown here make up the complete list of potential questions. During each interview, the actual set of questions was tailored to the individuals. Based on the individual's description of their career path and responsibilities, the relevant questions were selected from the larger set.

10.1 Interview Questions for Implementer Representatives

Part A: Introduction

1. Please describe your current position and responsibilities within your organization. What are the duties of your position?
2. How long have you worked for your organization? How did you come to work for your organization?
3. What is your educational background? Please tell us about your formal academic training.
4. Please tell us about your career path. (if necessary)
5. What was your role in the satellite project?
6. Did you have any other responsibilities outside of that role for your organization?
7. How did the project compare with your previous work or educational experiences? In what ways was it similar or different?
8. Which organizations were involved in the project? How would you describe the roles of each organization?
9. As part of your work on the project, did you interact directly with the supplier or other firms?
10. Please describe your work activities in the supplier nation.
    a. Did you have a primary mentor or point of contact within the supplier firm?
    b. Where you working in the supplier nation?
11. What expectations did you have for working with the firm? Would you say your expectations were fully met, partially met or not met at all? Why do you say so?

Part B: Capability Building Process

12. What were the objectives of the technology transfer aspects of the project?
13. What methods were used to address and monitor these objectives?
14. How did your work activities change during different phases of the satellite project?
15. What was the project review cycle? How was it implemented? What role did you play during project reviews?
16. What teams at the supplier firm did you work closely with during the project?
17. What are some examples of your accomplishments during the satellite project individually?
18. What accomplishments did you see at the ....Small team level? Large group level?
19. From your perspective, what were the primary needs that your organization sought to address by executing the satellite project? In other words, what benefits does the satellite project provide?
20. Now that the satellite is nearly finished being built, please think back to the beginning of the project. What aspects of the project surprised your or changed drastically since the beginning?
21. Do you think the satellite project was risky – either financially, technically or in other ways? Why or why not?
22. From your perspective, what aspects of the satellite project went very well? Why do you think they were so successful?
23. From your perspective, what aspects of the satellite project did not meet your expectations? Why do you think they were less successful?

24. Is there anything else you want to tell us about the satellite project?

Part C: Architecture & Context of the Project

25. Did your organization consider other methods besides the satellite projects to address national goals? In your opinion, did the satellite project provide the desired benefits? Do you think the satellite project was the best way to provide these benefits?
26. Was there a particular person or small team of people that took the lead in shaping the satellite project and making key, early decisions?
27. Were you involved with the decision to execute the satellite project? Which people and organizations were involved with making the decision to execute the project? What role did you play in the decision making process?
28. Were you involved with the decision to work with the firms that participated in the project?
    - *a.* Which people and organizations were involved with making the decision to work with the firm? What role did you play in the decision making process?
    - *b.* What were the major motivations for working with this firm?
    - *c.* Were there any areas of concern about working with this firm? Please tell us more about them.
    - *d.* Were other firms considered? How was the final decision made?
29. Within your country, were there any regulatory issues that have influenced the execution of the satellite project or the formation of the space agency? Were there any regulatory issues involved with working with the firms?
30. What has been the political context surrounding the satellite project?
31. Did you see any impacts to the project from the global economic environment in general? How about the global economic environment for space technology?
32. Are there any features of your country's natural environment that motivated or influenced the satellite project?
33. Are there other government agencies or private enterprises in your country that are concerned with space technology?
34. What are the long term goals of the space agency? How does this satellite project fit into the long term goals?
35. Let's talk about the community that will use the satellite data generated by the project.
    - a. What kinds of organizations are included in the user community? Will you please give some specific examples?
    - b. How were these potential users included in the execution of the satellite project?
36. Please describe operations for the satellite.
    - a. What role did the firm play in satellite operations?
    - b. Were there any new facilities or pieces of equipment required to do satellite operations here?
    - c. What is the funding source for satellite operations? Is it the same as for the satellite itself?
    - d. How does the funding for operations compare to the satellite?
37. Please describe the overall structure of your organization.
    - a. Why is it structured this way? What is the logic behind it?
    - b. Do you have documentation about the organizational structure, such as an organizational chart?

    c. In your opinion, is the space agency organization more hierarchical (meaning it has many vertical levels and a clearly defined chain of authority) or horizontal (meaning that it has few vertical levels and many divisions with equal authority)?
38. What are the 3 to 5 most important activities executed by the space agency? How would you describe the teams or groups that execute these important activities?
39. Who are the individuals with whom you work mostly closely in the space agency?
    a. What are their positions in the space agency?
    b. Do you work primarily with people in similar or different sections of the space agency than yours?
    c. What method did you usually use to interact with them – did you connect with them via email, phone, or in-person meetings perhaps?
40. What are the top 3 to 5 most important areas of intellectual strength in the space agency?
    a. Have these areas changed over time? What effort or choices facilitated this change?
    b. For your specific section of the space agency, are there any areas of knowledge in which the team wants to grow?
    c. What strategies or methods are you using to increase your knowledge in these areas? How do you feel this is progressing?
41. Does your team share knowledge or information with...
    a. Other teams in the space agency? (Please explain)
    b. Teams other government offices? (Please explain)
    c. Teams in non-government organizations or private companies? (Please explain)
42. Does your team have a particular way to capture or replace knowledge when an individual leaves the team?
43. Let's talk more about policy making with respect to the space agency. How would you describe the policy process that facilitates space agency activities?
44. Which government organizations are involved in setting the space agency's budget?
    a. What are the specific roles of the individual government organizations?
    b. Which government organizations are stakeholders that can influence the agency's choice of activities?
45. How would you describe the stability of the policy making process for the space agency since it was founded? Why do you think it happened this way?
46. Have there been any specific political debates surrounding space agency activities? If so, please explain.
47. How is the military involved with the space agency? Does the military do independent space activity that does not involve the space agency?
48. How are universities involved with the space agency?
49. Is there anything else that you think we should consider with regard to government policy and the space agency?
50. Who would you say are the people or organizations that the space agency serves? That is, who is like the customer for the space agency?
    a. What are the needs of these customers?
    b. What goals does the space agency set in order to meet these needs?
    c. What activities does the space agency do in order to meet these needs?
51. Do you think your country should continue to build and operate satellites?
52. What do you think the space agency should focus on in the future?

10.2 Interview Questions for Supplier Representatives

Part A: Introduction

1. What are your current position and duties in your firm? How long have you held this position?
2. What is your educational background and career path?
3. Please describe the meetings, deadlines and activities that make up your typical week or month.
4. In your current position, which other organizations from inside and outside your firm do you work closely with?
5. Which projects that included training were you involved in? What were your role and responsibilities in each of these projects?
6. When did you get involved with the project? How long did you continue to work on the project?
7. Was the project your main assignment at this time?
8. How did working on this project compare with your previous career experiences? In what ways was it similar or different?
9. Which organizations were involved in the project? What were the roles of each organization?
10. How was the supplier project team organized for this program?
11. Did you interact directly with a client representative in a particular position?
    a. What was the position of the people you interacted with most?
    b. What media did you usually use to interact with them – did you reach them via email, phone, or in-person meetings perhaps?
    c. What topics did you commonly discuss with your contacts from the client?
    d. How does your work with these contacts fit in with the overall project?

Part B: Capability Building Process

12. What was your role in the training aspects of the project?
13. Please describe the components of the training program for the project – such as lectures, engineering assignments, courses at university, reviews etc.
14. What did you view as the objectives of the training program during the project?
15. What methods were used by the firm to achieve those objectives and to monitor their achievement?
16. What accomplishments did you observe for the trainee engineers at various levels
    a. Individual?
    b. Small team?
    c. Large group?
17. What expectations did you have for working with the client? Would you say your expectations were fully met, partially met or not met at all? Why do you say so?
18. From your perspective, what aspects of the satellite project went very well – consider both the satellite and training aspects? Why do you think they were so successful?
19. From your perspective, what aspects of the satellite project did not go as well – consider both the satellite and training aspects? Why do you think they were less successful?
20. Do you think the satellite project was risky – either financially, technically or in other ways?
    a. (If not…) Please explain why you think it was not risky.
    b. (If so…) What aspects of the project made it risky?
21. What would you say were key sources of uncertainty during this project?

a. (If necessary…) Now that the project is finished, please think back to the beginning of the project. What aspects of the project surprised your or changed drastically since the beginning of the project?

22. What were the primary needs that the client sought to address by executing the satellite project? In other words, what motivated the client to pursue the satellite project?
    a. (If necessary…) I'm interested in technical, economic, political, social as well as other types of motivations.
23. What kinds of organizations are included in the satellite data user community? Please give some specific examples?
    a. How were these potential users (or their interests) included in the execution of the satellite project?
24. Once the satellite was built, who operated it (Or who will operate it)?
    a. What role did your firm play in satellite operations?
    b. Were there any new facilities or pieces of equipment required to do satellite operations?
    c. What is the funding source for satellite operations?
        i. Is it the same as for the satellite itself?
        ii. How does the funding for operations compare to the satellite?
25. How did the complexity of the satellite project align with the competence of the client?
26. [Were there any key technical decisions that drove the complexity, cost or schedule for the project?
27. Is there anything else you want to tell us about the satellite project?

Upstream and Downstream Influences on the Satellite Project Architecture

28. During your time at the firm have you observed occasions when there were multiple training teams at the firm during the same time?
    a. What were the pros and cons of having multiple teams here simultaneously?
29. Please describe the overall organizational structure of your firm.
    a. Why is it structured this way? What is the logic behind it?
30. In your opinion, is your firm's organization more vertical (meaning it has many vertical levels and a clearly defined chain of authority) or horizontal (meaning that it has few vertical levels and many divisions with equal authority)?
31. As part of your work on the project, did you interact directly with the client?
    a. (If so…) Did you interact with someone in a specific position that represented the client?
        i. What was the position of the person you interacted with most?
        ii. What media did you usually use to interact with them – did you reach them via email, phone, fax or in-person meetings perhaps?
        iii. What topics did you commonly discuss with your contacts from the client?
        iv. How did your work with these contacts affect (or fit in with) the overall project?
32. Were you involved with the negotiations regarding the contract for this satellite project?
    a. Can you tell us a little about the negotiation process?
33. How did working on this project fit into your firm's overall business strategy?
34. From your firm's point of view, were there any regulatory issues that influenced the execution of this satellite project or working with the client? (i.e. export control, etc)

35. Were you aware of any political context surrounding the satellite project?
36. Did you see any impacts to the project from the global economic environment in general? How about the global economic environment for space technology?
37. Who were the competitor firms that could also be considered for such a project?