The Use of Satellite-Based Technology in Developing Countries

by

Danielle Renee Wood

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

Submitted to the Department of Aeronautics and Astronautics and the Engineering Systems Division
In Partial Fulfillment of the Requirements for the Degrees of

Master of Science in Aeronautics and Astronautics
and
Master of Science in Technology and Policy

at the
Massachusetts Institute of Technology
September 2008

Author____
Department of Aeronautics and Astronautics and the
Technology and Policy Program, Engineering Systems Division
August 8, 2008

Certified by____
Annalisa L. Weigel
Assistant Professor of Aeronautics and Astronautics
and Engineering Systems
Thesis Supervisor

Accepted by____
Dava J. Newman
Professor of Aeronautics and Astronautics
and Engineering Systems
Director, Technology and Policy Program

Accepted by____
Prof. David L. Darmofal
Associate Department Head
Chair, Committee on Graduate Students
Department of Aeronautics and Astronautics

The Use of Satellite-Based Technology in Developing Countries
by
Danielle Renee Wood

Submitted to the Department of Aeronautics and Astronautics and the Engineering Systems Division
on August 8, 2008,
in Partial Fulfillment of the Requirements for
the Degrees of Master of Science in Aeronautics and Astronautics and
Master of Science in Technology and Policy

Abstract

Satellite technology in the areas of remote sensing, communication, and navigation can provide valuable information in a number of areas from business to disaster management to agriculture. There is great potential for such technology to help solve problems in developing countries. Unfortunately, due to lack of funds, expertise, equipment or awareness, developing countries are not using satellite technology to its full potential. This thesis is motivated by a desire to increase and improve the use of satellite-based technology in developing countries. Three Research Questions guide the study. Question 1 is, "How does national development level relate to national space activity?" For this question, national development level is measured by a series of Development Indicators such as Gross Domestic Product. The level of space activity is measured using a Space Participation Metric that is created by the author. Statistical analysis is used to learn if there is any significant difference in the space activity of countries at different development levels. Research Question 2 asks, "What Mission and Management Architectures are developing countries using to apply satellite-based technology to national needs?" The data used to answer this question comes from 90 Space Project Case Studies about satellite-enabled activities in Africa. The information from the Case Studies is organized so that trends can be found in the accomplishments of the projects. Research Question 3 asks, "How does national development level influence the Mission and Management Architectures used by developing countries in satellite-based technology projects?" This question builds on the data from Research Question 2. Statistical analysis is used to determine if African countries at different development levels perform differently in the Space Project Case Studies. In addition to addressing these three Research Questions, this study explores the policy context of African countries through a series of interviews. Thirty interviews were held with representatives from African embassies in the United States. The interview questions explore the institutional structure of the country's National Innovation System. To summarize the results, the analysis for Question 1 shows that there is a significant difference in the space activity of countries at different development levels. Question 2 shows that most African space projects involve either one African country or a collaboration with a non-African partner. The third Research Question shows that there is a significant difference in the level of technical expertise and programmatic leadership shown by African countries at different development levels. This study closes with policy recommendations for developing country policy makers about next steps for using satellite-based technology.

Thesis Supervisor: Annalisa Weigel
Assistant Professor, Aeronautics and Astronautics and Engineering Systems Division

Acknowledgements

It has been a great adventure to arrive at this point in my academic career. When I was an undergraduate at MIT, I was not confidant that I could succeed in graduate school. I must thank Prof Charles Coleman for speaking words of belief and encouragement about my abilities back then. As I began graduate school, I wanted to do research on this topic, but I did not know how to make it happen. I have been supported and guided by many helpful people. I thank Daniel Irwin of NASA and Ayanna Samuels (Dual SM at MIT, 2005) who showed me how my interests in international development and aerospace engineering could be combined in a practical way. I also thank Prof David Miller who was my academic and research advisor for parts of my undergraduate and graduate career at MIT. He consistently encouraged my ideas and plans, even when they inconvenienced him.

I thank Prof Annalisa Weigel who has advised me through this research process. It has been an honor and joy to work with her. I appreciate the way she encourages me to take initiative with my research.

I am thankful also for my experiences with the NASA Academy internship. It was during this summer program in 2004 that I discovered two things. First, I learned that I definitely wanted to go to graduate school and, second, that I wanted to find a way to research the use of satellites in developing countries.

I am also thankful for the various graduate fellowship programs that have made it possible for me to pursue this line of research. This includes the NASA Harriett Jenkins Pre-Doctoral Fellowship Program, the Departmental Fellowship from Aeronautics and Astronautics at MIT, the National Science Foundation and the National Defense Science and Engineering Graduate Fellowship.

On a personal note, I thank my husband, Jonathan, for being willing to date me and marry me even while we lived in two different states so that I could complete my Masters degrees. I also want to thank my parents and brothers for all the ways they have encouraged my interests over the years. Thank you for supporting me when I traveled to Kenya and South Africa to learn and serve. Thank you for believing that I could pursue all of my interests, from acting to engineering to language to salsa dancing. I am very thankful to God who has guided me through out this adventure and has placed all of these special people in my life.

Author Biography

Danielle Wood, formerly Danielle Adams, received her Bachelor of Science degree from MIT in Aeronautics and Astronautics with a Minor in Spanish in 2005. As an undergraduate, Danielle studied abroad at the Center for Cross-Cultural studies in Spain. She also traveled several times to Kenya to volunteer with homeless children. Since starting her university career Danielle has held several research positions at MIT and NASA centers. After completing her S.B., Danielle worked as the Operations Manager for the NASA Academy internship program at the Goddard Space Flight Center in Maryland in 2005. Danielle is the recipient of several federal, graduate fellowships including the NASA Harriett Jenkins Pre-doctoral Fellowship, the National Science Foundation Graduate Research Fellowship, and the National Defense Science and Engineering Graduate Fellowship. Danielle has presented posters and talks at several conferences including the NASA Institute for Advanced Concepts (2004), and the AIAA Regional Student Conference (2005), the Chapman Conference on Venus Exploration (2006). Danielle plans to continue her education in the Engineering Systems Division doctoral program. She married Jonathan Wood in 2007.

Table of Contents

List of Figures

List of Tables

List of Abbreviations

AEB	Agencia Espacial Brasileira (Brazilian Space Agency)
AGRHYMET	Agro-Hydro-Meteorological Regional Center (Niger)
ARMC	African Resource Management Constellation
ASECNA	Agence pour la Securite de la Navigation Aerienne en Afrique et a Madagascar (Agency for the Safety of Aerial Navigation in Africa and Madagascar)
COPUOS	Committee on the Peaceful Uses of Outer Space
EGNOS	European Geostationary Navigation Overlay Service
ESA	European Space Agency
ESL	Electronic Systems Laboratory (at Stellenbosch University in South Africa)
FEWS NET	Famine Early Warning System Network
GDP	Gross Domestic Product
GEO	Geostationary Orbit
GIS	Geographic Information System
GLONASS	Russia's Global Navigation Satellite System
GPS	Global Position System (United States)
GVF	Global VSAT Forum
HD Level	Human Development Level
HDI	Human Development Index
IAF	International Astronautical Federation
ICT	Information and Communication Technology
IMSO	International Mobile Satellite Organization
INTELSAT	International Telecommunications Satellite Consortium
IRNSS	Indian Regional Navigational Satellite System
ISRO	Indian Space Research Organisation
ITSO	International Telecommunications Satellite Organization
ITU	International Telecommunications Union
LEO	Low Earth Orbit
MARA	Mapping Malaria Risk in Africa
MDG	Millennium Development Goals
NASA	National Aeronautics and Space Administration
NIS	National Innovation System
NRC	National Research Council
OECD	Organisation for Economic Co-operation and Development
PSA	Program on Space Applications (United Nations)
PPP	Purchasing Power Parity
RASCOM	Regional African Satellite Communication Organization
SBT	Satellite-Based Technology
SPM	Space Participation Metric
SSTL	Surrey Satellite Technology Limited
UN	United Nations
UNISA	University of South Africa

UNISPACE	United Nations Conference on the Exploration and Peaceful Uses of Outer Space
UNOOSA	United Nations Office of Outer Space Affairs
US AID	United States Agency for International Development
VSAT	Very Small Aperture Terminal
WTO	World Tourism Organization

1 Introduction

Technology that is enabled by satellites holds great potential to meet significant needs in developing countries. Specifically, satellite-based remote sensing, communication and navigation capabilities can provide valuable services in the developing world. Unfortunately, the potential of these technologies is not fully met due to various barriers that prevent developing countries from making use of such technology. These barriers include lack of access to funding, expertise, infrastructure, equipment and education. The purpose of this research is to understand the mechanisms by which developing countries have overcome such barriers by examining examples of programs, projects and companies involved in bringing satellite-based technology to developing countries. Ultimately, this research will highlight ways that policy makers in the developing world can increase the benefit that their countries receive from satellite-based technology.

1.1 Overview of Thesis

The purpose of this study is to examine and improve the ways that satellite-based technology can meet needs in developing countries. Within this purpose, two broad goals guide the research design. The first goal is to increase our understanding of how satellite technology is used in developing countries. The second goal is to understand how development level is related to space activity.

The study is a multi-disciplinary analysis that draws from aerospace engineering and international development. Thus, the audience for this document is mixed. The author's goal is to make it understandable to engineers who are unfamiliar with development issues as well as to those who are experts in development but not familiar with satellite technology. The scope for the study is broad, but it has been narrowed by considering the work of an office that is an expert in this topic, the United Nations Office of Outer Space Affairs (UNOOSA). Based on their activities, the range of technologies to be studied includes satellite remote sensing, satellite communication and satellite navigation. UNOOSA has identified these technologies as having specific potential to benefit developing countries.[i]

There has already been a great deal of literature highlighting the potential benefits of satellite technology in developing countries. There is also a clear understanding in the literature that technical capability building is an essential element of socio-economic development. Finally, ample literature has highlighted the challenges associated with developing countries gaining space capability and accessing the benefits of space technology. This study makes a unique contribution by using quantitative and qualitative methods to understand the relationship between national development level and the use of space technology in developing countries. Specifically, this thesis will answer the following research questions.

1) How does national development level relate to national space activity?
2) What Mission and Management Architectures are developing countries using to apply satellite-based technology to national needs?
3) How does national development level influence the Mission and Management Architectures used by developing countries in satellite-based technology projects?

The answers to these research questions do not completely satisfy the two goals, but the questions allow the study to turn the goals into manageable tasks.

Five categories of data are used to answer these questions. The first data category is information about national space participation. This data measures the extent of space participation for all sovereign states in the world. The second category is project case studies. This data considers the technology and management characteristics of specific projects using satellite-based technology in Africa. The third category is case studies of national space programs for developing countries. The fourth source of data is a set of in-person interviews conducted with officials at embassies of African countries in the United States. These interviews help provide context for the technology and education policies of African countries. Each of these first four sets of data was created as part of this research. The fifth data set is borrowed from international organizations such as the United Nations. This set is made of numerical development indicators such as Gross Domestic Product and the Human Development Index. These are used to measure national development level for all the countries in the world.

Several kinds of data analysis are used in this research. Statistical analysis is used for Research Questions 1 and 3 to look for significant relationships between development level and space activity. The space program case studies and interviews are also reviewed qualitatively to look for trends and success stories.

The results of the study show that there is a statistically significant relationship between national development level and space activity. This can be seen when comparing all countries in the world or comparing just African countries. The results also show what level of technical activity is found in satellite projects in Africa. These conclusions pave the way for policy recommendations to African policymakers and their counterparts in other developing regions.

The figure below summarizes the organization and methodology of this thesis. Notice that the figure is in the shape of a triangle with the pinnacle pointing down. This is done to show that each element of the triangle is more narrowly scoped than the elements above. At the top of the triangle are the two broad goals that motivate the thesis. These goals are too broad to be fully addressed in a thesis, but they do influence all the steps below them in the figure. Each of the three research questions contributes to achieving these goals. Research Question 1 addresses both goals. Question 2 contributes to Goal 1; and Question 3 contributes to Goal 2. The Research Questions have different scopes. Question 1 considers space activity for all the sovereign countries in the world. Questions 2 and 3 consider Architectures for space activity only within Africa. The five data sources are shown in order from most broad to most narrow in scope. The first two relate to all countries; the last three cover only African countries. The data sources provide a great deal of information that could be analyzed in many ways. In that sense, choosing the analysis methods also requires narrowing the scope.

Figure 1: Overview of Thesis Goals and Methods

1.2 Definitions of Major Terms and Concepts

Several key terms will be used throughout this study. Some of them may cause confusion for the reader, due to their elusive definitions in literature and in common speech. Thus, these terms are defined in this section.

1.2.1 Satellite-Based Technology (SBT)

The author uses satellite-based technology (SBT) to indicate any technology that is enabled by satellites. This includes services performed directly by satellites as well as the information obtained using satellites. Thus, if a computer tool is developed based on satellite data, it can be considered an SBT.

1.2.2 Developing Country

The term "developing country" is used broadly, but there is not a clear method to determine which countries are developing and which are already developed. Of course, development is not a binary state; it is a spectrum. It is somewhat artificial to assign a specific boundary between countries. Thus, in this project, development is measured along a spectrum defined by a consistent source. The primary source is the Human Development Index (HDI). We use the Human Development Index as a measure of national development.[ii] The HDI was developed by the United Nations. It is a composite score based on several objective indicators of development. These indicators fall into diverse categories including economics, education policy, and health. The HDI assigns countries a score between 0 and 1 as a summary of social and economic development. The Index also divides countries into three categories: High, Medium and Low Development. As of the 2004 HDI rankings, High Development Countries have an HDI score of at least .80. Medium Development Countries are ranked at .5 and above. This leaves Low Development Countries with rankings below .5. Thus, in this analysis, countries are compared in terms of development based on their rankings in the HD Index as well as other Indicators provided by the Human Development Report. A full explanation of the HD Index and the rankings of all countries according to the Index can be found on the website referenced above.

1.3 Background and Motivation

Space enthusiasts are often challenged with questions like, "Why should we invest in space technology when there are starving people all over the world who could use that money?" Such a question reveals an ignorance of the way that satellite-based technology can help to improve food production for starving people. Satellite remote sensing can be used to better plan and understand food production on a regional or national scale, while the satellite-based Global Positioning System (GPS) enables precision farming techniques to increase crop yield. The following section explains some of the ways that satellite-based technology can be harnessed to meet needs in developing countries.

1.3.1 The Potential of Satellite-Based Technology to Meet Needs in Developing Countries

This research emphasizes three specific areas of satellite-based technology that can meet significant needs in developing countries. These are remote sensing, communication and navigation. This section explains each of these technologies and provides examples of the needs they can serve in developing countries.

In order to give context to the needs discussed in this section, we will refer to how they connect to the United Nation's Millennium Development Goals (MDGs). The MDGs are a set of eight goals that were adopted by the UN General Assembly in the year 2000. Each goal provides a measurable standard to be achieved by the year 2015. Together, the goals provide focus for the work of the United Nations in developing countries. The following list summarizes the eight goals.

1) Eradicate extreme poverty and hunger.
2) Achieve universal primary education.
3) Promote gender equality and empower women.
4) Reduce child mortality.
5) Improve maternal health.
6) Combat HIV/AIDS, malaria and other diseases.
7) Ensure environmental sustainability.
8) Develop a global partnership for development.[iii]

1.3.1.1 Overview of Satellite Remote Sensing

One service that satellites provide is earth remote sensing. The phrase "Remote Sensing" simply means "the … process of obtaining data or images from a distance."[iv] Thus, the concept is broad and can be applied to many types of technology. Here we refer to instruments mounted on satellites that can measure phenomena on earth. The *Space Encyclopedia* notes that satellite remote sensing is possible because "the satellites' instruments analyze light and other radiation reflected and emitted from surface features. Each feature…has a different signature of reflected or emitted radiation."[v] There are two major categories of remote sensing; these are imagery and scientific measurement. The data from satellite imagery can be used to create geographically referenced maps of locations on earth. The data from scientific measurements can be used to infer much about the state of the atmosphere, land or water.

Remote sensing has been widely used since the beginning of the satellite era. The first weather satellite, *Tiros 1*, was launched by the United States in 1960. It was the first of a series of ten successful weather satellite missions between 1960 and 1965.[vi] Landsat is a later remote sensing satellite series that has proved very beneficial. Since 1972, this program has provided valuable imagery of the land.[vii] In 1978, the US satellite Seasat became one of the first ocean observing satellites.[viii] Today remote sensing technology has advanced to allow imagery at such high resolution that driving and walking maps are based on satellite images. Meanwhile, great advances in scientific remote sensing measurements allow scientists to observe phenomena ranging from storms to forest fires to pollution.

Both satellite imagery and scientific measurements made by satellites have the potential to meet needs in developing countries, if the data is converted into useful information. Satellite imagery is often put into a Geographic Information System (GIS) in order to make it more useful. This allows users to reference the imagery with its geographic location and to add layers of other information based on the same geographic reference. GIS provides a powerful tool for organizing information. It allows a user to observe, analyze and design the way land is used. For example, the state of Massachusetts provides geographically referenced data that researchers and planners can access for analysis.[ix] Another example comes from the increasingly popular Google Maps website. The figure[x] below shows a snapshot of the Google Maps homepage in satellite view. Here a satellite image of the United States is overlaid with geographic information showing state boundaries and capitals. This is one example of the powerful combination of GIS and satellite data. Satellite imagery is produced both by government owned satellites as well as by commercial satellite operators.

Figure 2: Google Maps Homepage in Satellite View

When satellite remote sensing technology is used to measure environmental phenomena, there are various ways in which that data can be turned into valuable information that can help policymakers. One way is illustrated below in the figure[xi] from the NASA Applied Sciences division. It explains the process of taking scientific data from NASA satellites and creating useful information.

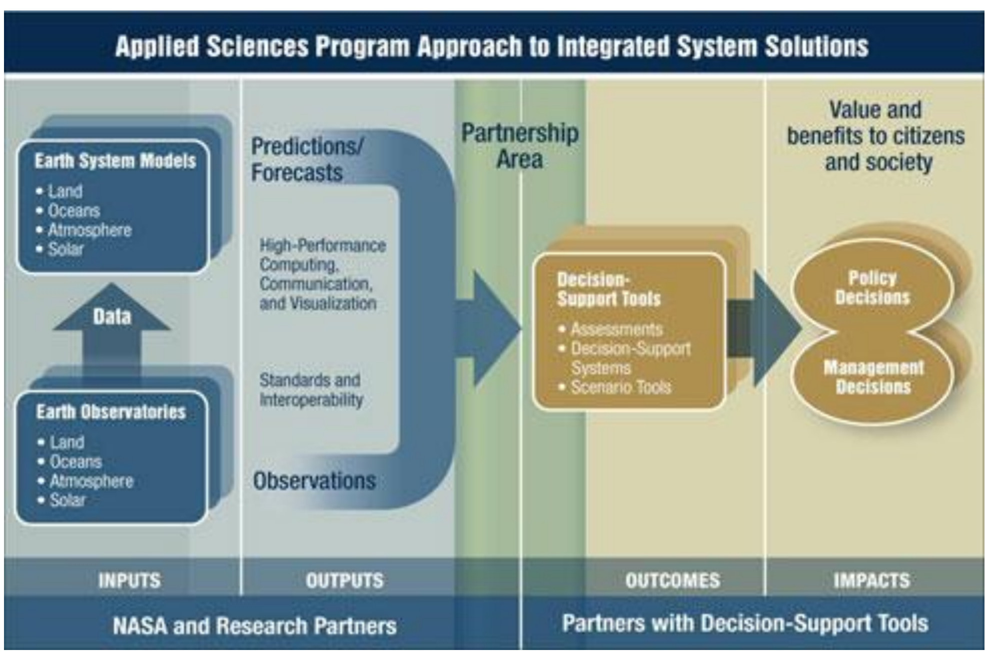

Figure 3: NASA Applied Science Division Approach to Using Satellite Data

As seen in the figure above, the data from earth observation satellites is fed into scientific models that describe the Earth System. These models are analyzed using high performance computers and visualization. The models are also validated using data from other sources such as ground based measurements. With these models, scientists can make predictions and forecasts about natural phenomena. They can format their models into Decision Support Tools. This means that the information will be provided such that it applies directly to the requirements of a customer that must make a decision. Such a customer may be a policy maker on the local, regional or national level. Ultimately, the satellite data is useful if it can be formatted such that it efficiently provides relevant information to help manage decisions.

There is a wide range of sensors that can be used on satellites to make scientific measurements. Some examples include NASA's Aqua satellite.[xii] One of its instruments is the Atmospheric Infrared Sounder or AIRS. It allows analysts to produce very accurate temperature and humidity profiles of the atmosphere. Also, the European Space Agency has the Earth Resource Satellite-1.[xiii] One of its seven instruments is the Radar Altimeter. It measures the time it takes for microwaves to travel from the satellite to the ocean and back. With this information it can calculate ocean altitudes. Finally, the Indian space agency – called the Indian Space Research Organisation – operates the Indian Remote Sensing Satellite System. One of the satellites is called RESOURCESAT-1. It carries three cameras, one of which is called a Linear Imaging Self Scanner (LISS). This camera can take images in both the visual and infrared spectral bands.[xiv] Most scientific remote sensing satellites are owned and operated by government organizations, but there are some commercial operators who produce scientific data. An example is the OrbView-2 satellite of the company GeoEye. It provides imagery of the sea that can be used by fishing vessels to find the best places to fish.[xv]

1.3.1.2 How Satellite Remote Sensing Can Meet Needs in Developing Countries

Next we consider how the capabilities of satellite remote sensing are relevant to developing countries. We discuss three of the pressing needs in developing countries that can be addressed through satellite-based remote sensing. The needs are as follows: **urban planning, disaster management,** and **food security.** Each of these will be discussed in more detail below. This is not an exhaustive list, but it shows the power of the technology. Other areas in which remote sensing can meet needs include the following: managing natural resources, monitoring pollution, preserving sites of natural or historical importance, preserving endangered species, facilitating water management, and creating land use maps.[xvi]

1.3.1.2.1 Urban Planning

Urban planning is an urgent need in many developing countries where so called "mega-cities" of over ten million people, such as Manila and Nairobi, are growing quickly due to urbanization.[xvii] Urbanization is the process of people moving from rural to urban settings, and it is happening much faster in developing countries than in industrialized ones.[xviii] Barney Cohen of the National Research Council notes that in the last century, the number of cities with over one million people has grown from 16 to 400. He goes on to say that "managing urban growth …has become one of the most important challenges of the 21st century".[xix] In many developing countries the rural population is quickly moving into urban centers in search of better jobs opportunities and access to education. These immigrants are often poor and end up living in "informal settlements" or slums rather than finding proper housing.[xx]

The influx of people taxes the fragile infrastructure of the cities.[xxi] The growth outpaces the ability of city planners to design solutions that could meet the needs of the new people. The first need of city planners is accurate and timely information about the rapid changes of a city that is experiencing urbanization.[xxii] High resolution satellite imagery used with GIS can provide planners with much needed information about the growth of their cities. This can assist them with such tasks as population estimates, the design of water or sewage systems, crime prevention and the development of alternative housing to replace informal settlements. As an example, the US Agency for International Development (US AID) sponsored planners in the Philippines who used satellite data from Russia to analyze land use patterns.[xxiii] Satellite technology can be one tool that helps urban planners to meet the 7th Millennium Development Goal: "Ensure environmental sustainability."

1.3.1.2.2 Disaster Management

The second need of developing countries that can be addressed by satellites is disaster management. Here the term "disaster" is used broadly. It includes what are commonly thought of as natural disasters, such as hurricanes, volcanoes and tsunamis. It also includes long term problems such as famine, drought and disease outbreaks. Developing countries are very susceptible to harm from disasters. Not only are they located in regions where disasters occur often, but they often have fragile infrastructure and limited resources.[xxiv] Thus, if medical supplies or food are destroyed by a tsunami or famine, the result is great want.

Satellite-based technology can serve several roles in disaster management. First, satellites can sometimes provide early warning about disasters through remote sensing. Satellite images of hurricanes forming over the ocean have become commonplace; this is a form of early warning for disasters. Satellites can also monitor volcanoes, tsunamis and fires to warn of danger. Additionally, there are projects such as MARA (Mapping Malaria Risk in Africa), that use satellite data to provide early warning of disease outbreaks. In this case, analysts use climate data to predict where malaria-carrying mosquitoes are most likely to flourish.[xxv] Also, satellite data can give warning of famine or drought conditions before they become severe. For example, one instrument on Landsat 4 is called the Thematic Mapper. One set of measurements it takes in the infrared shows how much moisture is in plants. A low moisture reading could be an indication of a failing crop.[xxvi] Because satellites have a global view and because they can revisit the same location on earth frequently, the warnings they provide about disasters cannot be matched by other platforms. The second way that satellites can help with disaster management is by providing back up infrastructure during and after a disaster. This includes remote sensing data that guides relief efforts as well as communication services in areas where the regular infrastructure has been damaged. Satellite communication will be discussed more in a later section. As an example of the remote sensing capabilities, consider the tsunami that devastated Asia in December of 2005. Satellites were used both to help workers identify the areas that most needed relief and to help scientists understand the dynamics of the tsunami.[xxvii]

When satellite technology is used for managing disasters such as famine or malaria outbreaks, it is helping to meet the 1st and 6th Millennium Development Goals. The first is "Eradicate extreme poverty and hunger." The 6th is "Combat HIV/AIDS, malaria and other diseases."

1.3.1.2.3 Food Security

The third example of a need felt in developing countries and served by satellites is food security. According to Smith's article called the "Geography and Causes of Food Insecurity in Developing Countries", "a person is food secure when he or she has access at all times to enough food for an active, healthy life."[xxviii] Smith goes on to point out that the world's food supply is enough to meet the world's need, but as of the year 2000 twenty percent of the world was chronically malnourished. This need is concentrated in the developing world. Meanwhile, for children under the age of 5, close to 1 in 3 in developing countries is malnourished.[xxix] One way to improve the problem of food insecurity in developing countries is to improve the information available to the agricultural sector. Satellites can be a part of this process.

Three ways that satellite remote sensing can improve food security are as follows: crop evaluation, weather forecast and pest detection. Crop evaluation means using satellite data to understand the health of crops. This could give national or regional policy makers warning if there is danger of a famine or drought as discussed above in the section on disaster management. Weather forecasting and climate data from satellites can help farmers make the best decisions about managing their crops as they grow. Finally, satellite data can alert farmers to the risk or presence of pests and diseases.[xxx]

One example of a satellite project concerned with food security is the Famine Early Warning System Network (FEWS NET). This program, funded by the US Agency for International Development, works with partners in Africa, Central America, Haiti and Afghanistan. Their goal is to provide warnings of food security problems in these regions. FEWS NET uses satellite data in several ways. They use infra-red measurements to evaluate the "Normalized Difference Vegetation Index" which shows the "vigor and density of vegetation."[xxxi] Another set of data is used to estimate rainfall. These are examples of how satellite data can indicate the health of food crops.[xxxii]

Clearly, using satellites in this way helps us reach the 1st MDG: "Eradicate extreme poverty and hunger."

1.3.1.3 Overview of Satellite Communication

Satellites provide many services in the area of communication. Fundamentally, they provide a platform to transfer data from one point on the globe to another. This data may be in the form of a phone call, an internet signal, a television broadcast or a radio broadcast. The key benefit of using satellites for communication is their global reach. By using a set of satellites placed strategically in orbit, one can create a network that can send data anywhere in the world. Communication satellites have traditionally been flown in Geostationary Orbit (GEO). This means that they orbit the earth directly above the equator at an altitude of about 36,000 kilometers; at this altitude the orbit is at the same rate as the rotation of the earth. Thus the satellite always points to the same location on earth. A satellite in geostationary orbit can see a large portion of the earth. In fact, a network of just three geostationary satellites provides coverage for the entire inhabited globe. It is clear that geostationary orbits are preferable for communication. Because of this, that orbital altitude is very popular and has grown crowded. An alternative to a 3-satellite network at GEO is a multi-satellite network at LEO (Low Earth Orbit). Low Earth Orbit refers to any orbit that is within about 250 kilometers of the earth. Because such satellites operate closer to earth, they do not need as much power to send their signal. Thus, they can be smaller. The trade off, however, is that it requires more complex coordination to send signals via a LEO network. LEO satellites do not stay constantly over the same location on earth.

If one satellite is handling a phone call over New York, but it is going to move away from that location, the data must be passed to another satellite.[xxxiii]

Whenever communication satellites operate in space, there must be a ground facility to send and receive the satellite signal. One type of ground hardware that is very useful in developing countries is the VSAT or Very Small Aperture Terminal. VSAT systems are stationary satellite earth stations that can be used for various types of data transmissions. The system includes the outdoor satellite dish and an indoor unit that is about the size of a desktop computer.[xxxiv] The VSAT system is described as "very small" because the satellite dish for the earth segment is usually between .9 and 1.8 meters.[xxxv] Because of its small size and simple set up, the VSAT is easy to use in developing countries.

1.3.1.4 How Satellite Communication Can Meet Needs in Developing Countries

Satellite based communication is helpful in developing countries for several reasons. It provides a communication infrastructure that is faster to deploy and more useful in remote areas than a ground based infrastructure such as a cellular network or fixed telephone lines. As population density decreases, it becomes cheaper to use satellite-based infrastructure than ground based infrastructure.[xxxvi] More generally, satellites play a role in providing phone, internet, and broadcast services in developing countries. The satellite option is most economical for phone communication outside the coverage of cellular networks; this is usually in rural areas. That being said, many cellular providers are using satellites for international calls.[xxxvii] Satellite-based internet in developing countries competes with several ground based options including fiber-optic under sea cables, cellular networks and dial-up on fixed telephone lines. There are pros and cons for each option in terms of availability, bandwidth, delay, and cost. The regulatory environment of each country strongly affects which technology is most affordable. Satellites are very well suited for broadcast, particularly of radio and television. While a satellite-based radio or television system is likely to be more expensive than conventional systems, the satellite allows for access to programming from around the globe.[xxxviii]

Communication technology can meet a variety of needs in developing countries. This includes improving access to the following: **education, medical care, government services,** and **economic efficiency**. The need for improvement in each of theses areas will be discussed more in the following section.

1.3.1.4.1 Education

There a strong need to improve education opportunities in the developing world. Rural schools in developing countries are often understaffed and lack basic resources such as textbooks, desks and boards. There is also concern about the level of teacher qualification.[xxxix] Teacher absence is very common in developing countries. Some authors attribute this to the challenging teaching conditions.[xl] In the face of such problems, satellite-based communication technology can provide improvements to both formal and informal education opportunities. One option is distance education. If there are not enough qualified teachers in one location, the students can connect with teachers in another location via satellite. This could be as a direct, two way link or the teacher could broadcast lessons to many classrooms. A second option is to use television, radio or the internet to provide opportunities for informal education. Students of all ages could access the material.

Consider three examples of satellite technology used for education in developing countries. First is the University of South Africa (UNISA). It is a large university that specializes in distance learning. They use satellite technology to connect teachers in their central campus with students in their remote hubs.[xli] Also in South Africa is the Mindset Network. Mindset uses satellites to offer educational content for use in both formal and informal education at many levels. They also ensure that schools and clinics have the equipment to effectively use their information.[xlii] Meanwhile Indonesia started using satellites to provide distance education in the 1980s. They saw that only 18% of applicants could be served in national universities; they responded by creating the Indonesian Open University which served 60,000 students via satellite.[xliii] As we see from these examples, satellites can help achieve the 2nd Millennium Development Goal: "Achieve universal primary education."

1.3.1.4.2 Medical Care

Satellite communication technology can improve medical care in developing countries by enabling telemedicine or transmitting valuable health-related data. The following section discusses the need for both and gives examples of successful projects.

In rural areas of developing countries, it may be difficult or expensive to get access to medical care. For example in India, the medical infrastructure is highly centered in urban settings. Although 75 percent of the population lives far from the major cities, there is a great shortage of secondary and tertiary medical care providers in the suburban and rural areas. As a consequence, many rural Indians with serious medical concerns cannot receive a diagnosis without traveling a great distance and incurring a large expense. This situation is a function of the overall infrastructure distribution of the nation. The rural settings do not have the necessary infrastructure to support the medical profession or to maintain a given health professional's salary.[xliv]

Satellites and other information technologies provide a potential method to address this problem through telemedicine. Telemedicine is "the delivery of health care and the exchange of health-care information across distances." Thus, health care providers and patients are connected virtually rather than being in the same place. They may communicate via video conferencing, email, pictures, or by sending medical data. Doctors provide diagnosis, treatment and counseling. The interaction may be recorded and passed between patient and doctor or it may be real-time. Most telemedicine currently occurs in remote areas in industrialized countries, but there is a growing effort to use it in developing countries. [xlv] Even in the urban centers of developing countries, there may be benefit from connecting virtually with international specialists in particular fields.

Martinez *et al* did a study of three telemedicine case studies in rural settings of Latin America. They noticed that one category of health care facility, called a health post, was most often located in small towns with no telephone infrastructure or roads. They concluded that telemedicine does have the potential to improve service in these health posts, but care must be taken to implement the technology in a manner relevant to the social and economic context.[xlvi]

Another way that communication satellites can improve health care is by facilitating the collection of health related data. This could include environmental data to explain the spread of a disease or data recording the provision of health care services. The Onchocerciasis Control Program is an example of communication satellites transferring environmental data for public health. Onchocerciasis is also known as river blindness. It is a disease spread by flies that can ultimately lead to total blindness. It affected most of sub-Saharan Africa until international efforts to fight the disease began in the 1970s. The control program was very successful in reducing the spread of the disease.[xlvii] As part of the effort to fight the disease, 150 sensors were placed in rivers. The data from these sensors guided the process of killing the fly larvae that spread the disease. Communication satellites played a role by transmitting the sensor data to data collection centers in real time.

The company Cell-Life provides an example of how data on medical care provision can improve health. Cell-Life is a non-profit company in South Africa that develops communication technology to improve the care of HIV/AIDS. South Africa and other Sub-Saharan nations face a huge AIDS crisis; close to two-thirds of those with the virus are in this region. South Africa has a national initiative to provide anti-retroviral treatment to those with HIV. The difficulty is that the drugs must be taken regularly and completely to be effective. If the patient takes less than 95% of the required doses, the virus could mutate and develop a resistance to the drug. Patients often need encouragement to stay on their regimen because of the uncomfortable side effects of the treatment. Because of this issue, medical staff provide accountability for patients by meeting with them regularly for consultations. The data from these meetings is valuable but cumbersome. Cell-Life has developed technology based on cell phones to collect data about patient adherence to their prescription. In this case, the technology is not satellite-based because a cell-based solution is more cost effective in the urban settings where Cell-Life works. A satellite-based solution could be appropriate in some settings, however.[xlviii]

Using satellites to enable telemedicine or improve health care can help advance the 4th, 5th, and 6th MDGs. Number 4 is "Reduce child mortality; #5 is "Improve maternal health; #6 is "Combat HIV/AIDS, malaria and other diseases."

1.3.1.4.3 Government Services

Rural communities in developing countries often have poor access to government services. It may be necessary for community members to travel long distances to urban centers in order to complete routine transactions such as obtaining a birth certificate or registering a deed. As a result, some community members take long, expensive trips and lose opportunities to earn income. Others simply miss out on obtaining the government service. In these same communities it may be difficult to access up to date information about government news or to effectively express an opinion about government behavior. In recognition of this problem, many have suggested e-government as a method for improving access to government services. The World Bank's Information for Development Program defines e-government as "the use of information and communications technologies (ICT) to transform government by making it more accessible, effective and accountable."[xlix] They go on to describe three phases of e-government, which are "publish, interact and transact."[l] Publishing includes making government information available, for example, on the internet. Interacting refers to providing opportunities for citizens to participate in public decision making and dialog with their government. Transacting refers to obtaining government services via telecommunications technology. [li]

Another area of concern in developing countries is the high level of corruption that frequently enters into government transactions. Authors Batabyal and Jick Yoo write about corruption in developing countries. They mention the high frequency of bribes to public officials and the tendency for people who wait for public goods to give bribes that move them up the queue.[lii] Because e-government activities increase the transparency of transactions, the methodology has the potential to reduce corruption.[liii]

Satellite technology can provide the communication infrastructure that will allow rural communities to participate in e-government activities, even if they live outside of the ground-based communication infrastructure. In this way, it would advance the 8th Millennium Development Goal. The first sub-goal under #8 is as follows, "Develop further an open trading and financial system that is rule-based, predictable and non-discriminatory, include[ing] a commitment to good governance, development and poverty reduction – nationally and internationally." [liv]

1.3.1.4.4 Economic Efficiency

Developing country markets can be highly inefficient due to imperfect information. This means that information about prices does not travel as it should throughout a market, thus there is the danger of arbitrage pricing. Arbitrage happens when the same products are sold at different prices in different geographic regions.[lv] If there is perfect information, lower prices in one region cause increased demand. Meanwhile, decreased demand in the high priced region causes prices to decrease. Ultimately prices are equal in both regions. When communication technology is used to connect various members of a market, it can reduce the opportunity for arbitrage. This is beneficial because it means that the most economic welfare will be gained in the market. If farmers or entrepreneurs are in rural areas in developing countries, the cost of information about fair market prices is high. They often rely on people to learn prices, and they run the risk of being cheated by intermediate buyers. [lvi] If they can access the internet or telephone via satellite or other technology, they can learn what the market prices are. Examples of this benefit come from the e-Choupal project in India. It allows Indian farmers to access information on market prices as well as weather and farming practices using rural internet kiosks.[lvii] The same kind of innovation is used in Kenya. The African Regional Centre for Computing was set up to help small farmers find correct market prices by internet. [lviii] This kind of progress also advances MDG #8 as discussed above.

1.3.1.5 Overview of Satellite Navigation

Satellite navigation involves the use of satellites and ground receivers to determine latitude, longitude and altitude. The technology works as follows. Navigation satellites are equipped with atomic clocks that keep very accurate time. The satellites broadcast their positions and the time to receivers on the ground. If a receiver can capture signals from at least four satellites, it can calculate its position in two steps. The first step is to find the distance between the receiver and each satellite. This is inferred from the time it takes for the signal to travel from each satellite to the receiver; the receiver knows the rate at which the signal travels and can thus infer the distance. The second step is to find the point that is the appropriate distance from each satellite.[lix]

There is one fully operational, global satellite navigation system. It is the US Global Positioning System (GPS); several other systems exist or are planned. The US GPS is a system that includes 27 satellites, a series of ground control facilities and receiver units. The constellation of satellites is complete as long as 24 are operating. With this capacity, the system can be used anywhere on earth and by spacecraft in low earth orbit.[lx] In May, 2000 the US government removed a technology called "Selective Availability" from the GPS system. Previously, the technology had decreased the precision of the GPS signal available for civilian use. Once this feature was removed, the usefulness of commercial GPS navigation systems greatly increased.[lxi]

Other satellite constellations used or planned for navigation include Russia's GLONASS, Europe's Galileo, India's IRNSS and China's Compass. The GLONASS has not always been maintained as a fully global constellation, but when it is complete it is very comparable to GPS.[lxii] Europe is in the process of creating the Galileo constellation. The first launch for Galileo was in 2005. The plan is to have the four satellites required for position determination by 2009. Ultimately, Galileo will have 30 satellites and cover the entire globe.[lxiii] India plans to deploy its own regional satellite navigation system. The project was approved in 2006 and will ultimately include 7 satellites.[lxiv] China is producing the Compass Navigation Satellite system. China launched four navigation satellites between 2000 and 2007.[lxv]

Navigation satellites have many uses including navigation, position and timing. The navigation application facilitates the operation of cars, planes, ships, and spacecraft. Hikers and pedestrians can also navigate by satellite. The excellent position measurements enable surveying and mapping as well as precision farming (to be discussed more below). Meanwhile, the signal from the atomic clocks is used by banks, cell phone operators and power grids.[lxvi]

It should be noted that the standard signals from GPS and GLONASS are not precise enough for some applications. For example, commercial aircraft could not depend solely on GPS information. The signal is not precise enough to completely guide take off and landing. To solve this problem, there are several augmentation systems that work with GPS to improve the performance of the system. These Augmentations include ground based and satellite-based systems.[lxvii] Two examples are the US satellite-based Wide Area Augmentation System (WAAS) and the European Geostationary Navigation Overlay Service (EGNOS).[lxviii]

1.3.1.6 How Satellite Navigation Can Meet Needs in Developing Countries

Satellite navigation is very relevant to developing countries in various ways. A key benefit of the technology is that the infrastructure is already in place. In fact, there are multiple, redundant systems currently in operation and more are being planned. A user of satellite navigation only needs to buy a receiver. Receiver technology is steadily becoming more mature and affordable. Thus satellite navigation is becoming a cost effective option for areas such as **aviation** and **wildlife tracking**.

1.3.1.6.1 Aviation

Civil aviation in developing countries can be a valuable source of economic growth. In some countries, aviation is a primary means for tourists to enter the country and stimulate the economy.[lxix] Unfortunately, civil aviation in developing countries suffers from safety concerns. The infrastructure that is required to maintain standard air traffic management can be very expensive. Also expensive are the government operations required to provide adequate safety oversight. Civil aviation safety is not always a high priority in "poor countries, with massive debt burden, basic health, sanitation, food and education concerns to address,"[lxx] as explained in a report of the World Tourism Organization. The WTO goes on to recommend that the air traffic management technology based on satellite navigation can be more affordable than traditional ground based infrastructure. It is particularly useful in remote airports that are used infrequently.[lxxi]

The European Union recognizes the value of satellite-based aviation navigation in developing countries. They are working in Africa to demonstrate and spread the use of the technology. The European Space Agency partnered with the African agency ASECNA (Agency for the Safety of Aerial Navigation in Africa). They used the EGNOS augmentation system, as described above, to increase the precision of the position information provided by GPS. To demonstrate the effectiveness for aviation navigation, they did a flight across Africa from Senegal to Kenya in 2005. Ultimately Europe plans to create an extension of EGNOS to cover the Africa-Indian Ocean region.[lxxii]

The efforts to use satellite navigation for aviation do not directly match any of the Millennium Development Goals. They do, however, fit the spirit of the goals. Indirectly, they are part of the solution. Improved aviation safety can lead to a better economy and will help with goals like "Eradicat[ing] extreme poverty and hunger."[lxxiii]

1.3.1.6.2 Wildlife Tracking

Wildlife is a valuable natural resource in many developing countries. As is well known, many species of wildlife are in danger of going extinct due to human activity. Thus, a key challenge in many developing countries is managing this precious and fragile resource. Wildlife management can be facilitated through the use of satellite-based wildlife tracking. GPS receivers are specially designed to attach to animals without harming them or impeding their movement. For example, the H.A.B.I.T Research company specializes in making small GPS wildlife tracking technology.[lxxiv] Researchers in South Africa used GPS to track the nation's national bird, the Blue Crane. The small transmitters were only 3 centimeters by 5 centimeters.[lxxv]

The use of satellite technology for wildlife tracking fits into the 7th Millennium Development Goal: "Ensure environmental sustainability."[lxxvi]

1.3.1.7 Using Satellite Technologies Together

Some satellite applications that can benefit developing countries use more than one satellite technology at the same time. One example is **precision farming.** This technique uses satellite remote sensing data as well as satellite navigation to manage crops. By mapping a farm with great precision and monitoring the land carefully, the care of the crops can be improved greatly. This can lead to improved crop yield, which would greatly serve developing countries. A second example is the **care of refugees and displaced persons.** On one hand, satellite navigation helps humanitarian workers travel during crises; meanwhile satellite imagery can help clarify where needs are and how to provide resources. A third example is **disaster relief.** The above section discussed using remote sensing and communications during disasters. Here we note two international programs that promote this. The International Charter on "Space and Major Disasters" is an agreement between several space agencies to provide satellite imagery at no cost during a disaster. An analogous agreement called the Tampere Convention on Emergency Telecommunications ensures that communication technology, including satellites, will be available during disaster relief efforts. It does this by eliminating the regulatory barriers that would prevent telecommunication technology from being used. [lxxvii] When satellite communication and remote sensing are combined during disasters, the impact is much greater.

1.3.1.8 Conclusion

This section provided a technical overview of three key types of satellite technology – remote sensing, communication and navigation. We discussed various problems that impact developing countries. We went on to show how satellite-based technology has the potential to address these problems. Also, this section gave examples of specific programs and projects in which satellite technology is used in developing countries. The next section will provide an overview of how satellite technology has been relevant to developing countries since satellites were invented.

1.3.2 Historical Overview of Satellite Technology for Developing Countries

From the early days of the satellite era, technology pioneers recognized the benefits of satellites for developing countries. The following section summarizes some of the initiatives that have provided satellite technology to developing countries. It begins with activities that started in the 1960s such as INTELSAT and concludes by highlighting more recent projects.

1.3.2.1 INTELSAT and INMARSAT

President Kennedy called for the development of American communication satellite technology that would serve the needs of developing nations and the world. Specifically, he urged that the system operate even in unprofitable regions and allow membership of any country. In response, Congress passed the Communications Satellite Act in 1962 which led to the creation of INTELSAT (International Telecommunications Satellite Consortium) in 1964. INTELSAT began as an intergovernmental organization that operated a global communication satellite system. *Early Bird* was the first communications satellite launched for INTELSAT. [lxxviii] When it launched in 1965, Brazil was among the first countries to have communication earth stations to receive her signals.[lxxix] Later in 2001, INTELSAT became a private company overseen by the member nations through the International Telecommunications Satellite Organization (ITSO).[lxxx] Today 148 countries, including many developing countries, are members of the ITSO and use its services.[lxxxi]

INTELSAT primarily provides satellite communication services for fixed ground systems. In 1979, a similar organization was developed to provide mobile satellite communication, particularly for maritime applications. Thus, INMARSAT was born.[lxxxii] It followed a similar path as INTELSAT and later became a company overseen by the International Mobile Satellite Organization.[lxxxiii] In its first year, developing countries such as Argentina, Brazil, China, and India joined INMARSAT. Many others joined in later years.[lxxxiv]

1.3.2.2 UN COPUOS

Since the 1950s, the United Nations has actively pursued what they called the "Peaceful Uses of Outer Space."[lxxxv] They wanted to understand and promote the non-military uses of space technology that would improve people's lives. The Committee on the Peaceful Uses of Outer Space (COPUOS) was established in 1958. The resolution that founded this committee included the desire that space technology would be to the "benefit of States irrespective of the state of their economic or scientific development".[lxxxvi] The Office of Outer Space Affairs implements the work of the Committee. This work includes the Program on Space Applications (PSA). The PSA was started in 1971 to "assist people from developing countries in acquiring the knowledge, skills and practical experience necessary" to use satellite technology.[lxxxvii] The PSA's activities include spreading awareness and building capacity in regard to satellite technology. They work in the following areas: Space Science, Satellite Navigation, Natural Resource Management, Satellite Communication, and Disaster Management.[lxxxviii]

1.3.2.3 SatelLife

SatelLife is an organization concerned with the use of information and communication technology to improve health care in developing countries. The goal of SatelLife is to facilitate access to information for health care workers in resource-starved areas. SatelLife offers this service at no cost. Some of their services include hosting discussion groups, providing publications, and a tool to retrieve web pages via email.[lxxxix]

SatelLite started its work with satellite technology. The Surrey Satellite Technology Ltd company in England built two satellites for the company. HealthSat 1 was launched in 1991, and HealthSat 2 followed in 1993. Since the satellites were in low earth orbit, not geostationary, they did not stay constantly over the same location on earth. The technology was a store-and-forward model. Earth stations collected data such as emails and waited for the satellites to pass before transmitting and receiving information.[xc]

1.3.2.4 Surrey Satellite Technology Limited

The Surrey Satellite Technology LTD (SSTL) company focuses on the production of small satellites. They grew out of research at the University of Surrey that dates back to the 1970s. The company opened in 1985. Their business model caters to customers that have not worked with space technology before. Through their Know How Transfer/Training program, they sell satellites along with training on how to implement satellite projects. Surrey has worked with many developing countries including Algeria and Nigeria.[xci]

1.3.2.5 SERVIR

SERVIR is a project that originated in the NASA Marshall Space Flight Center; it was officially inaugurated in 2005. The goal of the project is to give decision makers in Central America and Mexico ready access to NASA remote sensing data.[xcii] It is a partnership between NASA and the 8 countries in Latin America from Mexico to Panama. The main product of the program is a web-based portal that offers visualizations of data for the Central American environment. The data comes from NASA satellites. The applications covered by SERVIR include disasters, biodiversity, water, weather, climate and energy. NASA implemented the project first as an experiment at Marshall and then created an operational program headquartered in Panama and led by the Water Center for the Humid Tropics of Latin America and the Caribbean.[xciii]

1.3.3 Developing Country Space Programs

Several developing country governments have pursued their own national space capabilities for many years. Two of these countries – India and Brazil – are discussed below.

1.3.3.1 India

The Indian space program includes the Indian Space Research Organisation (ISRO) under the Department of Space as well as several other government agencies that make use of their space capabilities. India has had an indigenous launch capability since 1980. ISRO also focuses on satellite-based remote sensing, disaster monitoring, communication and broadcast. The space program includes a network of ground-based satellite operations centers, data processing centers, launch sites and research centers[xciv].

The story of the Indian space program is a remarkable example of a developing country that sought out and gained competence near the technological frontier in a new field. The space era began with the launch of the Sputnik satellite in 1957 by the Soviet Union. This led to a frenzy of activity in several countries that were eager to launch their own satellites. India had only been independent of British rule since 1947; thus it was remarkable that this young democracy also began work to develop a national space program in the 1960s[xcv]. By 1963, the first sounding rocket was launched from India. In 1967, a satellite telecommunication earth station was set up to receive NASA satellite data. The Indian Space Research Organization was founded in 1969. Aryabhata, ISRO's first Indian satellite was launched in 1975. These milestones[xcvi] demonstrate that India was able to become a space faring nation in a relatively short amount of time, given the long development time associated with space technology.

India's work in space technology can be divided into two distinct eras. Between 1962 and about 1983, most of the projects were experimental or focused on gaining new skills. Starting in the mid-1980s, India had a more established space program and a better skill set.[xcvii] India has moved from being a pure importer of space technology to also being an exporter and consultant. India works with a US company to sell its remote sensing imagery on a commercial basis. They also sell space hardware components to the US.[xcviii]

Vikram Sarabhai is a key figure in the history of the Indian space program. He was a scientist and manager who lead many programs and organizations in India. He served as the first leader of the Indian space program.[xcix]

1.3.3.2 Brazil

Brazil stands out among Latin American nations for its strong space capabilities. Part of the motivation for Brazil to pursue space technology is its geography. It is a large country with many fragile natural resources, such as the rainforest and coastlines. It has many remote regions with low population density. Brazil has thus pursued capabilities in remote sensing, communication and navigation.[c]

Brazil began building space expertise in 1961 with the founding of the National Institute of Space Research. This institute fostered scientific research and an understanding of the applications of satellite technology. In 1964, Brazil started a sounding rocket program. Sounding rockets are research rockets that do not go out of the earth's atmosphere. The Brazilian Telecommunications Company, Embratel, manages a number of communication satellites. The first of these was launched in 1985 by Arianespace of Europe. Starting in 1988, Brazil and China pursued a joint program in remote sensing. This has led to collaboration on four earth resource satellites. In 1990, Brazil started operating the Alcantara Launching Center, which is well positioned for the launch of geostationary satellites. By 1993, Brazil was ready to launch an indigenously built satellite. Later in 1994, Brazil founded a national space agency that is known as the AEB. These and other institutions make up Brazil's national space program.[ci] Brazil is also the only developing country that is participating in the International Space Station.[cii]

1.3.4 Barriers to the Use of Satellite-Based Technology in Developing Countries

The previous section outlined a plethora of ways that satellite technology is able to meet needs in developing countries. Unfortunately, this section did not tell the whole story. Despite the ripe potential of this family of technologies, there are several barriers that prevent developing countries from making full use of satellites. Some of these barriers are general; others are specific to the various types of satellite technology. This section explains the barriers that make it difficult for developing countries to develop their own satellite capability or benefit from satellite-based technology (SBT).

In general, it is inherent in the definition of developing countries that they have a lower capacity to use technology than developed countries. With this come several problems that impede the indigenous production of SBTs. Within developing countries there may be a lack of awareness of the benefits of SBTs. Policy makers may not know that satellite technology can help them reach some of their core goals, such as providing adequate food and education to their population. Satellites are a highly sophisticated technology and there may not be enough technical expertise available to pursue it. This lack of expertise may come from a poor education system that is not able to train enough skilled technical workers. Developing countries are generally poor and satellite technology is often beyond their budget. Also, designing, manufacturing and operating satellite technology requires a sound technical infrastructure. This is sometimes lacking in developing countries.[ciii]

Due to lack of indigenous capability in satellite technology, developing countries often collaborate with other countries to benefit from the technology. These collaborations can be useful, but there are several challenges that limit their effectiveness. These challenges will be discussed for each of the three technology areas, namely, remote sensing, communication and navigation.

In the area of remote sensing there is the potential for national security constraints, limitations on technology transfer and an increase in cost due to commercialization. The national security constraints refer to the prerogative of the data producers to choose not to share the data for security reasons. Security precautions may also limit the technology that a country shares with another country. Another limitation on technology transfer is economic considerations. A country that holds a technology may not have a financial incentive to share it with another country. They may choose instead to only share scientific data or out-dated technology. Finally, note that remote sensing is transitioning from being a government-only activity to being a government and commercial activity. Commercial remote sensing companies tend to charge more for their imagery and are less likely than governments to aid developing countries.[civ]

In the area of communication technology the scenario is a bit different. The entities operating satellites are largely multinational commercial entities. The barrier that can impede access to satellite technology is limiting policy on the part of the host developing country. The government may limit the companies that are allowed to receive licenses in order to protect a national telecommunications provider. This reduces competition and increases prices for the consumer. Groups like the International Development Research Center and the VSAT Forum have called for more open policies for the use of satellite communication tools.[cv,cvi]

In the area of navigation the barrier is more of a specter than a current reality. Until the year 2000, the US government limited the precision of the location information from GPS. The various governments that own the Global Navigation Satellite Systems have the power to limit the use of these systems at their discretion. Thus, developing countries that depend on the systems of other countries are ultimately powerless to ensure the continuing availability of the resource.[cvii]

This section has outlined various policy, technology and financial barriers that limit the use of satellite technology in developing countries. This leads to the two main goals of the thesis. One is to better understand how satellite technology is being used in developing countries. The second is to understand how development level impacts this satellite activity. The first goal will help developing countries find ways around the barriers that limit the use of satellite-enabled technology by investigating the current state of the field. The case studies in this research provide concrete examples of the results of these barriers as well as examples of how some groups have mitigated the barriers. In this way, this thesis expands our understanding of the ways developing and industrialized countries are using satellite technology. Beyond this, we explore how the level of development in a country relates to its use of satellite-enabled technology. As will be discussed in the literature review, it has been shown that technology is an important component in socio-economic growth. In general, countries that are less developed are less adept at using high technologies like satellites. This study finds quantitative data to probe this theory in the context of satellite technology. In order to do this, we use data on the use of satellite-technology as well as data on the development levels of countries.

---

[i] United Nations Office for Outer Space Affairs. “Space Solutions for the World’s Problems.” http://www.uncosa.unvienna.org/uncosa/reports/wssdpub/iam/menu.html April 2, 2008.
[ii] Human Development Report. http://hdr.undp.org/en/ April 5, 2008.
[iii] United Nations. “UN Millennium Development Goals.” http://www.un.org/millenniumgoals/ April 4, 2008.
[iv] "remote sensing." Webster's New Millennium™ Dictionary of English, Preview Edition (v 0.9.7). Lexico Publishing Group, LLC. 31 Mar. 2008. <Dictionary.com http://dictionary.reference.com/browse/remote sensing>.
[v] Couper, H. and Henbest, N. *Space Encyclopedia.* 1st ed., DK Publishing, New York, 1999, p. 54.
[vi] McDougall, Walter. *…The Heavens and the Earth.* 2nd ed., The Johns Hopkins University Press, Baltimore, 1997, p. 221.
[vii] Williams, Darrel. “The Landsat Program.” http://landsat.gsfc.nasa.gov/, 31 March 2008.
[viii] Couper, H. and Henbest, N. *Space Encyclopedia.* 1st ed., DK Publishing, New York, 1999, p. 55.
[ix] Government of Massachusetts. “Massachusetts Geographic Information System.” http://www.mass.gov/mgis/, 31 March 2008.
[x] Google Maps. “Homepage.” www.google.com/maps, 31 March 2008.
[xi] Sample, Sharron. “NASA Applied Sciences Program.” http://science.hq.nasa.gov/earth-sun/applications/, 31 March 2008.
[xii] Graham, S. and Parkinson, C. “Aqua: Project Science.” http://aqua.nasa.gov/, 1 April 2008.
[xiii] “ESA Missions, Earth Observation: ERS Instruments.” http://earth.esa.int/object/index.cfm?fobjectid=3978, 1 April 2008.
[xiv] “IRS-P6 (RESOURCESAT-1).” http://www.isro.org/pslvc5/index.html, April 1, 2008.
[xv] “GeoEye Imagery Products: OrbView-2.” http://www.geoeye.com/products/imagery/orbview2/default.htm. April 1, 2008.
[xvi] United Nations Office for Outer Space Affairs. “Space Solutions for the World’s Problems.” http://www.uncosa.unvienna.org/uncosa/reports/wssdpub/iam/menu.html April 2, 2008.
[xvii] United Nations Population Fund. *State of World Population 2007: Unleashing the Potential of Urban Growth.* http://www.unfpa.org/publications/detail.cfm?ID=334&filterListType= April 3, 2008.
[xviii] Daniels, P.W., “Urban Challenges: the formal and informal economies in mega-cities.” *Cities.* Vol. 21, No. 6, 2004, pp. 501-511.
[xix] Cohen. B., “Urban Growth in Developing Countries: A Review of Current Trends and a Caution Regarding Existing Forecasts.” *World Development.* Vol. 32, No. 1, 2004, pp. 23-51.
[xx] United Nations Population Fund. *State of World Population 2007: Unleashing the Potential of Urban Growth.* http://www.unfpa.org/publications/detail.cfm?ID=334&filterListType= April 3, 2008.
[xxi] United Nations Population Fund. “State of World Population, 2004.” www.unfpa.org/swp/2004/pdf/summary.pdf. April 3, 2008.
[xxii] Cohen. B., “Urban Growth in Developing Countries: A Review of Current Trends and a Caution Regarding Existing Forecasts.” *World Development.* Vol. 32, No. 1, 2004, pp. 23-51.
[xxiii] Burke, Lauretta, “Urban and municipal GIS applications in developing countries – The problems and the potential.” *Proceedings of the Fifteenth Annual ESRI User Conference.* Palm Springs, CA, 1995.
[xxiv] Alcantara-Ayala, I. “Geomorphology, natural hazards, vulnerability and prevention of natural disasters in developing countries.” *Geomorphology.* Vol. 47, 2002, pp. 107-124.
[xxv] Craig, M. “MARA: Mapping Malaria Risk in Africa.” http://www.mara.org.za/. April 1, 2008.
[xxvi] Couper, H. and Henbest, N. *Space Encyclopedia.* 1st ed., DK Publishing, New York, 1999, p. 54.
[xxvii] McKee, M., “Satellite imagery helping tsunami relief effort.” NewsScientist.com news service. January 5, 2005. http://www.newscientist.com/article.ns?id=dn6847 April 4, 2008.
[xxviii] Smith, L., Obeid, A., Jensen, H., “The geography and causes of food insecurity in developing countries.” *Agricultural Economics.* Vol. 22, 2000, pp. 199-215.

[xxix] Smith, L., Obeid, A., Jensen, H., "The geography and causes of food insecurity in developing countries." *Agricultural Economics.* Vol. 22, 2000, pp. 199-215.
[xxx] United Nations Office for Outer Space Affairs. "Space Solutions for the World's Problems." http://www.uncosa.unvienna.org/uncosa/reports/wssdpub/iam/menu.html April 2, 2008.
[xxxi] US AID. "FEWS NET: Maps, Data and Imagery." http://www.fews.net/pages/imageryhome.aspx?pageID=Ndvi April 4, 2008.
[xxxii] US AID. "FEWS NET." http://www.fews.net/pages/default.aspx?l=en April 4, 2008.
[xxxiii] Couper, H. and Henbest, N. *Space Encyclopedia.* 1st ed., DK Publishing, New York, 1999, p. 55.
[xxxiv] Khan, M. "VSAT Communication." http://www.satcoms.org.uk/articles/29.asp April 3, 2008.
[xxxv] Gilat Satellite Networks. "Glossary of Terms." http://www.gilat.com/Content.aspx?Page=glossary#V April 3, 2008.
[xxxvi] Samuels, Ayanna T., "Assessing the Technical, Economic and Policy-centered Feasibility of a Proposed Satellite Communication System for the Developing World," SM Thesis, Massachusetts Institute of Technology, 2005.
[xxxvii] Versi, Anver. "Africa's Telecoms Revolution." *African Business.* http://findarticles.com/p/articles/mi_qa5327/is_200708/ai_n21294289/print Accessed March 18, 2008.
[xxxviii] Song, Steve. "Viewpoint: Bandwidth Can Bring African Universities Up to Speed." International Development Research Centre. http://www.idrc.ca/en/ev-84498-201-1-DO_TOPIC.html Accessed April 18, 2008.
[xxxix] Glewwe, P., Kremer, M., "Schools, Teachers, and Education Outcomes in Developing Countries." Chapter in *Handbook on the Economics of Education* http://post.economics.harvard.edu/faculty/kremer/papers_kremer . April 3, 2008.
[xl] Chaudhury, N., Hammer, J., Kremer, M., Muralidharan, K., and Rogers, F., "Missing in Action: Teacher and Health Worker Absence in Developing Countries." *Journal of Economic Perspectives.* Vol. 20, No. 1, 2006, pp. 91-116.
[xli] "New Student hub opened at Unisa's Sunnytown Complex." UNISA Media Release. http://www.unisa.ac.za/Default.asp?Cmd=ViewNewsItem&NewsID=1166&Cmd=GetNav&NavID=6 April 4, 2008.
[xlii] Mindset Network. http://www.mindset.co.za/ April 4, 2008.
[xliii] Johari, Rajab and Shaw, Willard, "Higher Education via Satellite: The Indonesian Distance Education Satellite System." *International Review of Education.* Vol. 32, No. 3, 1986, pp. 325-330.
[xliv] Bagchi, S. "Telemedicine in Rural India". *Public Library of Science Medicine*. Vol 3, No. 3, 2006, p 299.
[xlv] Craig, J., Patterson, V., "Introduction to the practice of telemedicine." *Journal of Telemedicine and Telecare.* Vol. 11, No. 1, 2005, p. 3.
[xlvi] Martinez, A., Villarroel, V., et al, "Analysis of Information and Communication Needs in Rural Primary Health Care in Developing Countries." *IEEE Transactions on Information Technology in Biomedicine.* Vol. 9, No. 1, 2005, p. 66-73.
[xlvii] World Bank Group. "Global Partnership to Eliminate Riverblindness." http://www.worldbank.org/afr/gper/ April 5, 2008.
[xlviii] Anand, Samir and Rivett, Ulrike, "ICT in the management of HIV treatment: Cell-Life: A South African Solution." *Convergence.* Vol. 6, No. 3, 2005, pp 56-59.
[xlix] Khalil, M., Lanvin, B., Chaudhry, V., "The E-Government Handbook for Developing Countries." http://www.infodev.org/en/Publication.16.html April 4, 2008.
[l] Khalil, M., Lanvin, B., Chaudhry, V., "The E-Government Handbook for Developing Countries." http://www.infodev.org/en/Publication.16.html April 4, 2008.
[li] Khalil, M., Lanvin, B., Chaudhry, V., "The E-Government Handbook for Developing Countries." http://www.infodev.org/en/Publication.16.html April 4, 2008.
[lii] Batabyal, A., and Jick Yoo, S., "Corruption, Bribery, and Wait Times in the Public Allocation of Goods in Developing Countries." *Review of Development Economics.* Vol. 11, No. 3, 2007, pp. 507-517.
[liii] Khalil, M., Lanvin, B., Chaudhry, V., "The E-Government Handbook for Developing Countries." http://www.infodev.org/en/Publication.16.html April 4, 2008.
[liv] United Nations. "UN Millennium Development Goals, #8." http://www.un.org/millenniumgoals/# April 4, 2008.
[lv] "arbitrage." Dictionary.com Unabridged (v 1.1). Random House, Inc. 04 Apr. 2008. <Dictionary.com http://dictionary.reference.com/browse/arbitrage>.
[lvi] Brewer, E., Demmer, M., *et al*, "The case for technology in developing regions." *Computer.* Vol. 38, No. 6, 2005, pp. 25-38.

[lvii] "e-Choupal." http://www.echoupal.com/ April 4, 2008.
[lviii] Opala, Ken. "Kenyan Farmers Discover the Internet." International Development Research Centre. http://www.idrc.ca/en/ev-47033-201-1-DO_TOPIC.html Accessed April 18, 2008.
[lix] Couper, H. and Henbest, N. *Space Encyclopedia*. 1st ed., DK Publishing, New York, 1999, p. 50.
[lx] "The Global Positioning System." http://www.gps.gov/index.html April 4, 2008.
[lxi] Office of the Press Secretary, White House. "Statement by the President regading the United States' decision to stop degrading global positioning system accuracy." http://www.ngs.noaa.gov/FGCS/info/sans_SA/docs/statement.html April 4, 2008.
[lxii] Zarraoa, N., Mai, W., *et al*, "Preliminary evaluation of the Russian GLONASS system as a potential geodetic tool." Journal of Geodesy. Vol. 72, 1998, p. 356-363.
[lxiii] European Space Agency. "What is Galileo?" http://www.esa.int/esaNA/GGGMX650NDC_galileo_0.html April 4, 2008.
[lxiv] "Indigenous Navigation System." http://www.sac.gov.in/asac-ongoing-satellite-ins.html April 4, 2008.
[lxv] Staff Writer, GPS News. "China Puts New Navigation Satellite into Orbit." *GPS Daily*. http://www.gpsdaily.com/reports/China_Puts_New_Navigation_Satellite_Into_Orbit_999.html April 4, 2008.
[lxvi] "Global Positioning System: Serving the World." http://www.gps.gov/index.html April 4, 2008.
[lxvii] "Gauthier, L., Michel, P., and Ventura-Traveset, J., "EGNOS: The First Step in Europe's Contribution to the Global Navigation Satellite System." *ESA Bulletin*. Vol. 105, 2001, pp. 35-42.
[lxviii] "GPS Augmentations." http://www.gps.gov/systems/augmentations/index.html April 4, 2008.
[lxix] Clarke, John-Paul and Miller, Bruno, "Impact of Aviation Infrastructure on Economies of Developing Countries." *Proceedings of Aircraft Technology, Integration and Operations.* American Institute of Aeronautics and Astronautics, Los Angeles, 2002.
[lxx] World Tourism Organization. "Parameters of Aviation Safety." ICAO Directs General of Civil Aviation Conference. Montreal, 2006.
[lxxi] World Tourism Organization. "Parameters of Aviation Safety." ICAO Directs General of Civil Aviation Conference. Montreal, 2006.
[lxxii] European Space Agency. "Success for the first trans-African flight with EGNOS." http://www.esa.int/esaNA/SEMOZ00DU8E_index_0.html April 5, 2008.
[lxxiii] UN Millennium Development Goals. http://www.un.org/millenniumgoals/# April 5, 2008.
[lxxiv] HABIT Research. http://www.habitresearch.com/ April 5, 2008.
[lxxv] "GPS Tracking Helps 'Critically Endangered' Blue Crane." http://www.zimbio.com/GPS+Technology+Reviews/articles/237/GPS+tracking+helps+Critically+Endangered+Blue April 5, 2008.
[lxxvi] UN Millennium Development Goals. http://www.un.org/millenniumgoals/# April 5, 2008.
[lxxvii] United Nations Office for Outer Space Affairs. "Space Solutions for the World's Problems." http://www.uncosa.unvienna.org/uncosa/reports/wssdpub/iam/menu.html April 2, 2008.
[lxxviii] McDougall, Walter. *...The Heavens and the Earth.* 2nd ed., The Johns Hopkins University Press, Baltimore, 1997, p. 354-359.
[lxxix] Whalen, David. "Communications Satellite: Making the Global Village Possible." http://www.hq.nasa.gov/office/pao/History/satcomhistory.html. April 3, 2008.
[lxxx] INTELSAT. www.intelsat.com. April 3, 2008.
[lxxxi] "International Telecommunications Satellite Organization." www.itso.int April 3, 2008.
[lxxxii] Whalen, David. "Communications Satellite: Making the Global Village Possible." http://www.hq.nasa.gov/office/pao/History/satcomhistory.html. April 3, 2008.
[lxxxiii] "What is IMSO?" http://www.imso.org/whatisimso_UK.asp April 3, 2008.
[lxxxiv] "List of Parties to the Convention on the Internatioanl Mobile Satellite Organization." http://www.imso.org/member_states.asp April 3, 2008.
[lxxxv] UN Office for Outer Space Affairs. http://www.unoosa.org/oosa/en/OOSA/index.html April 5, 2008.
[lxxxvi] United Nations. "Resolution Adopted by the General Assembly, # 1348." http://www.unoosa.org/oosa/en/SpaceLaw/gares/html/gares_13_1348.html April 5, 2008.
[lxxxvii] United Nations Programme on Space Applications. "History of the Programme." http://www.unoosa.org/oosa/en/SAP/history.html April 5, 2008.
[lxxxviii] "United Nations Programme on Space Applications." http://www.unoosa.org/oosa/en/sapidx.html April 5, 2008.
[lxxxix] SatlLife. "What We Do." http://www.healthnet.org/whatwedo.php April 5, 2008.

[xc] Mullaney, John. "SatelLife: Pioneering the Path for Electronic Communication and Health Information in the Developing World." http://www.isoc.org/inet96/proceedings/a3/a3_2.htm April 5, 2008.
[xci] "Surrey Satellite Technology Ltd." http://www.sstl.co.uk/index.php?loc=1 April 5, 2008.
[xcii] Cook-Anderso, Gretchen and Beasley, Dolores. "NASA Develops Central American Monitoring System." http://www.nasa.gov/home/hqnews/2005/feb/HQ_05038_panama.html April 5, 2008.
[xciii] "Abour SERVIR." http://servirtest.nsstc.nasa.gov/about.html April 5, 2008.
[xciv] Sundararajan, V. "Emerging Space Powers – A comparative study of National Policy and Economic Analysis for Asian Space Programs (Japan, China, India)". AIAA Space 2006 Conference. San Jose, CA. Sept 2006.
[xcv] India. CIA World Factbook. https://www.cia.gov/library/publications/the-world-factbook/geos/in.html Accessed October 29, 2007.
[xcvi] Milestones. Indian Space Research Organisation. http://www.isro.org/mileston.htm Accessed October 29, 2007.
[xcvii] Harvey, B. *The Japanese and Indian Space Programs: Two Roads into Space.* Praxis Publishing, Chichester, UK. 2000.
[xcviii] Baskaran, A. "Competence building in complex systems in the developing countries: the case of satellite building in India". *Technovation.* Vol 21, pp 109-121. 2001.
[xcix] Harvey, B. *The Japanese and Indian Space Programs: Two Roads into Space.* Praxis Publishing, Chichester, UK. 2000.
[c] Kiratzi, Thasos. "The Space Sector in Brazil – An Overview." http://www.globalsecurity.org/space/world/brazil/index.html April 5, 2008.
[ci] "IAF Focus on Brazil." http://www.iafastro.org/index.php?id=57&no_cache=1&tx_iafmshow_pi1[tt_country]=BR April 6, 2007.
[cii] "Brazilian International Space Station Program." http://www.inpe.br/programas/iss/ingles/default.htm April 5, 2008.
[ciii] Romero, Juan Martin Canales. "Technology, Limitations and applications of space technology in developing countries." *Advances in Space Research.* Vol. 34, 2004, pp. 2203-2208.
[civ] George, Hubert. "Developing Countries and remote sensing: how intergovernmental factors impede progress." *Space Policy.* Vol. 16, 2000, pp. 267-273.
[cv] "Open and Closed Skies: Satellite Access in Africa." International Development Research Centre. http://www.idrc.ca/en/ev-51227-201-1-DO_TOPIC.html Accessed April 18, 2008.
[cvi] "The VSAT Industry: Regulatory Issues." The VSAT Forum. http://www.idrc.ca/en/ev-51227-201-1-DO_TOPIC.html Accessed April 18, 2008.
[cvii] George, Hubert. "Developing Countries and remote sensing: how intergovernmental factors impede progress." *Space Policy.* Vol. 16, 2000, pp. 267-273.

2 Literature Review

The following literature review has two major sections. The first section, called "The Role of Technology in Socioeconomic Development," draws from economic theory to explain how technological capability building is a vital part of national development. This section provides a theoretical grounding for the emphasis in this thesis on technology in a developing context. The second major section, called "The Use of Satellite Technology in Developing Countries," reviews some of the policy literature that articulates the issues and evolution of the field. After each section, a brief critique is offered to highlight the points in the literature that are most relevant to this study. The critiques also explain the unique contributions that this thesis provides to both bodies of literature.

2.1 The Role of Technology in Socioeconomic Development

The following discussion explores several issues related to the role of technology in the socioeconomic development of less developed countries. The first section explains the motivation for developing countries to build national technological capability. The following sections explain the various issues that a developing country encounters when seeking to make policy that encourages technical capacity building. First, there is the issue of **technology choice**; a country needs to decide how to invest in various levels of technology. Second, if a developing country does not have access to a technology domestically, they can consider options for **technology transfer** with other countries. Technology transfer can be very beneficial but there are many potential pitfalls that can make it ineffective as a vehicle for technological capability building. Third, a government can facilitate technological capability building by encouraging a strong **National System of Innovation**. Fourth, a country needs to establish the capacity for technical learning, called **absorptive capacity**. The fifth section explores the range of **roles a government** plays in order to facilitate technological capability building.

2.1.1 The Importance of Technological Capability Building

Technological capability building is a key to national socio-economic development. Robert Solow, Nobel Prize winner in Economics, demonstrates that technology plays a pivotal role in economic development.[cviii] This is not to say that technology always has positive impacts, but it has become widely understood that mastery of technology is a key step toward economic development. Cohen defines technology as "a set of specialized knowledge applied to achieving a practical purpose".[cix] Cohen goes on to categorize technology into five main forms, as follows: 1) theoretical and practical understanding of how to do things; 2) objects, good or tools; 3) installed techniques of production or processes; 4) skills and abilities of workers; and 5) organizational framework and managerial systems.[cx] In this study, all five forms of technology are relevant. Technological capability building is working intentionally to increase effectiveness or activity in each of these five areas. Huq summarizes the motivation for developing countries to pursue technical capability, saying, "Competitiveness and long-term growth are achieved through efficient technology management, innovation and technological progress."[cxi] He goes on to say that "the importance of building technological capability in developing countries and the significance of the role the state plays…cannot…be over-emphasized."[cxii] With this motivation in mind, the next sections discuss the challenges of pursuing technological capability building.

2.1.2 Technology Choice

Once a developing country chooses to invest in technological capability building, a fundamental question remains. What level of technology should the country pursue? Developing countries are, by definition, less advanced in technology than industrialized countries. Should developing countries try to gain skills in the advanced technology used by industrialized countries? Or should they instead invest in technology that is more "appropriate" to their stage of development?

Author Roy Grieve provides an historical overview of the changes in expert recommendations on this subject of technology choice.[cxiii] Grieve explains that in the 1960s and 1970s, development economists recommended that developing countries pursue "appropriate" technology that was highly labor intensive. A major problem of the time for developing countries was the lack of employment opportunity. Economists thus recommended that developing countries should invest in low-capital, labor intensive techniques wherever possible. This recommendation extended to large, medium and small scale enterprises. As Grieve summarizes, "The neoclassical appropriate technology strategy thus recommended that developing countries seek to achieve industrialization and build up their manufacturing capabilities on a *different* technological basis from that of the already advanced countries."[cxiv] The problem with this recommendation was that the low-capital, labor intensive technical option was not always readily available, even though theory suggested that it would be more beneficial. Thus, this neoclassical dream failed to lead to widespread improvement for developing countries.

In contrast to the neoclassical mantra of labor intensive technology, current development economics encourages developing countries to do their best to implement the same kind of technology that is used in industrialized countries. Indeed, as Grieve explains, "The recommended objective is to achieve a firm grasp of modern technology, learn from it, and on this basis, seek to develop innovation and technological capabilities."[cxv] The examples of several Asian countries, such as South Korea, show that a developing country can accomplish great economic growth by focusing on learning the technology used in more developed countries. Grieve thus concludes that the goal of developing countries should be "to leapfrog and narrow the technology gap or 'catch up' on the 'best practice' in advanced countries."[cxvi]

It should be noted, however that there is yet a third option. Starting in the 1970s and continuing through the turn of the century, another kind of appropriate technology movement developed in parallel with the recognition of the need for catch up. As Grieve explains, Dr. E. Schumacher is known as the father of the movement due to his seminal work called *Small is Beautiful.*[cxvii] This take on appropriate technology assumes that the efforts of developing countries to use technology will be dualistic. On one hand, developing countries will pursue the modern technology used by industrialized countries, particularly in urban centers. At the same time, to combat the problems of unemployment and to serve rural areas, countries should find ways to use "intermediate technology". Intermediate technology is characterized as labor intensive, suitable for small scale work and accessible to the context. Included in the idea of accessibility is that the technology is achievable given the financial and educational constraints of developing countries. The goal is not to limit innovation, but to use it creatively to find accessible ways to solve problems. Grieve concludes that this application of appropriate technology is basically successful and helpful but should be used in addition to, not instead of, the pursuit of advanced technology.[cxviii]

2.1.3 Technology Transfer

When developing countries do not have access to technology locally, they can seek to gain access to it from another country that has the technology. As discussed above, technology transfer can be a potential source of leap-frogging, but this is not automatic. According to Cohen, the success of technology transfer depends heavily on the initial technological capability of the recipient country.[cxix] Drawing on work by Bhalla, Cohen categorizes the world into three groups, "Technology leaders: the United States, Japan; Technology followers: other OECD countries; Technology borrowers: developing countries". Cohen finds that there is a cost associated with technology transfer and that this cost is higher if the countries involved are not in the same group, as defined above.[cxx]

Technology transfer may occur in a variety of ways, as outlined by Cohen. These include purchasing or licensing agreements, working with foreign experts, the presence of multi-national corporations in a developing country, training of workers in a developed country, creating institutions to facilitate technology transfer, or creating educational institutions.[cxxi] Cohen goes on to define a series of steps that a recipient country passes through during technology transfer. These stages are technology "assessment and selection, acquisition, adaptation, absorption and assimilation, diffusion, and development". These concepts bring together several of the other sections of this discussion. The assessment and selection stages relate to technology choice questions. The adaptation, absorption, and assimilation stages related to the sections below on National Innovation Systems and Absorptive Capacity.

Cohen's work explained what technology transfer is and how it can happen. Grieve's work, above, introduced the concept of leap-frogging, or using technology transfer to jump to a more advanced technology without going through the conventional, historical progression of learning and invention. But does leap-frogging really work? Gallagher, in her study on the potential for leap-frogging in the Chinese automobile industry, explains both the benefits and complications of leap-frogging through technology transfer. While the idea "captured the imaginations of innumerable scholars, students, and even some in the private sector," leap-frogging does not work automatically. Gallagher found that the effectiveness of leap-frogging is limited by three key areas: "1) un-strategic and inconsistent policies, 2) weak domestic technological capabilities, and 3) an apparent unwillingness of more advanced …firms to transfer …more efficient technologies beyond those simply required by the standards."[cxxii] In other words, even if advanced technology is available, the developing country may not benefit from it without specific ingredients. These ingredients will be discussed more in the section on absorptive capacity and National Innovation Systems below. These topics help address the apparent paradox that a developing country that wants to build technological capability must have technological capability. The sections below explain how a country can put itself in a good position to build technological capability through strong institutions and research.

2.1.4 National Innovation System

The institutional organization that facilitates technological capability building is the National Innovation System (NIS). The NIS framework provides a method by which to analyze the set of institutions concerned with science and technology and the interactions between those institutions. We can thus understand the ability of a nation to innovate, or build technological capability. Such institutions may include universities, firms, research agencies, administrative agencies, financial agencies and consumers. Some of the early studies based on this method were done in the 1980s by Freeman[cxxiii], Lundvall[cxxiv] and Nelson[cxxv].

Sharif[cxxvi] gives an overview of the development of the method. The NIS concept was developed partly in academia and partly in policy. As a result it is not a formal academic model, and may not necessarily be used to make predictions about the success of an NIS. It can be used, however, to describe systems and give useful policy insight. With regard to applying the framework, Sharif notes several cautions. The concept is very flexible and can be applied at different levels of analysis (national, regional, sectoral, etc). This does not mean it is always appropriate to apply it at these levels, however. One must consider how national sovereignty, cultural norms or globalization affect the analysis. Finally, there is disagreement as to whether every country has an NIS. Some contend that certain minimum requirements must be met while others argue that a system can always be defined, even if it is very poor.

Metcalfe[cxxvii] and Ramlogan used the NIS framework to examine innovation in developing countries. They offer some issues that arise when applying the framework to developing countries. First, one must be careful with the unit of analysis. When analyzing an activity that appears to be contained in a developing country, one should be aware that it may be connected to activities in other nations through global value chains or technical cooperation agreements. Because developing countries may have limited technology and expertise, they can be constrained to depend upon resources from other countries. Second, innovation can sometimes be taken to mean only invention of new technology. In the developing country context, however, innovation may come through imitation or technology transfer.

2.1.5 Absorptive Capacity

The ability to assimilate technology is known in literature as absorptive capacity. The concept of absorptive capacity was defined by three seminal papers written by Cohen and Levinthal in 1989[cxxviii], 1990[cxxix] and 1994[cxxx]. They argued that a firm's ability to use technology from outside sources is influenced by internal research and development[cxxxi]. They are viewed as the fathers of the concept, although they were not the first to make such an observation. Lane and Koka[cxxxii] reviewed the literature on absorptive capacity in 2006 and created a synthesized definition of the term based on all three seminal papers. From this synthesized definition several key ideas can be gleaned. First, a firm increases its capacity to learn about science and technology by doing research and development (R&D). Second, the overall organization will have better absorptive capacity if individuals are well informed and are also able to effectively communicate with other parts of the organization. Thirdly, there is a time component in absorptive capacity. It not only matters that firms can see what technology is currently relevant, but they also need to see what may be relevant in the future. Absorptive capacity thus includes a firm's ability to correctly understand the direction of technical change and make plans accordingly that will increase their profit.

This study uses the concept of absorptive capacity in a developing country context. Work by Lorentzen[cxxxiii] provides a precedent showing that the framework is appropriate when applied to a developing country. This paper uses data from the South African automotive component supplier industry and evaluates the validity of the absorptive capacity assumptions. Lorentzen divides the 25 firms of the study into four categories, "innovators, followers, mandate executers, cliff hangers". The overall behavior of these various groups does show consistency with the absorptive capacity model. The most successful group, the innovators, have high absorptive capacities. These firms invest highly in advanced technical training for their employees and have knowledge close to or on the technological frontier. At the other end of the spectrum are cliff hangers. These firms produce goods of decent quality but do not have an in-depth technical knowledge of the processes they follow. They rely heavily on their parent multinational corporation for technical direction. Lorentzen's work shows that the absorptive capacity concept can be used appropriately in a developing country context.

2.1.6 The Role of Government in Facilitating Technological Capability Building

The previous sections have developed the argument that it is vital for developing countries to build technological capability. They should seek to gain competence in the technologies used by industrialized countries. One way to achieve this is through technology transfer, in all of its various forms. Technology transfer is more likely to be successful if a country has a strong National Innovation System and absorptive capacity. Given all this, what is the role of government in promoting technological capability building? How can governments build absorptive capacity and strengthen the NIS? What activities should be performed by governments as opposed to the private sector?

There are a number of ways that governments contribute to technological capability building. Some of them are generally accepted as appropriate and necessary government activities, while some are more controversial. Each of these two categories of technology policy will be discussed below. Please note that this section is focused on *what* roles governments should take on. It does not provide complete answers for *how* governments should best accomplish these roles.

2.1.6.1 Points of Agreement on Government Roles

In his book *The Creation of Technological Capability in Developing Countries*[cxxxiv], J. L. Enos recommends a three-prong policy approach by which governments can facilitate industrial technological capability building. The points he outlines are generally not contested in literature. The three points are 1) The Nurturing of Skills, 2) The Creation of Organizations, and 3) The Instilling of Purpose. In the discussion on the Nurturing of Skills, Enos focuses on education policy. The author's main recommendations are to ensure universal primary education, to prioritize medium level technical or vocational training, and – at the university level – to put more emphasis on improving the technical fields than on the humanities. In the section on the Creation of Organizations, Enos recommends the creation of organizations that serve different purposes. Some provide various levels of technical training, some advance and disseminate technical knowledge and some improve productive efficiency. Together they facilitate the increase of technical capability. Finally, when considering the Instilling of Purpose, Enos points out that the coordination of activities and the manner in which information flows within an organization are key determinants of the group's sense of purpose. In summary, Enos suggests that governments should be concerned with providing education, creating appropriate organizations within the NIS – such as research institutions – and, ensuring coordination within the NIS.

Singh[cxxxxv] provides insight on the role of government in providing funds for research. He gives an historical overview of the government funding profiles of the industrialized countries including US, Japan and Europe. According to Singh, in the US the majority of research funding came from the government, not from private entities, in the period after World War II. Since that time, the trend has gradually reversed so that private funding is greater. Japan and Europe had a consistently lower level of research funding from government than private sources. Despite these trends, however, federal research funding was significant and helpful. Singh makes the point that even as federal research support decreased, federal policies still encourage research. Tactics such as tax concessions, public-private partnerships, and subsidies are growing in importance.

Another area in which governments contribute to technological capability building is by providing sound infrastructure. The United Nations' Task Force on Science, Technology and Innovation prepared a report entitled *Innovation: Applying Knowledge in Development*. One of the sections of the report outlines the benefits that come when developing country governments invest in infrastructure. On one hand, the infrastructure serves to facilitate the activities of firms and society in general. On the other hand, the process of creating infrastructure is an opportunity for countries to build technical capability. The report encourages governments to look at infrastructure projects as learning opportunities for domestic governments and firms. Infrastructure includes energy systems, communication, water, sanitation and even research facilities. The report notes that the lack of adequate infrastructure in developing countries is a barrier to growth in many countries.[cxxxvi]

Governments also influence technological capability building through trade policy. Salvatore provides an historical overview of trade policy in developing countries since the 1950s. He shows how initially many developing countries tried to establish a strong industrial base by closing their countries to imports. They sought to manufacture many of the items they had been importing. They minimized imports through quotas and tariffs. Later in the 1970s and continuing into the 1990s, countries gradually recognized that these import-substitution policies did not lead to economic growth. Consequently, instead of closing their economies, they began to liberalize their economies to allow more trade.[cxxxvii] Government policies can encourage access to foreign technology by reducing barriers to trade and creating favorable conditions for foreign investment.

The final element of government policy that is generally agreed upon as an appropriate role for government in encouraging technological capability building is macroeconomic policy. Bird describes the three facets of macroeconomic policy in his paper "Conducting Macroeconomic Policy in Developing Countries: Piece of Cake or Mission Impossible?" Macroeconomic policy includes monetary policy, fiscal policy and exchange rate policy. Governments can use these instruments to create an economic environment that is stable enough to encourage investment in technical learning and innovation. Developing countries face particular challenges in using these instruments, however. Bird recommends "that developing countries need to focus on long-term structural change aimed at reducing their vulnerability to external shocks and creating an economic environment which allows traditional measures of macroeconomic policy to work better."[cxxxviii]

2.1.6.2 Point of Contention on Government Roles

The main of area of contention about the role of government in technology policy is the question of whether the government should purposely try to promote specific sectors within the economy. Such tactics are often called industrial policy. Returning to Grieve's paper, we see that there are experts on both sides of the argument. Some urge that governments should create an environment that fosters innovation but not intervene directly. Others point to success stories in Asia as proof that government intervention is good. Such intervention can come in the form of building infrastructure to support a specific sector or licensing more foreign technology in a certain area. Grieve does not try to settle the dispute; he only explains the posture of each side.[cxxxix]

It should be noted here that neither side of the industrial policy argument is suggesting that the government should be a dominant player in the market. Both sides are assuming a generally free market economy with few state owned enterprises. This is worth mentioning because of the history of developing countries. Between the 1950s and the 1980s, when many developing countries engaged in limited trade as discussed above, there was also a trend toward strong nationalization and a heavy public presence in the economy. Some developing countries are still in the process of privatizing their major industries, but most started the effort in the 1980s.[cxl]

2.2 Critique of Literature

The above discussion is included in this study in order to provide a broad background on the relationship between technology and developing countries. The motivation of this work is a desire to understand and improve the use of satellite-based technology in developing countries. We can now argue that the use of such technology to meet needs in developing countries is appropriate. Not only can it solve problems, it is also part of their process of building technological capability. We can further argue that it is in the best interest of developing countries to progressively improve their understanding of satellite technology when they use it. From the discussion above, it is clear that more benefit will come to developing countries if they master and produce satellite technology than if they just benefit from its services. This principle is implicit in the methods and arguments used throughout this study. The same principle is also voiced in a paper by the United Nations in 1988.[cxli]

Some elements of the literature reviewed above do not apply directly to the study of satellite-technology in developing countries. The literature argues that technological capability building can be part of the process that leads to socio-economic development. While this is true, it will not be directly measured in this study. We will not demonstrate with data that building technological capability in satellite technology directly leads to socio-economic development. Rather, we use data on satellite usage and data on development level and ask if there is any statistical relationship between the two. This is partly to learn whether countries that are less developed tend to be excluded from the benefits of satellite technology. At the same time, we show whether countries that are more developed tend to benefit more.

It should be noted that much of the reviewed literature focuses on the firm as the central user of technology. This is true in the discussions above on absorptive capacity, on technology transfer and on the role of government. When dealing with satellites, the firm is not always the central player. Often satellite projects are funded by governments or by partnerships between governments and private entities. Current remote sensing satellites are sponsored by both governments and companies. The data they produce is bought and sold across public and private boundaries. The current satellite navigation systems are utilities owned by governments and used freely by everyone. Meanwhile, the ground equipment to access navigation satellites has spurred a major industry. Communication satellites are launched by governments and private entities. The original government communication organizations, like INTELSAT, are now operating commercially. In short, it is difficult to tie satellite technology to either the government or the commercial sector. In some aspects, satellites are a form of infrastructure that is best provided by government. But satellites can also be capital investments for commercial ventures. No attempt is made in this thesis to specify whether the use of satellite technology in developing countries should be a government or commercial activity. Instead we gather data about specific projects and learn about what kind of organizations are involved. There is a focus on government activity in several aspects of our data collection, however. The national Space Participation Metric data and the Space Program Case Studies primarily cover government activities.

As mentioned above, most of the literature on technology as a tool for development assumes the centrality of the firm. Here we identify a gap in the literature that we will help to fill. There is little discussion of technology transfer involving government entities, yet many of the project case studies found in this study are examples of this. Meanwhile, absorptive capacity is defined for firms, but could potentially be relevant for government programs as well. While we cannot blindly apply the findings discussed above on technology transfer, absorptive capacity or the role of government, the basic concepts in this segment of the literature review are valuable.

To summarize, this thesis does build on the foundations from the literature presented above. Technological capability building is a key step to development. From the discussion on technology choice, it is clear that developing countries should pursue competence in advanced technology like satellites. Further, they can gain this competence partly through technology transfer. The transfer process will be more successful if the country has a strong NIS and has organizations with good absorptive capacity. The role of government in this area includes investing in education, building basic infrastructure, making policies that encourage access to new technology and even investing directly in and operating satellite technology itself.

2.3 The Use of Satellite Technology in Developing Countries

There is a body of literature on the use of satellite technology in developing countries. Relevant publications include conference proceedings, workshop reports, news reports, agency reports and scholarly articles. This section provides an overview of some of these publication sources and the information they provide. In addition, we explain the gap filled by this research.

One of the main sources is work by the United Nations Office of Outer Space Affairs in partnership with organizations such as the International Astronautical Federation (IAF) and the European Space Agency. The UN holds a variety of types of workshops relating to satellite technology in developing countries. Some workshops provide training in specific topics such as satellite-aided search and rescue. Others give information about the current status of projects in a particular area. One specific example is the series put on as part of the Programme on Space Applications. The UN has hosted many workshops since 1998 to educate stakeholders about the benefits of satellite technology for developing countries. Summary reports from these workshops are available online.[cxlii]

As an example we summarize here the report on the UN/International Academy of Astronautics Workshop on Small Satellites in the Service of Developing countries held in Valencia Spain in 2006 as part of the International Astronautical Congress.[cxliii] The workshop grew out of recommendations made at the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE III) in 1999. At UNISPACE III, it was recommended that developing countries should seek to build and operate small satellites as a way to develop domestic industry for space technology. Small satellites were seen as particularly appropriate to meet needs in developing countries because they are cheaper, faster to build and less complex than larger satellite missions. The workshop included four presentations from speakers representing the French Space Agency, Surrey Satellite Technology Limited (SSTL), South Africa and Indonesia. The French speaker described an example of a small satellite bus platform and explained how it could be used in the context of developing countries. The speaker from SSTL described the international collaboration in the Disaster Monitoring Constellation, an effort that includes several developing countries. The speaker from South Africa talked about progress in the African Resource Management constellation project. Indonesia discussed satellite activities in both their country and Malaysia. As can be seen, such workshops are helpful for providing examples of satellite projects in developing countries. They do not, however, provide an overview of the technical community or analysis about trends. This thesis adds to the literature by filling these gaps.

In addition to the United Nations Office of Outer Space Affairs, other agencies provide publications that give insight into the use of satellites in developing countries. The International Telecommunications Union (ITU), for example, produces reports such as "ICT and Telecommunications in the Least Developed Countries – Mid-Term Review for the Decade 2001-2010."[cxliv] ITU reports like this provide a broad overview of trends in communication technology, but do not focus on satellite communications specifically. Also, the publications of the Global VSAT Forum (GVF) provide useful insight into regulatory issues surrounding the use of satellite technology for communications. The GVF is a professional association of companies involved in the fixed satellite communication industry. Their annual report from 2001 highlights the progress made in the deregulation of the VSAT industry in Africa, Asia and the Americas.[cxlv] Many countries have had a monopolistic satellite communication industry; the monopoly was often held by a state owned entity. The GVF lobbies governments to lower barriers to competition and provide licenses to more VSAT companies. This ultimately leads to lower prices for the consumers.

We turn now to scholarly publications on the topic of satellite technology for use in developing countries. A number of papers have described specific projects or satellite missions. This review focuses not on these types of papers, but on more general papers that have grappled with the topic at a high level. The papers are discussed in chronological order, where appropriate.

In 1983, Bhavsar wrote an article entitled "Earth Survey Satellites and Cooperative Programmes," which provided an overview of international cooperation in the first twenty years of satellite remote sensing.[cxlvi] The author was from the Space Applications Centre of the Indian Space Research Organisation. Overall, the article shows that in the 1960s most collaboration in remote sensing was bilateral partnership between the United States and other countries. By the 1980s, more countries had developed remote sensing capability and multilateral collaboration had become more common. A major turning point in this process was the first United Nations Conference on the Exploration and Peaceful Uses of Outer Space in 1968. This meeting "played an important role in creating world wide awareness about the peaceful uses of space."[cxlvii] In 1970, the author was part of a team asked by the United Nations to produce a report recommending ways to increase participation of developing countries in satellite remote sensing collaborations. As part of the project, the author visited Argentina, Brazil, France, Indonesia, Iran, Japan, the United Kingdom, the United States and the Soviet Union to learn about their satellite remote sensing programs. With this experience, they recommended that developing countries may be more likely to join partnerships if they are facilitated by neutral, multilateral organizations such as the UN. They specifically recommended that funding be made available to support travel, new organizations and projects in developing countries.

In a 1988 article, Kingwell wrote about the potential dangers for developing countries if the current space faring nations started to use Data Relay Satellites to transmit remote sensing data from satellites to centralized earth stations.[cxlviii] Kingwell contrasted two scenarios. The first was the status quo. In this case, most remote sensing satellites were in Low Earth Orbit (LEO) and transmitted their data to earth stations when they passed over them. If a developing country wanted to receive satellite data about its region that was produced by another country's satellite, they could buy or request the right to receive the data directly from the satellite. In this way, they did not have to depend on the country that owned the satellite to send the data to them later. The second scenario that Kingwell feared was as follows. Space faring nations use geosynchronous data relay satellites to send earth remote sensing data from LEO satellites to central data collection stations in the home country of the satellites. In this second scenario, if a developing country wants to have access to the data, they get it later from the home country. The potential disadvantages of this scenario for developing countries are given. First, they may have less timely access to the data. Second, they may receive data that is processed in a way that is not relevant to their physical circumstances. Third, it reduces the opportunity for developing countries to maintain or build skills in processing raw satellite data. The author recommended that if Data Relay Satellites were used, satellite owners should also continue to allow direct downlink of data to earth stations in other countries.

In 1988 Abiodun *et al* wrote an article in the journal *Space Policy* called "Development of Indigenous Capability in Remote Sensing."[cxlix] Abiodun was the UN Expert on Space Applications, but wrote in an unofficial capacity. The paper encouraged developing countries to pursue capability in remote sensing, but warned that they too frequently limited themselves to using applications of the technology. Rather, they should seek to understand the technology at a fundamental level and seek to build indigenous capability. The paper mentioned that many partnerships between developing countries and industrialized countries in remote sensing provided the opportunity for technology transfer. The warning was that such transfer can not succeed unless the recipient country is prepared to learn about the new technology. The paper suggested that developing countries seek to build research capability and supportive institutions. Abiodun goes on to describe the activities of the United Nations Programme on Space Applications as a partial solution to address these issues. Part of the work of the PSA included creating Regional Space Science and Technology Centres to equip developing countries with better skills in the field. With its focus on the need for in-depth technical understanding and research capability, the paper echoed the ideas presented above about building a strong NIS and increasing absorptive capacity in order to facilitate technology transfer. Another benefit of the paper is that it introduced the United Nations Principles of Remote Sensing. These principles were developed in 1986 to provide guidance for the legal and political issues surrounding remote sensing. The authors recalled that the Principles encouraged countries with remote sensing capability to share their data openly with the countries they observed. This provides a foundation for international cooperation in remote sensing.

Codding wrote an article in 1989 focused on issues in satellite communications for developing countries.[cl] Codding considered the state of INTELSAT as it faced new sources of competition including INMARSAT, under sea cables and regional satellite organizations. Codding presented the concern that INTELSAT could respond to such competition by changing its pricing to the detriment of developing countries. Codding particularly suggested that developing countries would lack access to domestic satellite communications. As a solution, Codding recommended that the ITU lead the formation of a global satellite communication system dedicated to domestic satellite communication for developing countries. The system would be called Glodom. Codding discussed the history of RASCOM and used it as a model for the formation of Glodom. RASCOM is the Regional African Satellite Communication Organization.

Consider the next set of three papers and the trends they reveal. Rao and Bhavan wrote in 1993 and provided an overview of satellite activity in developing countries in communication, education, remote sensing, disaster management and space science. Their main argument was that satellite technology could help developing countries but that most were not involved with the technology. Rao and Bhavan highlighted the activities of China and India in satellite technology as excellent, but exceptional. They closed with recommendations on how international assistance could be mobilized to get more developing countries involved with space technology.[cli] In 1993, Hubert George wrote a much more optimistic article called "Remote Sensing of Earth Resources: Emerging Opportunities for Developing Countries."[clii] At this time, George was seeing changes in the technical and political systems that influenced the use of satellite remote sensing technology in developing countries. Specifically, George mentioned five trends that could increase access to remote sensing technology for developing countries. First, the technology of remote sensing and the computation that supports it were improving, making it more affordable and easier to use. Second, the global community was paying more attention to environmental issues, thus prioritizing the need for earth observation data. Third, the cost of satellite missions was decreasing as smaller, less expensive satellites were becoming more capable. Fourth, more government and commercial entities were producing remote sensing data; this led to more options and potentially better prices for data consumers. Fifth, there was an increase in international efforts to coordinate earth observation data and to include developing countries. This was evidenced by the activities of specific international organizations. The third paper in this series, written in 2003 by Othman, is called "Small Satellites for the Benefit of Developing Countries."[cliii] Othman repeated some of the optimism of George and emphasized that it was feasible for many developing countries to pursue indigenous capability in satellite technology by investing in small satellites. Othman made the point that this was one of the major recommendations of the third United Nations Conference on the Exploration and Peaceful Uses of Outer Space in Vienna in 1999, as described above. He provided the example of the successful development of the SunSat spacecraft in a South African university. In addition, Othman mentioned examples of small satellite projects in Mexico, Peru, Brazil, Argentina and Chile. A brief look at these three articles shows an apparent increase in the participation of developing countries in satellite remote sensing technology between 1993 and 2003. Several helpful technology and policy changes eased access to the technology.

The paper by Barker, Barnes and Price from 1996 provided some technical insight into the design of communication satellites that is most appropriate for developing countries.[cliv] Specifically, the authors suggested several design features that could make communication satellites more affordable while still meeting the needs of developing countries. One example was the operational frequency band. The authors advised the use of the lowest frequency that would still meet the users' needs. A mix of lower and higher frequencies could be used to enhance performance. Also, the authors noted that it was generally advisable to have satellites send their data directly to earth stations rather than linking with other satellites first. Ultimately, the authors gave practical advice to decision makers in developing countries that want to pursue cost effective satellite technology.

Also noteworthy is a paper by Neumann from 2006.[clv] It discussed implications from space law on the use of satellite technology for developing countries. Neumann opened by questioning whether developing countries have any right to benefit from satellite communications based on international law. As part of the background of the paper, Neumann acknowledged the existence of a digital divide between developed and developing nations. Satellite technology was identified as one appropriate tool to reduce this divide. Neumann then analyzed five specific areas to see what rights were provided by international law for developing countries in this arena. Neumann used international agreements and treaties such as the Outer Space Treaty to draw five conclusions. The conclusions are as follows. First, developing countries have a right to use the geostationary orbits and communications frequencies assigned to them as part of international negotiations. Second, there is no specific right of developing countries to receive technology that is transferred from developed countries. Stated another way, developed countries are under no obligation to transfer technology to developing countries. Third, developing countries working with INTELSAT do have a right to ensure continuity of service. This right was established by contractual agreement when Intelsat was privatized. International law has no bearing on this, however. Fourth, developing countries do have a right to provide universal telecommunications service to their citizens even if this requires non-competitive practices. Fifth, while international law encourages collaboration between nations, there is no clear right of developing countries to benefit from collaborations with developed countries. In general, Neumann's analysis shows that nothing bars developing countries from using satellite technology; however, nothing in international law guarantees that developing countries will receive assistance from other nations.

2.4 Critique of Literature

What does this review of literature on the use of satellite technology in developing countries reveal? What knowledge is already established in the field and what remains to be researched? Several themes stand out and will be expanded upon here. To begin, note that the satellite community recognized from its early days that there was potential to meet the needs of developing countries with this technology. Conferences held by the United Nations and others gathered and recorded the knowledge of this potential. Also, from the early days of the space era, there was controversy about how to ensure that all countries would benefit from access to space. The controversy was rooted in concerns about security, intellectual property and political ideology. Another theme that echoed in several papers was that developing countries needed access to technology from developed countries in order to use satellites. There was also a gradual historical progress toward increasing activity of developing countries with satellite technology. Whereas older papers complained that only a few developing countries had any space projects, later papers were excited to explain that the technology was becoming more accessible to more countries. This increase is partly due to the emphasis on small satellites for developing countries. It should be noted here, though, that such "small" satellites can not be used for geosynchronous communication or weather missions. They are very well suited for non-real time remote sensing missions, however.

Consider now the style and methodology of the literature in this field. Most papers are written based on the experience of the authors, not based on verifiable data. A few papers provide examples case studies, but the number of case studies is very limited. The papers are useful to provide a qualitative understanding of the needs, issues and trends in the field. They are not, however, rigorous research papers in which questions are answered using quantitative methods. One reason why the papers are so qualitative in nature is that it is difficult to gather accurate data about the use of technology in developing countries. This thesis, therefore, is making a great contribution to the literature on satellite technology in developing countries. This study brings together copious data about space projects and programs in developing countries. The data is used in statistical tests to create new information. Note also that the results of this thesis inform about the relationship between development and space activity. This is valuable because it tests, for the first time, the assumptions and theories that undergird many papers about satellite technology in developing countries.

[cviii] Solow, R. "Technical Change in the Aggregate Production Function". *Review of Economics and Statistics,* Vol. 39, No. 3, pp. 312-320.

[cix] Cohen, Goel. *Technology Transfer: Strategic Management in Developing Countries.* Sage Publications. New Delhi. 2004, p. 66.

[cx] Cohen, Goel. *Technology Transfer: Strategic Management in Developing Countries.* Sage Publications. New Delhi. 2004, p. 35.

[cxi] Huq, Mozammel. "Building technological capability in the context of globalization: opportunities and challenges facing developing countries." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 155-171.

[cxii] Huq, Mozammel. "Building technological capability in the context of globalization: opportunities and challenges facing developing countries." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 155-171.

[cxiii] Grieve, Roy. "Appropriate Technology in a Globalizing World." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 173-187.

[cxiv] Grieve, Roy. "Appropriate Technology in a Globalizing World." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 173-187.

[cxv] Grieve, Roy. "Appropriate Technology in a Globalizing World." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 173-187.

[cxvi] Grieve, Roy. "Appropriate Technology in a Globalizing World." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 173-187.

[cxvii] Schumacher, E.F. *Small is Beautiful: A Study of Economics as if People Mattered.* Vintage Books, London, 1973.

[cxviii] Grieve, Roy. "Appropriate Technology in a Globalizing World." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 173-187.

[cxix] Cohen, Goel. *Technology Transfer: Strategic Management in Developing Countries.* Sage Publications. New Delhi. 2004 p. 139.

[cxx] Cohen, Goel. *Technology Transfer: Strategic Management in Developing Countries.* Sage Publications. New Delhi. 2004 p. 160.

[cxxi] Cohen, Goel. *Technology Transfer: Strategic Management in Developing Countries.* Sage Publications. New Delhi. 2004 p. 113.

[cxxii] Gallagher, K. "Limits to leapfrogging in energy technologies? Evidence from the Chinese Automobile Industry". *Energy Policy.* Vol 34. 2006, pp. 383-394.

cxxiii Freeman, C. (1995). The national system of innovation in historical perspective. Cambridge Journal of Economics, 19(1), 5–24.

cxxiv Lundvall, B. (1992). *National systems of innovation*. London: Pinter.

cxxv Nelson, R. R. (Ed.). (1993). *National innovation systems: A comparative analysis*. New York/Oxford: Oxford University Press.

[cxxvi] Sharif, N. "Emergence and development of the National Innovation Systems Concept". *Research Policy.* Vol 35. pp 745-766. 2006.

[cxxvii] Metcalfe, S. "Innovation Systems and the competitive process in developing countries". *The Quarterly Review of Economics and Finance.* 2007.

cxxviii Cohen, W., & Levinthal, D. 1989. Innovation and learning: The two faces of R&D. Economic Journal, 99: 569–596.

cxxix Cohen, W., & Levinthal, D. 1990. Absorptive capacity: A new perspective on learning and innovation. Administrative Science Quarterly, 35: 128–152.

cxxx Cohen, W., & Levinthal, D. 1994. Fortune favors the prepared firm. Management Science, 40: 227–251.

[cxxxi] Lane, Koka. "The Reification of Absorptive Capacity: A Critical Review and Rejuvenation of the Construct". Academy of Management Review. Vol 31, No. 4, 833-863. 2006

[cxxxii] Lane, Koka. "The Reification of Absorptive Capacity: A Critical Review and Rejuvenation of the Construct". Academy of Management Review. Vol 31, No. 4, 833-863. 2006

[cxxxiii] Lorentzen, J. "The Absorptive Capacities of South African Automotive Component Suppliers". *World Development.* Vol. 33, No. 7, pp. 1153-1182, 2005.

[cxxxiv] Enos, J., L. *The Creation of Technological Capability in Developing Countries".* International Labour Organisation. Pinter Publishers, London.1991.

[cxxxv] Singh, Lakhwinder. "Globalization, national innovation systems and response of public policy." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 215-231.
[cxxxvi] Juma, Calestous and Yee-Cheong, Lee. *Innovation: Applying Knowledge in Development.* UN Millennium Project Task Force on Science, Technology and Innovation. Earthscan. Sterling, 2005.
[cxxxvii] Salvatore, Dominick. "International Trade Policies, Industrialization, and Economic Development." *International Trade Journal.* Vol. 10, No. 1, 1996, pp. 21-47.
[cxxxviii] Bird, Graham. "Conducting Macroeconomic Policy in Developing Countries: Piece of cake or Mission Impossible?" *Third World Quarterly.* Vol. 22, No. 1, 2001, pp. 37-49.
[cxxxix] Grieve, Roy. "Appropriate Technology in a Globalizing World." *International Journal of Technology Management and Sustainable Development.* Vol. 3, No. 3, 2004, pp. 173-187.
[cxl] Al-Obaidan, Abdullah. "Efficiency effect of privatization in the developing countries." *Applied Economics.* Vol 34. 2002, pp. 111-117.
[cxli] Abiodun, Adigun, et al. "Development of indigenous capability in remote sensing." *Space Policy.* 1988.
[cxlii] "Index of Online Reports on the Activities of the United Nations Programme on Space Applications." UN Office for Outer Space Affairs. http://www.unoosa.org/oosa/en/SAP/activitiesrep/index.html Accessed April 19, 2008.
[cxliii] "Report on the Seventh United National/International Academy of Astronautics Workshop on Small Satellites in the Service of Developing Countries." United Nations, Committee on the Peaceful Uses of Outer Space. 15 January 2007. http://www.unoosa.org/oosa/en/SAP/activitiesrep/index.html Accessed April 19, 2008.
[cxliv] "ICT and Telecommunications in Least Developed Countries – Mid-Term Review for the Decade 2001-2010." International Telecommunications Union. http://www.itu.int/ITU-D/ldc/publications.html Accessed April 19, 2008.
[cxlv] "Reports and Accounts 1999-2001." Global VSAT Forum. http://www.gvf.org/gvf/about/index.cfm Accessed April 19, 2008.
[cxlvi] Bhavsar, P.D. "Earth Survey Satellites and Cooperative Programmes." *Advances in Space Research.* Vol. 3, No. 7, 1983, pp. 139-147.
[cxlvii] Bhavsar, P.D. "Earth Survey Satellites and Cooperative Programmes." *Advances in Space Research.* Vol. 3, No. 7, 1983, pp. 139-147.
[cxlviii] Kingwell, Jeff. "Data Relay Satellites and Remote Sensing." Space Policy. May 1988, pp. 103-107.
[cxlix] Abiodun, Adigun Ade, Camacho, Sergio, Oesberg, Rolf-Peter, Zhukov, Vladimir. "Development of Indigenous Capability in Remote Sensing." *Space Policy.* 1988, pp. 122-130.
[cl] Codding, George, "The Glodom Alternative." *Space Policy.* August 198, pp. 227-236.
[cli] Rao, U.R., Bhavan, Antariksh. "Space Technology in developing nations: an assessment." May 1993, pp. 166-171.
[clii] George, Hubert. "Remote Sensing of Earth Resources: Emerging Opportunities for Developing Countries." *Space Policy.* Vol. 14, 1998, pp. 27-37.
[cliii] Othman 2003 Othman, Mazlan. "Small Satellites for the Benefit of Developing Countries." *Acta Astronautica.* Vol. 52, 2003, pp. 687-690.
[cliv] Barker, Keith, Barnes, Carl, Price, Kent. "Space Based Communications Infrastructure for Developing Countries." *Proceedings of AIAA International Communications Satellite Systems Conference.* Washington, D.C. 1996.
[clv] Neumann, J. "Satellite Telecommunications as a Tool for Bridging the Digital Divide – Public International Law Implications." *Proceedings of the 57th International Astronautical Congress.* Valencia, 2006.

3 Data and Analysis Methods

The following section provides an overview of the analysis used in this study to answer the three research questions. The first section introduces the research questions and briefly summarizes the methods used to answer them. The next section provides more detail regarding the data sources used in the analysis. The last section discusses each research question in turn and shows how specific data sets are analyzed to answer them.

3.1 *Summary of Research Questions and Methodology*

This thesis is built around three research questions that seek the connection between space activity and development level in developing countries. The questions are as follows.

1) How does national development level relate to national space activity?
2) What Mission and Management Architectures are developing countries using to apply satellite-based technology to national needs?
3) How does national development level influence the Mission and Management Architectures used by developing countries in satellite-based technology projects?

Statistical analysis with quantitative data is used to answer these questions. Question 1 uses Chi-Squared analysis to measure whether there is a statistically significant difference in national space activity between countries at different development levels. Question 2 uses a large collection of case studies to understand the trends in accomplishment and implementation for specific space projects in Africa. Question 3 draws on the trends identified in Question 2. It uses statistical analysis to find whether there is a difference in space project activity between African countries at different development levels.

Note that the three research questions build on each other while providing different levels and scope for analysis. The first question considers space activity very generally, but includes all sovereign nations in the world. The second question zooms in geographically to focus only on African countries. This allows for a more detailed study of specific space activities. Question 2 is exploratory. The data is observed, categorized and organized in an effort to learn new information. Question 3 takes the observation a step further. While still considering specific space projects in Africa, it uses statistical analysis to concretize the observations in Question 2. Although the analysis does not completely answer the research questions, together the work provides strong evidence about the relationship between national development level and space activity. Complementing all of this quantitative data is a set of in person interviews with representatives of 30 African countries. These conversations provide valuable context for this entire analysis.

3.2 *Overview of Data Sources*

The next section explains the motivation and collection of the five major data sources in this research.

3.2.1 Development Indicators

As discussed earlier, one of the main goals of this project is to understand how national development level influences the use of satellite-based technology. In order to investigate this quantitatively, a method to quantify development is needed. There is no need for the author to derive a metric for development because many specialized agencies have created such indices.

Examples include the Global Competitiveness Report of the World Economic Forum[clvi] and the World Bank's World Development Indicators[clvii]. While many data sources could be used with equal benefit, this study relies mainly on the Human Development Report by the United Nations Development Program.[clviii] The Human Development Report is an annual summary of key development indicators for nations around the world. It is created based on the philosophy that development is "expanding the choices people have to lead lives that they value."[clix] Part of the goal of the report is to consider indicators beyond economic data to measure development.

The Human Development dataset is chosen for several reasons. First, it strives to provide data for every country in the world. This gives a total of 177 countries for this collection. Second, it provides a multi-faceted approach to measuring development. It provides statistics for many areas of life, from health to education to finances to equality. Third, it makes the statistics for each country available in a convenient format for independent analysis. Fourth, it includes an aggregate measurement of development called the Human Development Index (HDI). The 2006 version of the Human Development Report is the source used in this study. It was the latest version available at the time this analysis was initiated.

The Human Development report includes a huge set of data with many development indicators. Six specific indicators were chosen to be used in several stages of this analysis. They are listed below.

1. Human Development Index
2. Human Development Level
3. Gross Domestic Product (GDP), in billions of 2004 US dollars
4. Gross Domestic Product per Capita, with Purchasing Power Parity[clx] in 2004 US dollars
5. Public Education Expenditure as a percentage of GDP
6. Internet users (per 1000 people)
7. Cellular Subscribers (per 1000 people)

As discussed above, the Human Development Index is a composite indicator created by the authors of the Human Development Report. This index is one number – between zero and one – that combines several statistics in the report to describe a country's development level. This provides a convenient way to compare the development level of all countries. Specifically, the HDI considers the average status for four indicators – life expectancy at birth, adult literacy rate, school enrollment ratio, and GDP per capita.[clxi]

The Human Development Level is derived from the HDI. The Human Development Report divides all countries into 3 groups – High, Medium and Low Development – based on their Human Development Index. The group with the highest indices is considered "highly developed." The next group is in "medium development," while the lowest set of indices are termed "low development." It is possible for multiple countries to receive the same Human Development Index score. For the 177 countries ranked in the 2006 Human Development Report, the 63 countries with an HDI of .800 or above are labeled as highly developed. The middle set includes the 83 countries with HDI's between .500 and .798. The low development countries have HDIs from .311 to .492. In this research, countries are compared using both their HD Index (from zero to 1) and their HD Level (from low to high).

Gross Domestic Product, in total and per capita, are included because they are traditional measures of economic development for countries. It is also significant that access to satellite-based technology is expensive. One would therefore expect that national space activity increases with GDP. Note that the GDP per capita value is normalized using Purchasing Power Parity (PPP) rates of exchange. This means that when the diverse currencies are converted into US dollars, the price differences in the countries are taken into account.[clxii]

Public Education Expenditure is one of the development indicators included. It is chosen as a proxy measurement for the level of education in the country. The use of satellite-based technology requires a well educated workforce. It is therefore assumed that countries who are more active with satellite technology may invest more on education. Other indicators of the education level of the workforce or the emphasis on science and technology would be desirable. The Human Development Report does include a set of indicators meant to reflect "Technology: Diffusion and Creation." These include records on patents, license fees, as well as research and development expenditure.[clxiii] Unfortunately, many of these indicators have incomplete records. There are many gaps in the data, especially among African countries. Because this study focuses so much on Africa, we use the more complete education indicator only.

The final two development indicators pulled from the Human Development Report are Internet Users (per 1000 people) and Cellular Subscribers (per 1000 people). Both of these statistics show the use of relatively new communication technology. They are very relevant measures, especially because in many developing countries internet access and international cell phone calls are enabled by satellites. More generally, the adoption of these advanced technologies is a measure of development. Countries that have higher use of satellite technology may also have high usage rates for internet and cell phones.

Each of the indicators listed above shows different aspects of national development. It is assumed in each case that a higher score in the indicator equates to a higher level of development. Please note that the development indicators outlined here will henceforth be referenced by abbreviations, as given below.

1. HDI
2. HD Level
3. GDP
4. GDP per Capita
5. Education Expenditure
6. Internet Users
7. Cellular Subscribers

3.2.2 Space Participation Metric

Recall that a major goal of this work is to compare national development level with national space activity. The previous section shows that there are a variety of sources from which to draw quantitative development indicators for individual countries. The same is not true for national space activity. There is not a ready source of quantitative data that compares many countries on the basis of their space-related work. It was thus incumbent upon this researcher to create a method to measure national space activity. This has led to the creation of the Space Participation Metric (SPM).

The SPM is a value defined for all sovereign countries in the world. The purpose of the SPM is to provide a quantitative value that describes how active a given country is in space-related activities. The SPM for each country is assigned based on a simple point system. One point is awarded to each country for every space activity from the SPM List of Space Activities in which it participates. The List of Space Activities includes twenty-one items in four categories. The categories are designed to distinguish different levels of technical achievement. Thus, Category 1 is the set of activities with the lowest technical level. This category includes membership in a space related society, hosting a meeting with space themes or participation in regulatory action with regard to space. Meanwhile, Category 4 is the highest technical level. This includes the use and ownership of spacecraft and launching hardware. Categories 2 and 3 fill in the technical spectrum. Category 2 includes activities that show evidence for space related education, research or capacity building programs. Category 3 is for activities that show evidence of the use of ground based space hardware, such as communication or satellite tracking equipment.

The table below shows the full List of Space Activities considered for the SPM analysis. They are divided based on their Categories as outlined above. More detail about the specific activities with full nomenclature and references can be found in Appendix A.

Table 1: List of Activities Used in Space Participation Metric Definition

List of Space Activities Used in SPM Definition		
Category	**Definition**	**Space Activities**
1	Evidence of membership in international space related society, hosting of space meeting or space-related regulatory action	• UN COPOUS Members as of 2004 • Group on Earth Observations Member • Host an International Astronautical Congress Conference • Member of IMSO • Member of ITSO • Member of ITU • Member of IAF • Member of IAU • Signed Outer Space Treaty
2	Evidence of space related education, research, or capacity building programs	• Inclusion in UN Directory of Education for Space Science • National Space Program (according to *Jane's Space Directory)* • Space Institutes or Organizations (according to *Jane's Space Directory)* • Participate in UN PSA • Report to UNOOSA on nationals space activities or research

3	Evidence of ground based space hardware	• Domestic Communication Satellite system • International Communication Satellite Earth Stations • Earth Observation Facilities and Equipment (*Jane's Space Directory)*
4	Evidence of space hardware or launch facilities	• Launch Facilities (*Jane's Space Directory)* • Launch Vehicle(s) (*Jane's Space Directory*) • Participant in International Space Station • Appear on UN Launch Registry

Several factors limit the kinds of activities that can be included in the List. First, in order to use the activity, an accurate and exhaustive participation list must be available. This avoids the danger of giving some countries credit for participation in an activity while neglecting others that participate in the same activity. For example, it would be preferable to give space participation points for each country that has a national space program or national office concerned with space matters. It is very difficult, however, to say precisely which countries have national space offices of this kind. In this case, points are awarded to countries that are listed in *Jane's Space Directory*[clxiv] because it is a reputable publication that aims to include internationally relevant space information. A second criterion for including a space activity is that it must be, in theory at least, available to every country in the world. That is, there must an opportunity for every country to participate. Some activities on the list may not seem to meet this criterion. For example, not every country in the world was invited to participate in the International Space Station because not every country has the space expertise necessary to contribute. The author takes the stance that, in theory, any country could have achieved the necessary technical prowess to participate in the ISS. Thus this activity is included. A third criterion is applied when selecting Space Activities. They must be activities for which credit can be applied at a country level. This does not necessarily imply that every activity is done by a national government, though many are. This does imply that the context of the activity includes associating participants with their country. For example, there are several activities related to the United Nations. Individuals who participate in UN programs generally represent their country, and the UN tends to record participation based on countries. To summarize, the three criteria that are applied to the Space Activities are as follows: 1) An exhaustive participation list must be available; 2) The activity must be theoretically available to every country in the world; and 3) There must be a way to associate participation in the activity with specific countries. These criteria are summarized in the table below.

Table 2: Criteria Used to Select Space Activities for SPM Analysis

#	***Criteria***
1	Activity has an exhaustive participation list
2	Activity is available to every country in the world
3	Activity is associated with participation by specific countries

When classifying specific Space Activities in the various categories, there is some ambiguity. For example, a "capacity building program" may involve the use of ground based space hardware or it may be something less technically advanced. For cases such as this, the rule is to use the lowest appropriate category. If there is not undisputable evidence that an activity belongs in a high category, it is placed lower.

Two methods of tallying the SPM points to a given country are used in the research. Each country has an Aggregate score and a Categorized score. Both methods are used in order to ensure that both aspects of the data are considered. The Aggregate score is simply a sum of the points earned by a country, which is equivalent to the number of activities in which that country participates. The benefit of the Aggregate score is that it is a single number that summarizes space activity. The disadvantage is that this single number masks the technical nature of the activities; it gives equal weight to very different activities. Hence, there is a need for the Categorized score. The Categorized score counts the number of points each country receives in the various categories from 1 to 4. This allows a brief summary of the technical level of the country's experience. It shows at a glance whether the country is largely involved in highly technical activities.

Note that the categories are chosen after the list of activities is found. The categories are not chosen *a priori* as a guide for finding activities. The categories emerge as one logical way to divide the activities that meet the inclusion criteria. Part of the intention in using the categories is to address the fact it is overly simple to give the same credit for hosting a meeting as for launching a rocket. The other side of the argument, however, is that the Aggregate SPM captures the variety of ways that countries can interact with space technology. It gives credit to countries that may not be able to afford their own space craft, but have an interest in space none the less.

3.2.3 Space Project Case Studies

The Space Participation Metric (SPM) is a very helpful way to turn available information into quantitative data that can allow for statistical analysis. The SPM analysis is limited, however, by the strict criteria placed on the List of Space Activities. Many interesting examples of space activities can not be included on the List. Also, the SPM makes an effort to consider all the sovereign countries in the world. The result is a very high level analysis that leaves out a great deal of detail.

In order to pursue the two main goals of this thesis at a more detailed scope, the Space Project Case studies are pursued. As a reminder, the two goals of the thesis are to better understand the satellite-enabled activities in the developing world and to understand how the level of development of a country relates to its use of satellite technology. The Space Project Case studies form a set of 90 summaries of programs, projects and organizations that utilize satellite-based technology in Africa. This section explains the motivation for the scope of these case studies as well as the methods used for data collection. There are several aspects that limit the scope of Space Project Case Studies, including geography, technology area, project intent and depth. Each of these will be discussed in turn below.

Geographically, the Space Project Case studies include examples from the African continent. This includes satellites owned by African countries, collaborations between African countries and external partners, as well as organizations that offer a satellite-based service in Africa. Africa is chosen as a focal point for several reasons. First, it includes a large number of very poorly developed countries. This is supported by the rankings of the Human Development Index. The HD Report has data for 51 out the 53 countries in Africa. Of these 51 countries, 29 are in the "Low Development" category. Only 2 countries from outside of Africa, Yemen and Haiti, are in this low category. Note also that out of the 51 countries in African ranked by the HDI, only 2 are in the "High Development" category. The large percentage of poorly developed countries in Africa makes it an attractive region from which to learn about satellite technology. Africa is clearly a developing context; it is arguably the least developed continent. Thus, success stories about technology from Africa are very meaningful to the whole developing world. A second reason to use African case studies is that it includes a great deal of diversity. The African country with the highest Human Development Index is the Republic of Seychelles at an index of .842. The lowest ranked country is Niger at an HDI of .311. In between is a whole spectrum of development indices. Thus, despite the overall poor performance of the continent, there is enough diversity to allow for interesting analyses. The third reason for focusing on Africa is the great potential of satellite technology to meet needs in this region. The same reasons expressed in the introduction apply here. Africa suffers from systemic problems of famine, drought, disease and weak communication links. There is a role for satellite technology in solving each of these problems. Finally, a fourth reason to study case studies in Africa is the wealth of examples of the use of satellite technology there. The prevalence of satellite technology in Africa may be surprisingly high to some readers.

In terms of technology area, the Space Project Case studies are limited according to the same scope as the overall thesis. Examples are sought in satellite communication, remote sensing and navigation.

Project intent is another factor considered when choosing African Space Project Case Studies. Only projects that involve direct use of satellite technology are included. Some projects are found that involve only awareness building or education about space technology. These are excluded.

Finally, the Case Studies are scoped in terms of depth. For each example project, a maximum of 19 questions are considered. In most cases, not all 19 questions are applicable, and some queries are ignored. The main goal of the questions is to understand what work was done, who lead it, who funded it, who provided the satellite expertise and how the African participants were involved. The table below summarizes the questions asked about each Space Project Case Study and provides an example of the responses for one specific case, the Center for Remote Sensing and GIS at the University of Ghana.

Table 3: Example of Space Project Case Study Data Sheet

Factor	*Factor Value*
Project Name	Centre for Remote Sensing and GIS at University of Ghana
Project Leader	University of Ghana
Other Designation	CERGIS
Financing?	Some funding for specific projects comes from donor agencies or contracts for service
Country	Ghana
Purpose (Remote Sensing/Communication/Nav/Etc)	earth observation/remote sensing
Architecture (single sat/multi-sat/data buy/data proc, etc)	data processing; use satellite data to make useful data products
Instruments/Sensors/Equipment	Uses SPOT, LANDSAT and NOAA data
Cost	Unknown
Weight	Not applicable
Launch Vehicle	Not applicable
Initiation Date	1993
Launch Date (targetted or past)	Not applicable
Is project in the context of larger national space program?	no
Is project motivation by a desire for national development?	yes
What method does country use to procure technology? (Who built sat and how did country participate?)	local effort with some outside funding for specific projects
Is project part of a series of projects on the same topic or application?	no
Is there already a well established ground segment to the project?	Not applicable
Termination of project	on going
Reference	Rochon, et al. "Applicability of Near-Real-Time Satellite Data Acquisition and Analysis & Distribution of Geoinformation in Support of African Development" www.uneca.org/codi/Documents/WORD/ECA_CODI_IV_Paper_Rochon.doc. Accessed Feb 27, 2008

Data is collected for the Space Project Case studies from many sources. Examples come from conference proceedings, news articles, journal articles, and organizational websites. Some entities, such as the European Space Agency or the United Nations, report on their own activities to promote satellite technology in Africa. Most of the case studies are found via the Internet but care is taken to confirm the credibility of the site.

The African Space Project Case Studies provide a rich collection of examples showing how space technology is usefully applied in a developing context. Within the Case Studies are examples of Africans designing and launching satellites as well as Africans working along side external partners to apply satellite data to their problems. The case studies give much more detail than the SPM data can provide. This Case Study process is not hampered by a desire to be exhaustive. Of course, this ad hoc data set can not claim to capture all of the space activities in Africa or even all of the important ones. This thesis does claim, however, that the information in the case studies provides factual examples of space activities. It is expected, also, that the large number of case studies provides a representative account of how satellites are used in Africa. A full list of the Space Project Case Studies with references can be found in Appendix B.

3.2.4 Space Program Case Studies

The Space Project Case Studies provide many examples of the use of satellite-based technology in Africa. The activities vary from simply using satellite data to satellite design. Several countries in Africa have formal, government space agencies. The number is small enough that it is very feasible to make case studies for each agency. To be more specific, two countries – Nigeria and Algeria – have officially named Space Agencies. Meanwhile, South Africa is in the process of creating one, as of the time of this writing. Egypt does not have one agency for space programs, but they do have two government entities that direct the two facets of their space policy – Remote Sensing and Communication. These two Egyptian agencies are clearly specialized entities that focus on space topics. The space programs of these four countries are reviewed in short case studies. These case studies pursue the first goal of this thesis, to increase our understanding of the space activities in developing countries.

Several measures are used to ensure that no African space agency is left out of this analysis. Certainly, other countries such as Morocco and Kenya are very involved in space activities. Such countries are considered for inclusion, but they do not have advanced, multi-faceted space agencies. After reviewing various sources, such as *Jane's Space Directory,* the proceedings of the African Leadership Conference on Space Science and Technology for Sustainable Development[clxv], and various articles about space in Africa[clxvi], this set of countries is chosen.

There are 10 questions in the Space Program Case Studies. These questions seek to show a little about the history of the program as well as its status within the government. The questions are listed below.

1. When did the country start to use satellite technology?

2. Is there an official space program? If so, when did the country officially create a national space program?

3. Is the space program part of a long term policy commitment to space?

4. Is the space effort integrated into other government policy?

5. Is the space effort motivated by a desire for national development? What are the main motivations?

6. Where is the country in the four phases of space technology?
    a. Phase 1: Buy technology from elsewhere.
    b. Phase 2: Work with a foreign partner to build technology while training domestic personnel.
    c. Phase 3: Build technology in the country
    d. Phase 4: Share technology with other countries

7. What is the relationship between government, private industry and academia with respect to the space program?

8. What educational resources are there in the country to train potential entrants into the space industry?

9. What is the magnitude of the space program (in terms of # of projects per unit time, # of employees, etc)?

10. Is the country collaborating with other countries on space projects? If so, what are some examples?

The questions are answered as completely as possible. In some cases it is very hard to find documentation to answer a given question. Note that the concept of the four Phases of Space Technology is borrowed from a paper that does a case study on Malaysian space activities.[clxvii] The geographic scope of the Space Program Case Studies is limited to African countries, in parallel with the Space Project Case Studies.

No formal analysis is done with the Space Program Case Studies for this thesis. The information, however, does provide valuable background that helps in interpreting the overall results of the analysis. The African Space Program Case Studies are referred to in the discussion of the analysis results in Chapter 4.

3.2.5 Embassy Interviews

The fifth and final source of data used in this research is the set of responses from 30 interviews with representatives of African countries at embassies in Washington, DC. The purpose of the interviews is to learn about the policy context of African countries and its influence on the use of technology. The interviews include representatives from only African countries, consistent with the scope defined in the Space Project Case Studies. The motivation for pursuing these interviews is the difficulty in finding documented information about technology policy in Africa. The interview questions focus on the structure of government with respect to technology, the relationship between government and academia or industry, and the government's use of satellite technology. It should be acknowledged that many of the embassy officials find the questions quite daunting and do not feel that they are fully competent to answer correctly. The answers thus reflect their best understanding of the situation. This, however, has its own value. Most of the interviewees are not technical experts. The interviews thus show how an African government official who is not a specialist understands the use of satellite technology in their country. Because satellite technology requires such specialized knowledge, any understanding shown by a novice in the field is all the more noteworthy. On one hand, the responses regarding factual questions about the structure of the government can generally regarded as true. The responses about the use of satellite technology can be regarded, at worst, as evidence of the understanding of a technical novice in the community under consideration. At best, they provide accurate information.

The interviews are conducted in person, when possible. In a few cases, they are conducted by phone due to scheduling difficulties. Two countries prefer to send responses by email. The interviews are semi-structured. The same 10 questions are asked to each person, but conversation beyond the questions varies according to the natural flow of the interaction. The persons interviewed are recommended by the relevant embassies. In almost every case, they are employees of the embassy. In one case, the interviewee is an appropriate person outside the embassy. In a few cases, more than one person participates in the interview. Most interviews last between 30 minutes and 1 hour. The interviews are performed between August 2007 and April 2008.

The interview questions are chosen to probe into the structure of the National Innovation System, as discussed in the literature review. The paradigm of the NIS encourages study of the relationships between the various actors concerned with science and technology. The first set of questions asks about the government structures for addressing technology issues. The next section asks about how the government relates to academia and industry. Later questions ask specifically about satellite technology, and the final set asks about the educational system. The interview questions are summarized below.

1. In your country, are there one or more central government bodies that are responsible for national science and technology issues? If so, what are they?

    a. How would you describe the financial resources allotted to these bodies?

2. What is the relationship between the government and other entities such as the Universities, Industry and National Laboratories?

3. Is there a central government body that is responsible for national space-related issues?

4. Does your country have a national space program?

5. If your government wanted to have a satellite launched into space, how might they obtain this service?

6. What are some ways that your government uses satellite-based technology to meet national needs? Some examples could be for improving communication, for monitoring the environment, for providing weather information, etc.

7. On a scale of 1 to 5, how important would you say that satellite-based technology is to your country? (1 means “Not important at all”; 5 means “Extremely important”) Please explain briefly.

8. In your country, are there one or more central government bodies that work on environmental issues (water, air, agriculture, fisheries, forestry, etc) on a national level? If so, what are they?

    a. If so, do these bodies make use of satellite-based technology? In what way?

9. What is the relationship between government, private industry and academia with respect to science and technology issues?

10. What educational resources are there in the country to train potential entrants into scientific or technical careers? Examples include university degree programs, scholarships, internships, etc

A key strength of the Embassy Study is that the countries represented cover a wide geographic range of Africa. Countries from each corner and region of the continent are included – from the North, South, East, West and Central areas of Africa. Countries from each of the major European language groups are included – Francophone, Anglophone and Lusophone. The countries also represent a variety of levels of space activity. Some of the 30 countries, including Nigeria and Algeria, have an official space program or national satellites. Others have no official space policy. The map below shows the countries that are interviewed. The countries which are interviewed are indicated with circles around their names. Circled countries include Niger and Chad. No circle means the countries are not interviewed. Grey shading means there is no embassy in the US for that country or territory; this is true for Somalia and the territory of Western Sahara. The island country of Cape Verde is not shown on this map, but it is also included in the interviews.

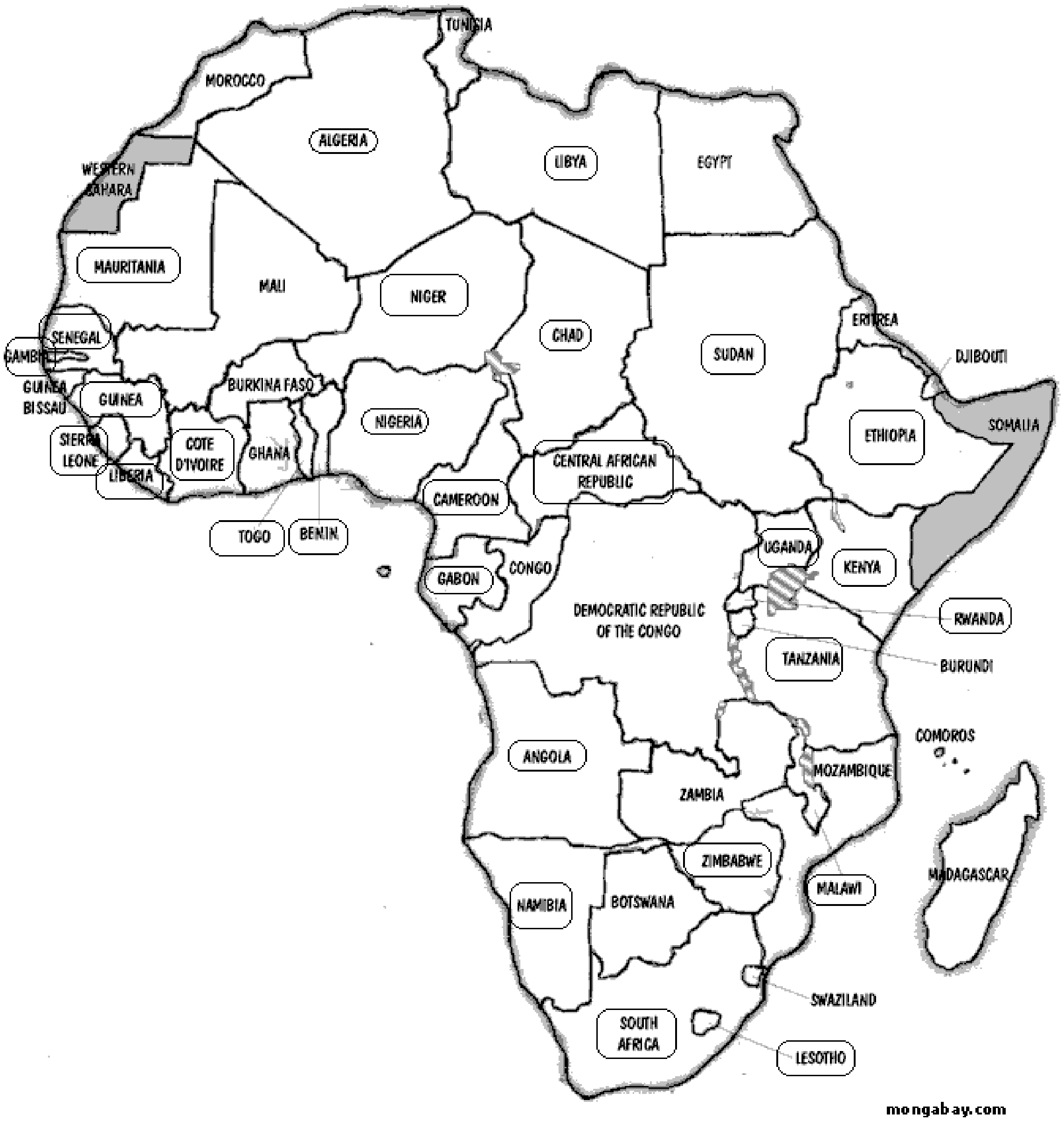

Figure 4: Map of Africa Showing Countries Included in Embassy Interviews

3.3 Research Questions, Data and Analysis

The two main goals of this thesis are pursued through answering three specific research questions. This section reviews the questions, explains the purpose for including them and shows how the data sources described above are analyzed to answer these research questions. Together these research questions help increase our understanding of satellite technology use in developing countries while helping us learn how development level relates to satellite technology use. In addition to the analysis for each research question, this section also explains the analysis done for the Embassy Interview data. The analysis methods for the entire thesis are introduced in this section. The results are shown and discussed in the next chapter.

3.3.1 Q1: National Space Activity versus National Development Level

This section explains the motivation, scope, analysis and methods for the first Research Question.

Motivation and Scope

The first research question is "How does national development level relate to national space activity?" The answer to this question is at the heart of the second goal of this thesis. In order to answer it, data is collected that meets the first goal – learning more about how satellite technology is used in developing countries. The benefit of pursuing this research question is that it uses quantitative data to test what we suspect to be true from theory or personal experience. It probes the assumption that more developed countries are more active in space. Policy makers in developing countries can learn what kind of space activity is normally achieved by countries in their development level. They can also see the exceptional developing countries that achieve more than the norm and learn from them. All sovereign countries are included in this analysis.

Summary of Analysis

The data used to address Question 1 is the Space Participation Metric (SPM) and Development Indicator data for all sovereign countries. Chi-squared statistical analysis is used to test for a statistically significant difference in the SPM scores among countries grouped according to their development scores. The result of the Chi-Squared is the probability that differences among the groups happen by chance. If the probability is very low (in this thesis, a cut off of 5% is used), the difference is considered meaningful or significant. The SPM scores in Aggregate and Categorized form are compared to the Development Indicators in a series of Chi-Squared tests.

Methods and Assumptions

The Chi-squared statistical test is chosen for several reasons. First, much of the data is in integer form; it is not continuous. This test handles discontinuous well. Second, the Chi-Squared method allows one to test for differences among groups. This is the right kind of method to answer whether there are differences in the ways different groups of countries behave. There are several steps in Chi-Squared analysis and the choices made at each step effect the results. This section explains the rational behind the construction of the Chi-Squared tests.

The first step is to divide all the sovereign countries in the world into groups to be compared based on Space Participation. For the Aggregate SPM, this division is done based on the percentages of countries in various levels. When using the Aggregate SPM (a sum of all space participation points), about half of the countries earn 5 points or less. Close to one quarter earn between 6 and 10 points, and the remaining quarter earn 10 or more points. Since these percentages created such symmetric groups, there are chosen as the bins or groups for the Chi-Squared Tests. This is summarized in the table below.

Table 4: Categories of Countries for the Aggregate SPM Analysis

Categories of Countries (Aggregate Space Participation Metric)		
Category	# of SP points	% of Countries
SPM1	>10	24%
SPM2	6-10	24%
SPM3	<=5	53%

Another method for grouping the countries is used with the Categorized SPM data. In this case, the four categories of space activities create natural bins or groups. Thus, once countries are divided according to development level, the number of projects in each category for each country is counted. This number is used in two ways in the analysis. Chi-Squared tests are performed by adding all the projects done in a particular space category by a particular set of countries. This is referred to as "Counting Activities." Another set of Chi-Squared tests is done by adding up how many countries appear at least once within a particular space category and development level. This is referred to as "Counting Countries."

The second step is to divide all the sovereign countries into groups based on each development indicator. The countries are divided into different development levels, called bins, in three different ways. The first way is to create four groups that have the same number of countries in them. The countries are ordered based on their value of the development indicator in question, from lowest to highest. Thus, the four groups represent progressively higher levels of development. The second way is the same but uses three equal groups that have low, medium and high values for that development indicator. The disadvantage of these first two methods is that there is no guarantee that the lowest and highest groups are different by any particular amount. The benefit is that the test is more likely to be valid because the groups are of similar size. Tests sometimes become invalid when very small groups are compared to very large ones. In order to respond to the actual data, however, a third method is used to create bins of countries based on development. According to the type of data, the countries are either divided based on the range of the data or on the order of magnitude of the data. For example, when dividing countries based on the Human Development Index, all the values are of the same order of magnitude and the countries are spread out fairly evenly between the lowest and highest value. In this situation it is useful to divide the countries at evenly distributed points along the range from the lowest to the highest data point. In some other cases, such as GDP, the values in the data change drastically in order of magnitude. The lowest values are order 10^{-1} while the largest are order 10^{3}. If the range of data is to be simply divided evenly, most of the countries would end up in the lower group with only a tiny minority in the highest groups. This often leads to an invalid test. Thus, in a case like this, the data is divided based on the order of magnitude.

In addition to using several methods to bin countries based on development level, two methods are used to count countries within the bins. This is done to ensure that the results are consistent. These two methods specifically apply to the Categorized method for binning the Space Activity points, as mentioned above. The methods ultimately lead to testing two null hypotheses. The first method is to count each instance when a country has a space activity in a particular category. Thus, if Country A has 3 activities in Category 1, they get credit for each of these 3 activities. The other method is to just count the instances of countries in each category. In this case, County A only gets 1 count for its three activities in Category 1. The first method, Counting Activities, addresses the following question, “Is there a significant difference in the number of space activities in various categories for countries of different development levels?” In this case, the null hypothesis is that there is no difference in the number of activities pursued in the various categories for countries at different development levels. The second method, Counting Countries, addresses this question, “Is there a significant difference in the number of countries in different development levels that appear in the various space activity categories?” In other words, does a particular category see more countries at a particular development level? The null hypothesis here is that there is no difference in the number of countries from various development levels that appear in a particular space activity category. These two sets of null hypotheses are summarized in the table below.

Table 5: Hypotheses Tested in SPM Analysis

Two Hypotheses Tested within Aggregate SPM Analysis		
Method	**Question**	**Null Hypothesis**
Counting Activities	Is there a significant difference in the number of space activities in various categories for countries of different development levels?	There is no difference in the number of activities pursued in the various categories for countries at different development levels.
Counting Countries	Is there a significant difference in the number of countries in different development levels that appear in the various space activity categories?	There is no difference in the number of countries from various development levels that appear in a particular space activity category

The chart below summarizes the various combinations of binning methods used in the Chi-Squared tests. Each of the Development Indicators, as described above, is used in comparison with the Aggregate and Categorized SPM scores. Thus the chart below is repeated six times in the analysis; there are seven indicators, but the HD Index and HD Level tests are combined. The tests using the Aggregate SPM and Counting Countries method are only done with one kind of binning for the Development Indicators. This is sufficient because they agree with the other tests, which are done more extensively with the method of Counting Activities.

Table 6: Bins used in SPM Chi-Squared Analysis

Development Indicator Bins:	Four Equal Groups	Three Equal Groups	Data Range or Order of Magnitude
Categorized SPM:	x	x	x
Aggregate SPM (Count Activities):	x	x	x
Aggregate SPM (Count Countries):	x	----	----

The Chi-Squared test is performed in many ways to ensure that the answer is not just a result of the problem construction. This sensitivity analysis gives more confidence in the results.

3.3.2 Q2: Mission and Management Architectures

This section explains the motivation, scope, analysis and methods for the second Research Question.

Motivation and Scope

The second research question of this thesis is, "What Mission and Management Architectures are developing countries using to apply satellite-based technology to national needs?" The goal of this question is to explore at a detailed level the satellite-enabled activities in developing countries. This question is addressed by analyzing data from the 90 African Space Project Case Studies. This part of the research is inductive. The goal is to observe reality, collect data about it and organize that data in a way that will help the reader understand the reality better. The results of this section of analysis include a categorization of the Space Project Case Studies in several ways that help explain trends in the field.

Note that the scope of this analysis is the same as that of the Space Project Case Studies; it is limited to African examples of the use of satellite communication, remote sensing and navigation technology. The author does not assume that the trends observed in Africa can be generally applied to other regions. It is thought, however, that a more detailed study can be made by focusing on a limited geographic region. Some lessons from studying Africa will be applicable to other regions, especially considering the diversity of development levels within Africa. As discussed in the introduction, the particular technology areas are chosen because they have such strong relevance to developing countries.

The terms "Mission" and "Management" architectures require explanation. The Mission Architecture refers to the type and level of technology used. Satellite-based missions may include designing and launching a satellite, or operating ground based satellite technology, or using and processing satellite data, for example. The various missions each depend on satellite technology, but they require different levels of involvement with an actual satellite. There are, of course, multiple ways that different missions could have been defined. It may have been based on the purpose of the project or the field of satellite technology. In this case, the missions are defined based on the level of technical activity for a specific reason. It is natural to assume that more developed countries would work on projects of higher technical sophistication. The

Architecture categories created in Question 2 lay the foundation for testing this assumption in Question 3. In short, Mission Architecture answers *what* is accomplished in the project.

The Management Architecture refers the organizations involved in executing the project. If Mission Architecture tells *what*, Management Architecture tells *who*. Part of the reason for defining the Management Architecture is that many of the Space Project Case Studies involve partnerships. Some partnerships are between African organizations or countries. Some are between African entities and external entities. A study of the trends in these partnerships is revealing. While many African countries do not have the capabilities to execute a complete satellite project on their own, they may be able accomplish it with a partner. Some examples of Management Architecture include, "One African Country or Organization," or "An External Partnership with Satellite Expertise from External Partner."

Summary of Analysis

The primary goal of the Mission and Management Architecture categorization is to place all the Space Project Case Studies on a Master Architecture Matrix with "Mission" and "Management" as the axes. This allows for rapid, visual comprehension of how the projects in the Case Studies compare to each other. It also shows what kinds of projects dominate numerically. In addition to the Master Architecture Matrix that includes all 90 case studies, three smaller matrices are presented. These specialized matrices separately show the subset of projects that can be classified as remote sensing, communication or navigation.

Three kinds of supporting analysis complement the Architecture Matrices. First, the projects are categorized in terms of their Purpose. Purpose here is defined from the technology user's perspective. The second kind of supporting analysis is a graphical depiction of Roles and Actors in the Space Project Case Studies. This is done separately for each of the three areas of satellite-based technology considered in this thesis (remote sensing, communication and navigation). The third supporting analysis is an exploratory look at the Time Trends in the Space Project Case Study data. The Time Trend analysis considers what Mission and Management Architectures have been used over time, based only the case studies in this collection.

Methods and Assumptions

Most of the analysis in Question 2 is done by manually reviewing the case studies and placing them in the appropriate Architecture categories. This simple explanation, however, disguises many layers of decisions and assumptions that are implicit in the organization of the data. This section explains several key choices that direct the classification. The choices include what Achitecture categories to include, how to distinguish between potentially ambiguous Achitectures, how to order the Achitectures, what color code to use,and the criteria to assign projects to Achitecture categories. The Mission Architectures are discussed first; the Management analysis follows. The Specialized Matrices showing Remote Sensing, Communication and Navigation Projects follow the same methods as the Master Matrix. The goals of the Project Purpose and Roles and Actors Analysis are discussed as well.

A different kind of analysis is done to understand the potential time trends in the Space Project Case Study data. This requires statistical tests.

<u>Mission Architectures</u>

This section explains the methods and assumptions used in creating the Mission Architectures.

Choosing the Architectures. For both the Mission and Management analysis, the categories emerge after much data is collected. They are refined continually as more information is found. This means that the categories represent what the data actually show rather than a pre-conceived idea of what it might show. The categories are not a generic representation of what might be; they show only the examples found in the case studies. The reader may distinguish logical gaps where an intermediate category could have been defined between two existing categories. This only shows that there are not case studies that apply to the missing category.

The categories used in the Mission Architecture analysis show the technical activities accomplished by the project. This choice flows from the goal of elucidating what satellite technologies are being used in developing countries. Specifically, the architectures show what satellite-enabled activity is done. The architectures are described based on the type of technology, not the user's purpose for the project. Thus, the architecture "Operate Ground-Based Satellite Technology" is used instead of "Use satellite communication for telemedicine." The purpose is to show the level of satellite technology.

The list below shows the set of Mission options used in the Master Architecture Matrix.

1. Participate in Regulatory Action Regarding Satellites
2. Use Satellite Data Products or Decision Tools
3. Process Satellite Data and Create Data Products or Decision Tools
4. Operate Ground Technology to Send and/or Receive Satellite Data
5. Lease Satellite Capacity and Distribute Satellite Service
6. Operate the Satellites of Others
7. Lease and Operate a Satellite
8. Buy and Operate a Satellite
9. Design and Build a Satellite
10. Design, Build, Launch and Operate a Satellite

There are several ways that architectures could have been defined based on the available information. It is possible, for example, to create a category for all the projects that operate a satellite (6, 7, 8 and 10). This, however, does not show the technical steps that some projects take before operation begins. The system here starts by considering all the aspects of running a satellite system and then creating architectures that are a subset of these aspects. A complete project includes the design, manufacture, launch, and operation of a satellite. Part of the operation includes using ground equipment to receive data from the satellite as a product and to send data to a satellite for control or communication. Most projects achieved a subset of this collection of technical activities. Ultimately, categories are created by showing which set of these are accomplished.

Ordering the Architectures. The order of the categories for the mission architectures is intentional. Part of the goal of the Architecture matrix is to show a spectrum of ways that satellite technology can be accessed. The Architecture categories are listed above in ascending order. The lowest numbers reflect the lowest level of connection to the technology. The higher the number, the closer the Mission is to actually operating a spacecraft in space. The philosophy is to include as many activities as possible that are enabled by satellites. Then the activities are ranked according to how close the user is to controlling the space hardware. Overall, there is a progression from activities involving work on a spacecraft (designing, building, operating a satellite) to activities involving work on ground based technology to activities that only involve the data received from spacecraft. This order does not attempt to imply that it is always more technically challenging to do a higher category. Instead, the order of the category reflects the level of control the participants have over the actual spacecraft and the data. If they participate in the design of the spacecraft, they have the highest level of control. If they only have access to data collected by others, they have very little control.

Another facet of the order is that the highest level of projects implicitly includes the lower levels, as appropriate. For example, if a project receives credit for operating a satellite, it is implied that they also receive and process data in a way appropriate to their application. The main exemption to this inclusiveness is perhaps the lowest project architecture, "Participate in Regulatory Action Regarding Satellites." It is not assumed that all projects include this activity.

Color Coding the Architectures. In addition to ordering the architectures from the least interaction with a spacecraft to the most, a color code is used in the Matrix to reinforce the hierarchy. The colors provide visual support for the idea that there is a spectrum of technical activities enabled by satellites. The architectures are labeled with the colors of the visible spectrum, from red to violet. Red is used for the mostly highly ranked architectures; violet is for the lowest. In between, the colors are spread as appropriate following the general pattern of the rainbow – Red, Orange, Yellow, Green, Blue, Indigo, and Violet. Since there are more Mission Architectures than there are colors, several colors are used more than once. The colors group families of architectures. For example, red is used for projects that involve designing and building a satellite. Green represents the use of ground-based satellite technology. The idea of a spectrum of Architecture levels from red to violet is used multiple times in this analysis. The number of Architectures and the transitions between colors is not consistent, however. Each is chosen to fit the given scenario. What is consistent is that red always represents the high end of the spectrum and violet is the low end.

Assigning Projects to the Architecture Categories. Focus now on methods for assigning projects for the Mission Architecture analysis. The key rule here is that architecture categories are created and projects are assigned in various mission categories according to what is accomplished in the case study. Each case study has implicit boundaries based on the available documentation. These boundaries are used in defining the mission category. This is helpful because every satellite-based activity ultimately can be traced to someone launching a satellite. Some projects, however, do not include this early step in their context. For example, a project may involve the installation of satellite-based communication equipment in a university. The entities involved in this particular task may be paying a service provider who ultimately leases time on a satellite. Assume that the documentation on the project is explicitly about the ground based equipment. This is considered an instance of the use of satellite-based technology. Its Mission Architecture considers only the ground based part of the task. This narrow focus helps to highlight the part of the activity in which the African entity in question is directly involved. If there is ambiguity as to the accomplishments of a project, it is placed in the lower of the levels. For instance, if it is not clear whether a country processed satellite data themselves or only used data processed by others, it is assumed that they used data processed by others. To summarize, the Mission Architecture assignments reflect what is accomplished by the entities involved in the case study as represented by the available documentation.

<u>Management Architectures</u>

This section explains the methods and assumptions used in creating the Management Architectures.

Choosing the Architectures. The goal of the Management Architectures is to show who is directly involved with the project. Below is a list of the Management Architectures.

1. External Company or Organization; Provides Satellite Service in Africa
2. External Collaboration; Satellite Expertise from External Partner
3. External Collaboration; Satellite Expertise from Both Sides
4. External Collaboration; Satellite Expertise from African Partner
5. Regional African Collaboration (and possible contractors)
6. Non-regional African Collaboration (and possible contractors)
7. One African Country or Organization (and possible contractors)

The Architecture titles require further explanation. Architecture 1 is "One African Country or Organization." This means that the primary participants in the project represent an African national government, an African organization within a country, or an African company (that may or may not be multi-national). Architectures 2 and 3 cover collaborations in which the primary actors are Africans from different countries. Architectures 4, 5, and 6 refer to collaborations in which at least one partner is from outside of Africa. The word "external" here simply means external to Africa. It is not clarified whether the partner is from a developed or industrialized country. These three architectures (4 to 6) include a note as to where the satellite expertise originates. It comes either from the non-African partner, from the outside partner and the African partner, or from only the African partner. Note that this refers to the particular expertise required to do the project. In other words, choosing Architecture 2 does not imply that the African partner has no satellite expertise. It does imply that the expertise needed to accomplish the task in the Mission Architecture is supplied by the external partner. Architecture 1 refers to cases in which a non-African entity offers a service using satellites in Africa, but not through a specific partnership. This includes non-African companies that sell satellite-based phone or internet service in Africa. In this case, it is easy to see that there is no observable partnership with an African entity. Another example is a company that owns satellites that provide communication coverage to Africa. They are affecting Africa, but not through a clearly defined partnership.

There are several possibly ambiguous Architectures in the Management list. The distinction between Architectures 2 and 3 merits discussion. Architectures 2 and 3 both represent collaborations between African entities. These entities could be governments or private organizations. Regional and non-regional collaborations are distinguished for a reason. Regional implies that several countries that are near each other within Africa are cooperating. Non-regional means the countries are not in the same part of Africa. Some regional collaboration is pursued because of common language, geography or heritage among countries. One example is the Case Study Project AGRHYMET. This is a regional scientific center concerned with agriculture, water resource management and meteorology in Western Africa. The countries involved primarily speak French. They face common geographic problems, such as desert encroachment and drought. In some cases, the same ethnic people groups have been spread among the various countries. Contrast this with the Case Study Project ARMC, the African Resource Management Constellation. In this case, Nigeria, Algeria, South Africa and Kenya are partnering to create a satellite constellation for Africa. The countries are from three different corners of Africa – west, north, south and east. They have very different environmental concerns and different language and culture. It is concluded based on cases such as this, that a non-regional collaboration has some key differences in motivation and structure from a regional collaboration. This is why they are kept as separate Architectures. Note, however, that if the goal of a collaboration is to invite all or most African countries, it was considered “regional”. In this case, Africa is the common region.

Consider the inclusion of contractors in Architectures 1 to 3. Architectures 1 through 3 show the main actors as one or more African entities, but include the possibility of the involvement of contractors. One might argue that, if contractors are involved in an undefined way, the categories do not represent what is done by the African participants. It is true that the specific accomplishments of the African player are not shown in the Matrix. That is done in a separate analysis that will be discussed in Question 3. The goal of the categories here is to show who is involved in the projects. The categories distinguish between contractual relationships and partnerships. In Architectures 1 to 3, an African government or organization may hire some entity to do work. The entity may be from Africa or from outside Africa. The key here is that the initiative for the project comes from the African customers; they have control over the project. This is different from the collaborations described in Architectures 4, 5 and 6. These represent partnerships between African and non-African organizations or governments. The African partner is not necessarily in control of the project or the source of the initiative for starting the project. There is not a commercial contract governing the project. Both African and external partners invest in the project because they expect mutual benefit from their participation. This explains the motivation for distinguishing between contractual relationships and collaborations.

Ordering the Architectures. The order of the Management Architectures is meant to reflect the level of challenge, initiative or leadership shown by the African entity. Thus, Architecture 7 is a case where all the initiative and leadership comes from one African country or organization. If a contractor is involved, it is under the leadership of that entity. Architectures 1 to 4 all show involvement and some level of initiative from a non-African partner. Architectures 5 to 7 show the initiative coming from Africa. Thus, the lowest numbers show the least advanced project effort from Africa. The higher the number, the more management initiative comes from the African player.

A specific decision is made to rank a non-regional collaboration higher than a regional collaboration. Based on the arguments mentioned above, it is concluded that a non-regional collaboration requires more effort than a regional collaboration. It is likely to require more distance traveled for meetings, more language barriers and more compromise. This is the motivation for ranking the non-regional collaboration as slightly higher than a regional one. It shows more initiative on the part of the African countries.

Color Coding the Architectures. The color codes use in the Management Architectures follow the same structure as the Mission Architecture. Red is for the highest ranked Architecture. Violet is for the lowest. In this case, the number of colors in the spectrum equals the number of architectures, so there is one color per level.

Assigning Projects to the Architecture Categories. Next consider the rules and assumptions guiding the assignment of projects to particular Architectures. In this case, the project category shows who is directly involved in accomplishing the project. Again, the project boundaries are drawn from the available documentation and context. In some cases the projects are clearly done on behalf of national governments. In other cases, entities within a particular country act. Still other projects involve the work of regional organizations. The Management Architecture options do not distinguish between work done by a government and work done by a private entity; this is found in the Roles and Actors analysis. The main information here is whether the work is done by one African organization, a group of African organizations or collaboration between Africans and non-Africans. The non-African partners are not specified at this point as being from developed or developing countries; the goal is to show whether the resource comes from inside or outside Africa. In the case of collaborations, the Master Architecture Matrix defines who brings the satellite expertise. In general, collaborating partners could bring money, initiative, expertise, training or equipment. Expertise is specifically noted here to show whether the partnership might be allowing the African entity to achieve something beyond its own expertise.

The Master Space Project Matrix

The graphic below shows the Master Space Project Architecture Matrix without the projects filled in. This visual brings together all the methods described above. The horizontal axis shows the seven Management Architectures. The vertical axis shows the ten Mission Architectures. The top left corner of the matrix holds the highest level projects in both the Mission and Management Architectures. This corner represents projects with strong interaction with actual space hardware in which the African entities are highly involved. The top right corner shows projects in which the technical content is high, but the African contribution is smaller. In the bottom left corner, the technical content is low, but the African initiative is high. The bottom right corner is the lowest set of projects. Here the technical mission is less involved with a spacecraft and only uses satellite data or deals with regulation. In this corner, also, the African partner is in collaboration and may not be contributing much satellite expertise. The colors are used to indicate moving along the spectrum of Architectures. The leftmost column and top row are red to show higher values on that axis. The rightmost column and the lowest row are violet to indicate the lowest level.

Master Matrix	*One African Country + Contractors*	*Non-Regional African Collaboration + Contractors*	*Regional African Collaboration + Contractors*	*External Collaboration; Sat expertise from African partner*	*External Collaboration; Sat expertise from both sides*	*External Collaboration; Sat expertise from external partner*	*External Company or Organization; provides sat service in Africa*
Design, Build, Launch, Operate Satellite							
Design, Build Satellite							
Buy and Operate Satellite							
Lease and Operate Satellite							
Operate Others' Satellites							
Lease Sat Capacity and Distribute Service							
Operate Ground Segment; send or receive data							
Process Sat Data; create data products							
Use Sat Data Products							
Participate in Regulatory Action							

Figure 5: Master Space Project Matrix

Specialized Matrices

Recall the three specialized matrices focusing on remote sensing, communication and navigation respectively. Each one is constructed with the same basic rules as outlined above. The difference is that the Mission and Management categories are defined differently based on the available data. In some cases, the data is more refined; this allows for more specific categories. In all three technology areas, some context-specific categories are used to give the reader more information about the activities.

Project Purpose

The Project Purpose Analysis for the Space Project Case Studies is a straightforward review of what the users in the projects state as the ultimate goal of the activity. The purpose is determined by a manual review of the documentation for each Case Study. Some projects have more than one stated purpose; in such a case each purpose is counted. Thus, the summary data on project purpose has more than 90 entries. The purposes are organized within the three major satellite technology areas: Remote Sensing, Communication and Navigation. The final result is a table showing the stated purposes from the Case Studies and the number of projects that mentioned that purpose. Examples of project purposes include facilitating tele-medicine, tele-education, meteorology, natural resource management and a national census.

Roles and Actors

An analysis of the Roles and Actors is done for each of the three satellite areas: remote sensing, communication and navigation. This analysis complements the information from the Management Architecture work. The Management Architecture analysis is helpful for understanding what kind of entities are involved in the projects but it does not give a full picture. The Case Studies provide enough information to understand what kind of organizations offer what kind of services in the three satellite fields. The Roles and Actors analysis shows, at a glance, where African and non-African entities are involved in each area.

The Roles and Actors summary is created as follows. One satellite area, such as remote sensing, is considered. The Roles are chosen by finding, from the case studies, the major steps required to complete the activities. The Actors are filled in to each step. Next the actors are categorized based on their similarities. For example, in remote sensing, there are several activities in the life cycle of a satellite project. This includes building the satellite, operating the satellite, processing satellite data, coordinating satellite projects and using satellite data. Within the role of "Satellite Builder", the Space Project Case Studies reveal several kinds of organizations that do this. Some are non-African space agencies; some are non-African commercial companies; still others are African entities. In addition to identifying these major groups, the individual examples from the case studies are shown. One more step adds information to the Roles and Actors analysis. The Roles are ranked by order and color to show closeness to the satellite. This method parallels the ranking and ordering of the Mission Architectures. Thus, Satellite Builders are at the top in red while the Data Users are the bottom in blue.

Space Project Time Trend Analysis

As part of the Space Project Case Study data collection, time information is collected whenever possible. Specifically, the Case Studies look for the initiation of the project, the launch date of the satellite (if applicable), and the termination of the project. In many cases the launch data is not relevant and the termination date is not known or has not arrived. Thus the initiation date is the most consistent data. This data on initiation dates is used to search for time trends. Projects that do not have a specific initiation date are neglected in several cases. A few projects have launch dates but not initiation dates. In such cases, it is assumed that the initiation for the project is 5 yeas before the launch date.

Note that the data collection process does not specifically look for an historical overview of space projects in Africa. Rather, most projects are either currently happening or were recently accomplished. Some projects are currently existing organizations that began many decades ago. The data set does not attempt to be historically complete or representative. Because the case study data set is so large, however, some exploratory time analysis is done to see if any trends can be found.

The methods are as follows. The Mission and Management Architecture assignments from the Master Space Project Matrix are used to label projects. The labels are simply the numbers associated with each Architecture in the lists above. Thus, Management Architecture number 1 is "External Company or Organization; Provides Satellite Service in Africa." Because the Architectures are ranked from lowest to highest, they can be considered in groups for statistical analysis. For example, the first four Management Architectures can logically be grouped as "low," while the top three are called "high". The next step is to see if projects in a particular time period are distributed between low and high Architectures in a way that is significantly different from other time periods. A Chi-Squared analysis is used to explore this.

The Mission and Management trends are considered separately. For the Mission time analysis the following question is asked, "Is there a statistically significant difference in the breakdown of Mission categories at different time periods?" The null hypothesis is that there is no difference in the number of projects in various Mission categories at different time periods. The Management analysis asks a parallel question, "Is there a statistically significant difference in the breakdown of Management categories at different time periods?" The null hypothesis is that there is no difference in the number of projects in various Management Architecture categories at different times.

The Chi-Squared Tests are set up with several binning methods to find valid and appropriate tests. Time can be divided in several ways; six methods are tried here. First, the total range of data is divided into five equal groups. Second, the data is divided based on decades (as in from 1991 to 2000). Third, the projects are sorted by initiation data and divided in three groups; each group has the same number of projects. Fourth, the projects are sorted by initiation data and divided into four equal groups. Fifth, the time is divided based on historical events of importance to the field. The last method is to divide the years into two groups and repeat the test many times with different breakpoints in the sets of years. The breakpoint is the year that cuts off the early time period from the late time period. This sixth method shows what set of years can be used as a breakpoint to calculate a significant difference. The bins for Architectures are also created in several ways. The 12 Mission Architectures are combined into three and four groups for the Chi-Squared tests. The 7 Management Architectures are considered in 7, 3 and 2 groups.

The fifth method mentioned above for binning projects based on time is to divide the years based on historical events. The historical events used are major conferences related to the use of satellite technology in development. Specifically, the three United Nations Conferences on the Exploration and Peaceful Uses of Outer Space, called UNISPACE Conferences, as well as the World Summit on Sustainable Development are used. UNISPACE I was in 1968. UNISPACE II was in 1982. UNISPACE II was in 1999.[clxviii] The World Summit on Sustainable

Development was in 2002.[clxix] Each of these meetings worked to spread awareness about the benefits of satellite technology for developing countries. It is logical to wonder whether the Mission or Management Architectures improved after the meetings.

The tables below summarize the Chi-Squared tests performed in this Space Project Time Analysis. The first table is for Mission tests; the second for Management tests. The top row of each table shows the set of binning options used for the time variable. The far left column shows the options for binning the Mission or Management data. An "x" in the matrix shows that the corresponding combination of bins is used in a Chi-Squared test. The choice of what combinations to do is guided by the results of previous tests. More results will be discussed in the next section. Here, note only that most of the Chi-Squared tests are not valid. Thus, observations from the Mission tests informed the choice of Management tests.

Table 7: Chi-Squared Tests Used to Look for Time Trends in Mission Architectures

Mission Time Trend Tests	Range of Time Bin	Decade Bins	Three Equal Groups	Four Equal Groups	Historical Events	Two Time Periods
Four Bins	x	x	x	x	x	****
Three Bins	****	x	x	x	x	****
Two Bins	****	x	****	****	****	x

Table 8: Chi-Squared Tests Used to Look for Time Trends in Management Architectures

Management Time Trend Tests	Range of Time Bin	Decade Bins	Three Equal Groups	Four Equal Groups	Historical Events	Two Time Periods
Seven Bins	****	****	x	x	****	****
Five Bins	****	****	x	x	****	****
Three Bins	****	****	x	x	****	****
Two Bins	****	****	x	x	****	****

3.3.3 Q3: Architectures versus National Development Level

This section explains the motivation, scope, analysis and methods for the third Research Question.

Motivation and Scope

The third research question in this thesis is closely related to Question 2. Question 3 asks, "How does national development level influence the Mission and Management Architectures used by developing countries in satellite-based technology projects?" The heart of the question is to learn whether the observations found in Question 2 lead to any statistically significant differences for countries of different development levels.

The scope of this analysis is the same as that of Question 2. It uses the data from the 90 Space Project Case Studies. Thus, all the examples are from Africa. They include projects in the areas of Remote Sensing, Communication and Navigation. The projects under consideration show an active use of satellite technology, not awareness building activities.

The analysis in Question 3 uses a two step mapping to facilitate statistical analysis. Projects are ranked according to various criteria; those projects are associated with specific countries. The countries thus receive credit for the ranking of the projects. Because of this mapping, some of the 90 Space Project Case Studies are not included in the analysis. A few of them do not have a specific list of African countries or organizations that can be given credit for their project ranking. Some of them ostensibly serve every country in Africa. In this case, no country is given credit because this credit would not aid in the process of differentiating countries based on space activity. Twelve projects are thus excluded from the analysis in Question 3.

Summary of Analysis

There are three main steps in the Question 3 analysis. First, the Master Space Project Matrix concept is adapted to allow for more precise project rankings. The result of this step is a set of five Ladders that rank the Space Project Case Studies according to various rules. The projects are ranked at certain levels in the Ladders. Next, the countries associated with these projects next receive credit for these rankings. Third, the country information is used to do Chi-Squared tests that parallel the Question 1 analysis. In this case the space activity is based on information from the Space Project Case Studies instead of the Space Participation Metric. The other difference is that the only countries considered are African countries, instead of all sovereign nations. The analysis is like Question 1 because the space activity data is compared to the Development Indicator data to find trends. The same Development Indicator from Question 1 are used. The ultimate result of this analysis is the answer to the following question, "Is the performance of countries in the Space Project Case Study Data shown by statistical tests to be different for countries of different development levels?"

Methods and Assumptions

There are two major steps in the Question 3 analysis. The first step is creating the Ladders that rank the projects and mapping those rankings to specific countries in Africa. The second step is performing Chi-Squared statistical tests using the Ladder rankings as a measure of space activity and the Development Indicators as a measure of national development. The following section explains both of these stages in turn.

Creating the Ladders

The results of Question 2 are designed to provide a quick and informative summary of the satellite-enabled activities in Africa. It is organized to most conveniently show what kinds of projects are accomplished and who is involved. This is primarily shown through the Master Space Project Matrix. It would be ideal to take the exact results of Question 2 and apply them to Question 3. This would mean giving countries credit for the project rankings in the Master Space Project Matrix and using these rankings in the statistical analysis. This is not practical for several reasons. First, the Master Space Project Matrix purposely leaves some ambiguity as to the source of expertise, leadership, and financial resources in some categories of projects. For example, if a project includes one African country and a contractor, the Space Project Matrix does not show how the contractor contributes. Nor is it intended to. Second, the Master Matrix includes some projects that do not have a clear set of countries to which they map. Third, the rankings on the Master Space Project Matrix can be seen as non-monotonic. For example, if an African country hires a company to build a satellite for them, they gain the highest rankings in both Mission and Management Architecture. This is because they are working at a level of high control over the spacecraft (Mission) and they are working on their own initiative (Management). Meanwhile, if an African country partners with a non-African country to build a satellite, they would end up at a lower overall ranking. It can be argued, however, that the experience of building a satellite with another country can involve more technical expertise than hiring a contractor to build one. For the sake of the Question 3 analysis, it is desirable to eliminate this kind of ambiguity. This leads to the definition of five Ladders for ranking the Space Project Case Studies.

Each Ladder is a set of categories or levels that is defined with methods very similar to the ones used in Question 2. They are based on information and examples in the data, not pre-conceived expectations. Thus they are not collectively exhaustive. It is possible that higher levels on the ladder include or imply lower levels, if this is logical. Each ladder is unique in that it measures one specific aspect of the Space Project Case Studies. As in Question 2, the Ladders are color coded with red showing the highest ranking and violet showing the lowest. Numbers are also used for ranking, with one being the lowest.

The topics considered in each Ladder are chosen to help answer the question of how Architectures relate to development level. The ladders provide Architectures that are more specific than the Mission and Management Architectures. They are all aspects of a space project that could be expected to vary with development level. Specifically, two Ladders clarify the Mission Architecture. These Ladders show us what is technically accomplished in each project and what technical expertise is displayed by the African participants in each project. Three Ladders clarify the Management Architectures. Management includes the source of leadership, expertise and funding. Each of these aspects of Management is considered individually in a Ladder. The goal is to learn whether each of these project elements shows the same statistical relationship to development level. Once each ladder is defined, projects are manually assigned to the appropriate level.

Project Technology Ladder. The first Ladder is the Project Technology Ladder. The goal of this ranking is to specifically consider what is technically accomplished in the Space Project. This is generally the same as the Mission Architecture in Question 2. The projects are re-assessed, however. The chart below shows the 9 levels of the Project Technology Ladder. Here red shows projects that include satellite design. Orange shows projects that include satellite operation. Yellow is for projects that include leasing satellite capacity from another operator. Green means operating ground-based satellite equipment. Blue means working with satellite data. Violet means participating in regulatory action.

Table 9: Project Technology Ladder

Rank	Color	Level
9	Red	*Design, Build, Launch, Operate Satellite*
8	Red	*Design and Build Satellites*
7	Orange	*Buy and Operate Satellite*
6	Orange	*Lease and Operate Satellite*
5	Orange	*Operate others' satellites*
4	Yellow	*Lease sat capacity and distribute service*
3	Green	*Operate ground segment to send/receive sat data*
2	Blue	*Process Sat Data and create data products/decision tools*
1	Violet	*Participate in Regulatory Action regarding Satellites*

Country Technology Ladder. The second Ladder is the Country Technology Ladder. Its purpose is to rank projects based on what is accomplished by the African entity involved. This is a departure from anything done in Question 2 analyses. Now the difference between an African country buying a satellite from a contractor and an African country building their own satellite can be more clearly seen. One key difference from the Master Space Project Matrix is Level 8.

This is included to cover projects in which African countries buy satellites from contractors, but also participate in the design as a training exercise. The Ladder is shown below. This Ladder has one more level than the Project Technology Ladder, but this is completely a result of what appeared in the data.

Table 10: Country Technology Ladder

Rank	Color	Level
10	Red	*Design, Build, Operate Satellite*
9	Red	*Design, Build Satellite*
8	Red	*Buy and Operate satellite; Train in sat design*
7	Orange	*Buy/Lease and Operate Satellite*
6	Orange	*Operate others' satellites*
5	Yellow	*Lease sat capacity and distribute service/content*
4	Green	*Operate ground segment to send/receive sat data*
3	Blue	*Process Sat Data and create data products/decision tools*
2	Blue	*Use/Help Define sat data product*
1	Violet	*Participate in Regulatory Action regarding Satellites*

Leadership Ladder. This is the first of the Ladders that relate to the Management Architecture analysis. The three Management Ladders represent different aspects of project execution. This ladder ranks projects according to the source of the initiative or coordination for the project. Note, that the source of Leadership does not have be the organization that provides expertise or financial resources. Those are treated in their own ladders. Initiative and coordination can be strictly organizational roles that are accomplished by non-technical entities. In each case study, the key words for Leadership include terms such as "founded", "coordinated," "led," and "contracted."

The table below shows the Leadership Ladder for the Space Project Case Studies. It has 6 levels that reflect the different examples seen in the Case Study data. This draws from the pattern set by the Management Architectures. The main difference is that collaborations are compared based on the source of initiative instead of the source of expertise.

Table 11: Leadership Ladder

Rank	Color	Level
6	Red	Single African country or organization
5	Orange	Non-regional Group of African countries or organizations
4	Green	Regional group of African countries or organizations
3	Blue	External Collaboration, Initiative from Africa
2	Indigo	External Collaboration, Initiative from African and external partners
1	Violet	External collaboration, initiative from external partner

Finance Ladder. This is a second Ladder that clarifies the Management rankings. This one ranks projects based on the source of financial resources. The Ladder is shown below.

Table 12: Finance Ladder

Rank	Color	Level
6	Red	Single African country or organization
5	Orange	Non-regional Group of African countries or organizations
4	Green	Regional group of African countries or organizations
3	Blue	External Collaboration, Funding from Africa
2	Indigo	External Collaboration, Funding from African and external partners
1	Violet	External collaboration, Funding from external partner

Expertise Ladder. Finally, the Expertise Ladder is the one that most closely resembles the Management Architecture analysis. The projects are re-assessed, however, to make sure that the evidence for knowledge from the African partner is correctly interpreted. The Ladder is below, without the projects.

Table 13: Expertise Ladder

Rank	Color	Level
6	Red	Single African country or organization
5	Orange	Non-regional Group of African countries or organizations
4	Green	Regional group of African countries or organizations
3	Blue	External Collaboration or contract, Expertise from Africa
2	Indigo	External Collaboration or contract, Expertise from African and external partners
1	Violet	External collaboration or contract, Expertise from external partner

Assigning Project Points to Countries

Once all the Space Project Case Studies are assigned to appropriate Ladders, the next step is to assign the project rankings to the corresponding countries. This is done separately for each Ladder. One of the queries of the Project Case Study data is the set of African countries involved in the project. A matrix is created with all the African countries on the horizontal axis and all the Case Study Projects on the vertical axis. If a particular country is involved in a project, the ranking for that project is placed in the appropriate cell. The table below shows a notional example.

Table 14: Notional Example of Ladder Rankings Assigned to Countries

Ladder 1	Country 1	Country 2	Country 3	Country 4
Project 1		6		
Project 2			3	3

From this table we can conclude that Country 2 is involved in Project 1 and it has a ranking of 6 on Ladder 1. Also, Countries 3 and 4 are involved with Project 2 and receive rankings of 3 on Ladder 1. Note that each Ladder has the same set of countries associated with particular projects. It is possible, however, for the rankings of a project to vary between Ladders.

In this analysis there are 5 Ladders (as defined above), 53 African countries, 78 projects (out of the original 90 Project Case Studies), and rankings defined for each Ladder.

Performing the Chi-Squared Tests

Once the African countries receive credit in the various matrices for project rankings, the next step is to perform Chi-Squared tests. Two families of variables are considered. Countries are described based on the Space Project Rankings and the Development Indicators described above. The Space Project Rankings represent a measure of space activity; the rankings from each Ladder show a specific aspect of space activity accomplishment (technical, leadership, financial, etc). Note that the Human Development Report from which the Development Indicators are drawn does not have data for two African countries, Somalia and Liberia. These countries are thus excluded from the Chi-Squared analysis. As in Question 1, a cut off probability of 5% is used to determine if the null hypotheses can be rejected.

The same methodology is used for each of the 5 Ladders to perform Chi-Squared Tests. First, the matrix that assigns country rankings for the projects is used to create a frequency summary for each country. This summary shows how many instances of a particular ranking a country receives. This is the country data used in the Chi-Squared tests. The table below shows examples from the rankings of several African countries for the Project Technology Ladder. Algeria is shown to have 2 projects at level 1, 2 projects at level 2, 1 project at level 3 and so on.

Table 15: Example of Frequency Summary for Ladder Chi-Squared Tests

Project Tech Rankings	Algeria	Angola	Benin
1	2	1	2
2	2	0	1
3	1	1	2
4	0	1	0
5	0	0	0
6	0	0	0
7	2	1	1
8	0	0	0
9	4	0	0
10	0	0	0

Separate Chi-Squared tests are done with each of the seven Development Indicators (HDI, HD Level, GDP, GDP per Capita, Education Expenditure, Internet Users, and Cellular Subscribers). For each Indicator three methods are used to bin the countries based on development data and one method is used to bin the countries based on space data. This analysis is done with methods that parallel the Chi-Squared tests in Research Question 1. The Architecture Rankings are divided into 2 bins of equal numbers of levels. The bins are created for the Development Indicators by ranking the countries based on the indicator and then dividing the countries in three ways, as follow: four groups with an equal number of countries, three groups with an equal number of countries, and groups divided based on the range of data or the order of magnitude. If the range of data is used, the range between the highest development data point and the lowest is divided into three ranges and countries are binned accordingly. If order of magnitude is used, bins are based on the changing magnitudes of the data. If Chi-Squared tests performed in this way are invalid because some of the expected values are less than 5, the method is slightly altered to see if larger bins create valid tests. This may mean using 2 instead of three development bins.

For each of these tests, the hypothesis is that countries in different development bins will have significantly different results for their space project rankings. The corresponding null hypothesis is that there is no difference in space project rankings for countries of different development bins. The theory presented in the literature review suggests that more countries with higher space project rankings should be more developed. If the Chi-Squared tests are shown to be statistically significant and the null hypothesis is rejected, the data must be reviewed to find whether the difference shows more developed countries to be more advanced in their space project architectures.

3.3.4 Embassy Interviews

This study includes 30 interviews with officials from African embassies. In the section above on data sources the motivation and methods for data collection in these interview are explained. This section explains the methods used to analyze the interview data.

The first method used to analyze the interview discussions is a frequency analysis. The responses from each interview are recorded by the author by typing notes on a laptop during the interview. This is done in a word processing document. The information is transferred to a spreadsheet document for processing. Within the spreadsheet, a matrix is formed with responses on the horizontal axis and countries on the vertical axis. A separate matrix is formed for each question in the interview. For every country, the key ideas from their responses are identified. If the same idea has been expressed by a previous country, that instance of the idea is counted. If it is a new idea, it creates a new column among the responses. Repeating this process for each idea from each country leads to a count of how many countries mentioned each idea. The countries associated with each response are also recorded. The table below provides a notional example of the matrix used for this frequency analysis.

Table 16: Notional Example of Frequency Analysis for Embassy Chi-Squared Test

	Response 1	Response 2	Response 3	Response 4
Country 1	x	x	x	
Country 2		x	x	x

This tables shows that Country 1 said Responses 1 to 3. Country 2 also mentioned an idea like Responses 2 and 3. They did not say anything like Response 1. Country 2 added a new response, #4, that had not been mentioned by Country 1.

The results from the frequency analysis can be synthesized in two ways. One perspective is to look for common trends throughout Africa. The countries represent much of the geographic, cultural and language diversity in Africa, thus, the results can be considered as representative of the continent. For this method, simply use the totals from the frequency analysis that count how many times each idea is mentioned. The ideas that are mentioned the most can be considered the most conclusive. A second perspective considers how common responses divide the countries. Look for responses that are said by many of the countries but not by all of them. If 15 or 20 out of 30 countries make a comment, it may be worth looking for how the countries who do say it are different from those who do not. Care must be taken, however, to make sure that if a country does not say a comment it implies that it is not true for them. Some of the interview questions are framed this way; many are not. For example, all the countries are directly asked if they have a national space program. In this question, a definitive answer is received from each country. Meanwhile, many countries also talk about the importance of privatization in their economy. This is not directly asked as part of the interview, so it can not be assumed that it is not important for a country that does not mention it.

A few questions divide the countries in a way that facilitates statistical analysis. Chi-Squared analysis is applied here that parallels the tests done in Question 1 and Question 3. These are cases in which the question is asked to each country, the answer can be considered binary, a large majority of the countries give the same answer, and those that gave a different answer form a group large enough to compare in statistical tests. Four responses from the interviews fit these criteria. The four ideas are listed below.

1. Government agencies in our country that are concerned with the environment use satellite technology.
2. In my country, the Ministry in charge of science and technology is very large; it has hundreds of employees or more.
3. In my country, financial resources for science and technology are inadequate.
4. The government body in my country that is in charge of communication/information technology/broadcast is the agency that primarily deals with science and technology issues.

It is not obvious, *a priori*, whether to compare countries that made these statements based on space activity or development indicators. Both are done. For the thirty countries in the embassy study, they are grouped based on whether they say each of these responses. Then Chi-Squared tests are done to see whether the group that said the response is significantly different from the group that did not say it. The Chi-Squared tests compare these two groups in three areas, as follows: the rankings from the Project Technology Ladder, the Human Development Index, and the Aggregate Space Participation Metric score.

Each set of Chi-Squared tests is done in two ways. For the Embassy response versus the Project Technology Ladder, each variable in the Chi-Squared tests has two bins. The bins for the Ladder are the high and low halves of the rankings. One test is done by counting projects in the Ladder results for each embassy group. The other test is done by counting countries in the Ladder results. For the Embassy Data versus Human Development there are also two bins for each variable. One test is done that bins the development data based on the range of HD Index scores. The other puts the HD Index data into two groups with equal numbers of countries. For the Embassy Data versus Space Participation, there are two binning methods. One method creates SPM groups based on the divisions used in Question 1 analysis. One group scores less than 6; one group scores more than 5. The other method splits the countries into two equal groups that are sorted by SPM. Each method is chosen based on experience with the variables in Questions 1 and 3 analyses. The table below summarizes the various combinations of Chi-Squared tests. All the tests use 2 bins for each variable. The bin for the embassy data is always two groups: those that made the comment and those that did not. The chart summarizes the binning methods for the other variables. The chart below is repeated four times – once for each Embassy Response listed above.

Table 17: Overview of Embassy Chi-Squared Tests

	Project Tech Ladder		**Human Development**		**Space Participation**	
Embassy Data (yes or no)	Bins: Low Rankings (1 to 5) and High Rankings (6 to 10); Count Projects	Bins: Low Rankings (1 to 5) and High Rankings (6 to 10); Count Countries	Bin based on the range of HD Index data, Low HDI and High HDI	Bin using 2 groups with the same # of countries, Low HDI and High HDI	Bins: Low SPM (<6) and High SPM (>5)	Bin: 2 groups with the same # of countries; Low SPM and High SPM

The Chi-Squared analysis addresses the question, "Is there any difference in the space and development data for countries that make this comment and countries that do not?" The null hypothesis is that there is no difference in the space or development data for countries that make the comment and those that do not. Each Chi-Squared test is evaluated for validity and significance. The test is valid if all of the expected values generated in the test are greater than 5. The test for significance is if the probability of achieving the given results is less than 5%.

3.4 Conclusion

This chapter has accomplishes three tasks. First it provides an overview of the analysis process for this thesis. Second, it provides a detailed discussion of the data sources and the methodology for collecting them. Third, it describes the analysis and shows how it is used to answer each research question. It must be noted that the research questions are not completely answered by these analyses. The work is limited in geographic scope and the Case Studies may not cover every aspect of the field. The analysis does significantly and convincingly increase our knowledge of the answers, however. The results from this analysis are presented in the next chapter.

[clvi] World Economic Forum. "The Global Competitiveness Report." http://www.weforum.org/en/initiatives/gcp/Global%20Competitiveness%20Report/index.htm. Accessed June 5, 2008.

[clvii] The World Bank. "World Development Indicators." http://web.worldbank.org/WBSITE/EXTERNAL/DATASTATISTICS/0,,contentMDK:21725423~pagePK:64133150~piPK:64133175~theSitePK:239419,00.html. Accessed on June 5, 2008.

[clviii] UNDP, "Human Development Reports." http://hdr.undp.org/en/. Accessed on June 5, 2008.

[clix] "The Human Development Concept." http://hdr.undp.org/en/humandev/ Accessed June 5, 2008.

[clx] "Why is GDP per capita (PPP US$) used over GDP per capita (US$) in the HDI?" http://hdr.undp.org/en/statistics/indices/hdi/question,72,en.html Accessed June 5, 2008.

[clxi] "What is the human development index (HDI)?" http://hdr.undp.org/en/statistics/indices/hdi/question,68,en.html Accessed June 5, 2008.

[clxii] "Why is GDP per capita (PPP US$) used over GDP per capita (US$) in the HDI?" http://hdr.undp.org/en/statistics/indices/hdi/question,72,en.html Accessed June 5, 2008.

[clxiii] "Indicators by Tables." http://hdrstats.undp.org/indicators/indicators_table.cfm Accessed June 5, 2008.

[clxiv] Clark, Phillip. *Jane's Space Directory*. Jane's Information Group, Alexandria, VA, 2005/2006.

[clxv] "South African Space Portal." www.space.gov.za/alc2007/programme/index.php Accessed June 12, 2008.

[clxvi] Campbell, Keith. "Key African countries stepping up their space efforts." http://www.engineeringnews.co.za/print_version.php?a_id=125912 Accessed June 12, 2008.

[clxvii] Peter, Nicolas. "Nanosatellite for Remote Sensing Experiments, the Case of Malaysia." 55th International Astronautical Congress. Vancouver, Canada. 2004

[clxviii] Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space. http://www.unoosa.org/oosa/en/unisp-3/index.html Accessed on June 26, 2008.
[clxix] Home Page for World Summit on Sustainable Development. http://www.un.org/jsummit/ Accessed June 26, 2008.

4 Results and Discussion

This chapter presents the results of the analysis for each Research Question and for the Embassy Interview Analysis. It also provides a discussion that interprets the quantitative results. Note that the discussion in this chapter is intended to be strictly descriptive and not prescriptive. The policy prescriptions of the author are presented in a later chapter.

4.1 Q1: National Space Activity versus National Development Level

The results in this section contribute toward an answer to the first Research Question. This section helps in reaching the first and second goals of the thesis: 1) To understand how developing countries are using satellite technology; and, 2) To understand how development level impacts satellite activity.

4.1.1 Summary of Analysis

The first research question of this thesis is, "How does national development level relate to national space activity?" As discussed in Chapter 3, statistical analysis is used to answer this question. Chi-Squared tests are performed using Development Indicators and Space Participation data for all the sovereign countries in the world. Two sets of Chi-Squared tests are done. One uses the Aggregated Space Participation Data. The other uses the Categorized Space Participation Data. Both sets of tests consider all seven Development Indicators (HDI, HD Level, GDP, GDP per Capita, Education Expenditure, Internet Users, and Cellular Subscribers). The Chi-Squared tests are done with various binning and counting methods to ensure robustness in the results.

4.1.2 Results and Discussion

Overall, the results from the Chi-Squared tests consistently show that there is a statistically significant difference in the number of projects and countries that appear in the various categories of space activities when the countries are divided based on Development Indicator. In other words, the statistical tests show that there is a meaningful difference in the space activities of countries at different development levels.

The Chi-Squared tests are not set up to directly confirm the theoretical assertion that countries of higher development level show higher space participation scores. When the data is considered, however, with the knowledge that the groups are significantly different, there is evidence that the more developed countries have higher Space Participation scores.

Over 35 Chi-Squared tests are done using Development Indicators and Space Participation data. The cut off probability used in this analysis to reject the null hypothesis is 5%. All except two of the tests are considered valid because they have Expected Values of 5 or greater. Only two of the tests are not statistically significant. Both of them use the number of cellular subscribers as the Development Indicator. The major result remains that the tests show a relationship between development level and space activity.

The tables below summarize the results of the Chi-Squared tests for this research question. On each table, the far left column lists five of the development indicators; the top row shows the binning methods used to divide countries according to these development indicators. The first table shows the Chi-Squared test results for the Aggregate SPM tests. Recall that Aggregate SPM counts all the activities of a country in any category. The Aggregate tests show two invalid tests; the rest are valid and significant. The second table shows the results from the Categorized SPM tests. Categorized SPM counts activities within various technical categories. All the tests are significant except the last two under the Cell Phone Development Indicator. Note that the Cell Phone data is missing for many countries; this makes it harder to see a significant difference.

Table 18: Summary of Results from Aggregate SPM vs Development Indicator Chi-Squared Tests

Aggregate SPM Results	*Four Equal Bins of Countries*	*Three Equal Bins of Countries*	*Range of Data/Order of Magnitude*
GDP	Valid and Significant	Valid and Significant	Valid and Significant
GDP per Capita	Valid and Significant	Valid and Significant	Valid and Significant
Education Exp.	Valid and Significant	Valid and Significant	INVALID
Internet Users	Valid and Significant	Valid and Significant	Valid and Significant
Cellular Subscribers	Valid and Significant	Valid and Significant	INVALID

Table 19: Summary of Results from Categorized SPM vs. Development Indicator Chi-Squared Tests

	Counting Projects			**Counting Countries**
Categorized SPM Results	*Four Equal Bins of Countries*	*Three Equal Bins of Countries*	*Range of Data/Order of Magnitude*	*Four Equal Bins of Countries*
GDP	Valid and Significant	Valid and Significant	Valid and Significant	Valid and Significant
GDP per Capita	Valid and Significant	Valid and Significant	Valid and Significant	Valid and Significant
Education Exp.	Valid and Significant	Valid and Significant	Valid and Significant	Valid and Significant
Internet Users	Valid and Significant	Valid and Significant	Valid and Significant	Valid and Significant
Cellular Subscribers	Valid and Significant	Valid and Significant	**Valid not significant**	**Valid not significant**

Consider first the few exceptions to the general trends in the results. Several of the Cellular Subscriber tests are not significant. They may be explained as follows. The test with four equal development bins that counts countries is not significant. Neither is the test that uses Order of Magnitude to create development bins significant. Note, however, that four other tests done with the cell phone indicator are shown to be very significant. Their results are on the order of 10^{-4} – much lower than the .05 cut off. A possible reason why the exceptions occurred is the unusual numbers in those tests. In the Order of Magnitude test the data is in a form that does not facilitate Chi-Squared. There are four different orders of magnitude in the data but a strong majority of countries are in the middle two. This leaves a small group at the top and bottom of just 3% of the countries. Such a lop-sided grouping is not handled well by Chi-Squared. The test that counts countries with four equal development bins may be off because the cell phone data is missing for many countries. Instead of testing for the 172 countries for which we have space data, only 152 countries are included. These occurrences may explain the anomalies.

Once satisfied that the results of the Chi-Squared tests provide a consistent message, what can be concluded from the results? The theory in this field expects that countries who show a greater use of technology should be of higher development level. The Chi-Squared tests do not prove this directly, but they do provide the tools to look for evidence. This evidence is discussed below.

The table below shows the set up and results for the Chi-Squared Test that compares GDP and Categorized Space Participation. This test bins the development data into four groups of equal numbers of countries. Since there is GDP data for 172 countries, each of these four groups has 43 countries. Since the 172 countries are sorted from least to greatest GDP, the four groups of 43 countries represent different levels of GDP from low to high. The data counted is the number of activities by countries of various development levels in each space category. Examine the chart below.

Table 20: Example Results from Chi-Squared Categorized Space Participation Tests

Chi-Squared Test: Four Equal Groups of GDP - Categorized SPM - Count Activities					
Observed	*Count 1 (Low)*	*Count 2*	*Count 3*	*Count 4 (High)*	**Total**
GDP4 (Low)	95	14	42	0	151
GDP3	134	36	43	0	213
GDP2	210	67	48	7	332
GDP1 (High)	337	133	79	65	614
Total	776	250	212	72	1310
Expected	*Count 1 (Low)*	*Count 2*	*Count 3*	*Count 4 (High)*	
GDP4 (Low)	89.45	28.82	24.44	8.30	
GDP3	126.17	40.65	34.47	11.71	
GDP2	196.67	63.36	53.73	18.25	
GDP1 (High)	363.71	117.18	99.36	33.75	
Chi-Squared test result					
1.96×10^{-15}					

The top section of the chart shows the Observed values, those found in the data. The cells that read Count 1 to Count 4 are heading columns that count the number of activities in each corresponding category. Under "Count 1", the activities in Category 1 are counted. The cells that read GDP4 to GDP1 label the four levels of GDP for the countries. Each of these GDP groups has 43 countries. GDP4 includes the lowest set of countries by GDP; GDP1 holds the highest set. The middle section shows the Expected Values. These are the values that the Chi-Squared test predicts will appear if the null hypothesis is correct and there is no difference between the groups. The bottom number shows the result of the Chi-Squared Test. It means that the probability of the observed data occurring by chance is 1.96×10^{-15}. This is a very low probability! It is much smaller than the cut off of .05. Thus, this test is considered significant. It shows that any difference between the categories chosen is likely to have meaning and not be random chance.

Next, examine these non-random differences in the Observed data. Recall that the Category 1 Space Activities are the lowest level of activity. This category includes items such as attending a space related meeting. It is expected that every development level, from GDP4 to GDP1, should see the higher scores in Category 1 than in other Categories; and this is what appears. Category 1 has much higher counts than other Categories in each GDP level. The number of counts in Category 1 also increases with GDP level. In fact, this is true in each Category. As GDP increases from level 4 to level 1, the space scores increase. This is strong evidence that more developed countries show higher space scores. Focus also on Count 4. Category 4 includes activities with owning and operating space hardware. It is very telling that no projects for GDP4 or GDP3 countries are in this category. That means that the countries with the lowest GDP's do not have or operate space hardware, according to the sources in this study. Meanwhile, the highest GDP level has 65 instances of Category 4 activities. This is strong evidence that higher development is associated with greater space activity.

Consider also the Aggregate SPM versus GDP results for confirmation. They are shown in the chart below.

Table 21: Example Results from Chi-Squared Aggregate Space Participation Tests

Chi-Squared: Four Equal Groups of GDP – Aggregate SPM – Count Countries				
Observed	*SP1 (10-21)*	*SP2 (6-10)*	*SP3 (0-5)*	**Total**
GDP4 (Low)	0	2	41	43
GDP3	0	11	32	43
GDP2	10	21	12	43
GDP1 (High)	36	7	0	43
Total	46	41	85	172
Expected	*SP1*	*SP2*	*SP3*	
GDP4 (Low)	11.5	10.25	21.25	
GDP3	11.5	10.25	21.25	
GDP2	11.5	10.25	21.25	
GDP1 (High)	11.5	10.25	21.25	
Chi-Squared Test Result				
1.86×10^{-28}				

In this chart, Space Participation is binned based on a sum of all the points. Each country earns one point for each of their space activities, and their Aggregate SPM score is the total number of points. The Aggregate analysis with GDP tells the same story as the Categorized analysis. In this case, the columns in the Observed data show how many countries from each GDP level have the specified number of Aggregate SPM points. This analysis should be biased towards the less developed countries because they receive the same credit for Category 1 activities as for higher Categories. Look at the Observed results under SP1. This shows how many countries in each GDP category have greater than 10 Space Participation points or activities. This is the highest Space Participation Category. None of the GDP4 or GDP3 (the low score GDP countries) achieve this high space score. Focus on the row of GDP4. These low GDP countries only have 2 representatives in the middle space participation level. Forty-one out of forty-three are in the lowest category. The column of SP3 is also telling. The number of countries in this low space category monotonically decreases as GDP increases. Finally, in the GDP1 category, there are no countries with less than 5 Space Participation Points. The trends in this data certainly support the idea that countries with higher development levels have higher space participation. This is what is expected based on theory.

So far this section has looked closely at the results from the GDP analysis to see if there is evidence of greater space participation for higher GDP countries. Next, compare the results from GDP to the other Development Indicators to see if the relationship is always of the same strength.

The table below shows the Chi-Squared test results for 5 of the Development Indicators in one instance of the test. The second row shows tests that use the Aggregate SPM bins and the 4 equal groups for the Development Indicator bins. The third row shows the results for the Categorized SPM bins and 4 equal group development bins. Note that this third row data counts activities not countries. All of the Chi-Squared tests represented here are valid and significant.

Table 22: Results from SPM Chi-Squared Tests with Five Development Indicators

	GDP	Per Capital GDP	Education Expenditure	Internet Users	Cell Subscribers
Aggregate SPM	1.86×10^{-28}	1.30×10^{-6}	2.90×10^{-4}	4.75×10^{-8}	4.17×10^{-6}
Categorized SPM (Count Activities)	1.96×10^{-15}	1.01×10^{-5}	1.6×10^{-4}	6.7×10^{-6}	5.82×10^{-4}

This chart shows decimals that represent small probabilities. Each of them is much less than .05; this is why the tests are considered significant. Focus on the exponent on the 10 in each result. This shows the order of magnitude. In general, if the order of magnitude is very negative, it implies a stronger affect of the variable. This is read with caution because the accuracy of the software used in the test is not accounted for. The overall trend, however, can be considered. Look at the row for Aggregate SPM. The probability for GDP is much more negative than any of the other indicators. The same is true for the Categorized SPM row. This is evidence, though somewhat weak, that space participation may follow GDP more than the other Development Indicators. Further analysis with other methods, such as regression, could be employed to confirm this suspicion.

Finally, summarize the conclusions from the Question 1 data analysis. The results of the Chi-Squared tests clearly and consistently show that there is a meaningful difference in space activity for countries at different development levels. There is strong evidence in the data that countries with higher development rankings also have higher space participation scores. The reverse relationship is also suggested. Countries with higher quantity and quality of space activity are more highly developed. It is possible that GDP is the best Development Indicator to predict space participation among all countries. This could be confirmed by future regression analysis.

4.2 Q2: Mission and Management Architectures

The results in this section contribute toward an answer to the second Research Question. The analysis for Question 2 is primarily exploratory and inductive. This section helps in reaching the first goal of the thesis: to understand how developing countries are using satellite technology.

4.2.1 Summary of Analysis

The second research question is this, "What Mission and Management Architectures are developing countries using to apply satellite-based technology to national needs?" The data used in this analysis are from the Space Project Case Studies that review satellite-enabled activities in Africa. These activities are in the areas of remote sensing, communication and navigation. The main steps in this analysis are to define appropriate categorization schemes and organize the projects within them. The results of this analysis are a series of matrices and tables that show trends in space activities of African countries and organizations.

4.2.2 Results and Discussion

There are several layers to the results from Research Question 2. The following section shows the Master Space Project Matrix, the Specialized Space Project Matrices, the Roles and Actors Analysis, Trends in Project Purpose, and Trends in Project Architectures over Time.

Master Space Project Matrix

The first result is the Master Space Project Matrix. It takes all of the 90 Space Project Case Studies and organizes them to show their Mission and Management Architectures. Recall that the Mission Architectures reflect what is technically accomplished in the project. The Management Architectures show who is directly involved in the project. The Master Space Project Matrix is shown below with the numbers of projects in each category filled in. The full matrix with project names can be seen in Appendix C. The horizontal axis shows the Management Architectures. The vertical axis shows the Mission Architectures. Note that some of the Architecture names have been shorted to facilitate visual presentation.

Master Matrix - 90 Projects Total	*One African Country + Contractors (37)*	*Non-Regional African Collaboration + Contractors (2)*	*Regional African Collaboration + Contractors (4)*	*External Collaboration ; Sat expertise from African partner (3)*	*External Collaboration ; Sat expertise from both sides (13)*	*External Collaboration ; Sat expertise from external partner (23)*	*External Company or Org.; provides sat service in Africa (8)*
Design, Build, Launch, Operate Satellite (9)	8				1		
Design, Build Satellite (2)	2						
Buy and Operate Satellite (15)	6	1	1				7
Lease and Operate Satellite (1)	1						
Operate Others' Satellites (1)	1						
Lease Sat Capacity and Distribute Service (6)	5						1
Operate Ground Segment; send or receive data (22)	12		1		1	8	
Process Sat Data; create data products (31)	2		2	3	9	15	
Use Sat Data Products (1)		1					
Participate in Regulatory Action (2)					2		

Figure 6: Master Space Project Matrix with Results

Consider first observations from the Matrix about the Management Architectures. The totals for each row and column are shown in parentheses along the top row and far left column. The matrix shows that most projects fall in the red, blue and indigo columns (#1, #5 and #6 counting from left to right). Thirty-seven of the ninety projects involve an African country working on its own or with contractors. The total number of collaborations with external partners is the sum of columns #4 to #6 in green, blue and indigo. This gives a total of thirty-nine out of ninety. Meanwhile, only six projects in the orange (#2) and yellow (#3) columns involve collaborations between African countries. There is much more collaboration between Africans and external partners than between African partners. Looking further within the external partnerships shows that in most collaborations, the external partner is bringing satellite expertise. Sometimes the African partner brings it as well, as shown in the blue column (#5). In twenty-three out of thirty-nine cases, however, the external partner provides all the relevant satellite expertise. This is contrasted with the three projects in the green column (#4) in which the external partner brings some other resources such as funding or coordination.

Now focus on the Mission Architecture trends in the rows of the matrix. The largest rows are green and blue (#4 and #3 counting from bottom). Thirty-one of the projects involve processing satellite data and twenty-two involve operating satellite-enabled ground equipment. These Mission Architectures are relatively low in the spectrum. They rank as levels 4 and 3, while 10 is the highest. Despite this concentration near the bottom, there is an optimistic concentration near the top as well. There are nine projects in the top row – Design, Build, Launch and Operate a Satellite. There are fifteen projects in the third row from the top – Buy and Operate a Satellite. In this case, seven of the fifteen projects are done by external organizations that provide service in Africa. Thus, the real focus for African activity is in the other eight projects involving buying and operating satellites. Six of these are done by single African countries while two are done by African collaborations. In terms of project Mission Architecture, there seems to be heavy activity in either buying and building satellites or just using satellite data from others. There are fewer examples of middle level Mission architectures such as leasing the satellites of others or leasing capacity on the satellites of others.

Next inspect the matrix as a whole for trends. Think of the matrix as having four quadrants, top-left, top-right, bottom-left and bottom-right. The projects generally fill in all the quadrants except the top-right. The largest numbers can be found in the bottom right quadrant. In that section there are fifteen projects for processing satellite data that involve external collaborations in which satellite expertise comes from the external partners. Meanwhile, nine projects process satellite data with satellite expertise from both the African and external partners. Another high scoring cell is eights projects that operate ground based satellite equipment and use external expertise. By contrasting the two quadrants on the right side of the matrix, it is clear that most external collaborations lead to low Mission Architectures. There are very few data processing projects that involve only African entities. This may be because the partners tend to supply the data in such projects. Thus, African groups on their own do not have the data resources. The top-left quadrant shows quite a few African projects that pursue high mission architectures. There are more projects involving a single country or organization in this quadrant than there are inter-African collaborations.

The next section discusses the Specialized Space Project Matrices. They will provide additional insight into the information on the Master Space Project Matrix.

Specialized Space Project Matrices

Three matrices are produced based on the same rules and assumptions as the Master Space Project Matrix. Each one only includes the projects in its specific area of technology specialization. The three areas are remote sensing, communication and navigation. Each of these subordinate matrices are presented and discussed below.

Remote Sensing

A total of fifty-three projects out of the ninety space project case studies can be classified as Remote Sensing. They receive this classification if the final goal of the project is related to remote sensing, as evidenced in the project documentation. The Matrix of Remote Sensing Projects is shown below with the numbers of projects in each category filled in.

Remote Sensing Matrix - 53 Projects Total	*One African Country + Contractors (19)*	*Non-Regional African Collaboration + Contractors (2)*	*Regional African Collaboration + Contractors (3)*	*External Collaboration; External Funding; African Funding and Expertise (3)*	*External Collaboration; Funding + Sat expertise from both sides (3)*	*External Collaboration; External Funding; Sat expertise from both sides (8)*	*External Collaboration; External Funding and Expertise (15)*
Design, Build, Launch and Operate Satellite (9)	8				1		
Design, Build Satellites (1)	1						
Operate Satellites (5)	3	1			1		
Operate Ground Segment to Send or Receive Data (1)			1				
Process Satellite Data to Create Data Products (31)	2		2	3	1	8	15
Use Satellite Data Products (6)	5	1					

Figure 7: Remote Sensing Space Project Matrix

This matrix has similar but not identical axes as the Master Matrix. The horizontal axis is still showing the Management Architectures. The vertical axis shows the Mission Architectures. The specific entries in the Architectures are chosen based on the data available in just the remote sensing case studies. The Mission Architectures that are shown here all appeared in the Master Matrix. The Management Architectures bring added information about the source of funding in collaborative projects. Notice that there are four categories of external collaboration instead of the three in the Master Matrix.

How do the trends in the Remote Sensing Matrix compare to those of the Master Matrix? First, notice that the overall layout of the projects within the Remote Sensing Matrix is similar. There are few projects in the top right quadrant; far more in all the other quadrants. There are many projects in the lower right quadrant that involve processing satellite data. This shows that the bulk of the projects in that group on the Master Matrix are actually remote sensing projects. There is also a matching large group of projects in the top left quadrant of both the Master and Remote Sensing Matrices. Thus, most projects in which individual African countries build a satellite are remote sensing projects. A preliminary conclusion may be that African countries demonstrate a high level of accomplishment in the area of satellite design for remote sensing. This will be clarified and qualified more in future analyses. For now, note that the projects with the highest Mission and Architecture rankings are in remote sensing; they are not in communication or navigation. There is no Management Architecture for "External Company or Organization that provides services in Africa". This is not a mode that is observed in Remote Sensing, only in other satellite areas.

Consider specific columns. The most populous columns are the red, indigo and violet or #1, #6 and #7 as read from left to right. Nineteen of the fifty-three remote sensing projects are done by one African country who may hire contractors. Fifteen is the next highest column. These projects are done in external partnerships. The funding and execution come from outside, but some of them include training opportunities for the African partners. In third place is the indigo column with eight projects. These are external partnerships in which the funding is from outside Africa, but both sides contribute satellite expertise. There are only two or three projects in each of the other columns. There is little collaboration among Africans in remote sensing and little external collaboration in which the Africans bring both funding and expertise.

Consider specific rows. The most populous rows are the first row, "Design, Build, Launch and Operate Satellite" and the second row from the bottom, "Process Satellite Data…" Together these two rows make up forty-one of the fifty-three projects. None of the other rows even have project numbers in the double digits. Thus, remote sensing projects tend toward two extremes: those providing complete control of the satellite to the African country or those that provide no control of the satellite to the African country. In the data processing projects, Africans are working with satellite data that is collected by other entities for their own purposes. Focus on the bottom row, "Use Satellite Data Products or Decision Tools." These types of projects involve African actors obtaining satellite data that is already somewhat processed and using it. The data may be purchased or it may be freely available. The common way of using it is to input it into a Geographic Information System and organize it in a way that is relevant to the user. There are no external collaborations in this row. This may imply something important. This work requires less specific knowledge of satellite-based technology. Note the five projects that intersect "Use satellite data products" and "One African country or organization." These projects involve both remote sensing and navigation. In the Master Space Project Matrix, they are categorized based on their performance in the navigation area because they rank higher in navigation than in remote sensing.

Focus now on the projects that involve external collaborations. Most of them work on processing satellite data. Observe the green column (#4 from the left). Here are three satellite data processing projects in which the African partner has the requisite expertise and some funding. They need a partner to help with funding, but not to supply the expertise. Note that all three of the Case Study Projects in this column are not short term efforts, but well-established centers that provide data processing services and training to other Africans. Here external funding has lead to a long term benefit and the productive use of African skill. What does this imply about the barriers that prevent African countries from using satellite technology? Is lack of money or expertise a bigger barrier? The other three columns showing collaborations seem to imply that external expertise is sorely needed. The majority of these projects depend heavily on outside expertise. Many of these projects are short term efforts that are meant to lead to more long term work. A majority of them is sponsored by the European Space Agency (ESA) and rely on data collected by various ESA satellites. The influence and benefit of outside expertise can not be denied.

Communication

The Communication Specialty Matrix has twenty-seven case studies. The Mission Architectures that describe communication projects vary notably from those of the Remote Sensing Matrix, although they are all found on the Master Matrix. The Management Architectures are less specific on the Communication Matrix than on the Remote Sensing Matrix, simply because the case studies do not provide as much detail. Note that the column for "External Company or Organization that Provides Services in Africa" is needed for Communication projects whereas it is not used in the Remote Sensing Cases. The Communication Matrix is shown below.

Communication Matrix - 27 Projects Total	*One African Country + Contractors (12)*	*Non-Regional African Collaboration + Contractors (0)*	*Regional African Collaboration + Contractors (1)*	*Collaboration Between African and External Partners (6)*	*External Company or Organization; Provides Services in Africa (8)*
Buy and Operate Satellite (12)	4		1		7
Operate Leased Satellite (1)	1				
Lease Satellite Capacity and Distribute Content or Service (6)	5				1
Operate Ground Segment of Satellite Comm System (7)	2			5	
Regulatory Action in Satellite Communication (1)	0			1	

Figure 8: Communication Space Project Matrix

What can be learned from the Communication Matrix? First, note that the range of technology in the Mission axis is limited. The highest level of project in Remote Sensing involves building, designing and operating a satellite. Here, the highest level of project involves buying and operating a satellite. This is logical because communication satellites are more complex and challenging to design than remote sensing satellites. African countries have chosen to only buy communication satellites rather than be involved with their design. Second, note the Communication Matrix has an overall distribution of projects that echoes the Master Matrix. A major difference is that the top right corner does not seem so empty. It is dominated by External

Companies that operate satellites that service Africa. There is only one column showing external collaborations and only one project that includes African collaboration.

Consider specific columns. The first column from the left has almost half of the projects. There is a healthy range of Mission Architectures in this column, from buying communication satellites to operating the ground segment. Note that the projects in which an African entity buys a satellite only involve 2 countries, Nigeria and Egypt. Egypt actually accounts for four of the five projects in the first two cells in this left-most column. There are five projects that involve leasing satellite capacity and distributing service or content. Most of these projects are implemented by commercial or non-profit organizations. Only one is a quasi-governmental organization that operates in a commercial manner. No other column has as much diversity of Mission Architecture as the first.

It should be noted that the Communication Matrix may not adequately represent realistic proportions of the kinds of projects that are done in Africa. The examples represent well the kinds of activities that are done, but the numbers may be uninformative. The Space Participation data and the Embassy interviews evidence a great deal of satellite communication activity in African. The fact that there are fewer Communication projects than Remote Sensing projects should not be taken as evidence that communication is less important or prevalent. The communication simply activity has a different structure, as will be seen in the Roles and Actors analysis.

Navigation

Fourteen of the ninety Space Project Case Studies are on the use of Satellite Navigation technology. The Mission Architectures used to describe this limited data set are very specific to the activities in this field. It is the only way to show differentiation between the projects. African use of satellite navigation technology is limited to the architectures that involve operating ground-based technology to receive data. No African country owns navigation satellites. They benefit, like many other countries, from the availability of two global satellites systems that are owned by the United States and Russia. When they partner with Europe, Africans also benefit from the European satellites that augment the signal from the US system. The Mission Architectures in this matrix show the sophistication with which the navigation satellite signal is received and processed. See the table below for the full matrix.

Navigation Matrix - 14 Projects Total	One African Country + Contractors (10)	African Collaboration + Contractors (0)	External Collaboration Sat Nav Expertise from both sides (1)	External Collaboration; External Sat Nav Expertise (2)	External Company or Organization; Provides Services in Africa (1)
Manufacture or Sell Products that include Sat Nav Receivers (1)					1
Use Sat Nav with Augmentation (1)				1	
Use Sat Nav with GIS (8)	8				
Use Sat Nav Receiver Only for Position Determiniation (4)	2		1	1	

Figure 9: Navigation Space Project Case Studies

The highest Mission level is for companies that create and sell products that can receive signals from the navigation satellites. No African entities are involved in this, but such products are sold in African markets. The second Architecture is using navigation satellite signals with Augmentation. This refers specifically to Europe's system of satellites that provide corrections to the signals of the GPS systems of the US. This makes it feasible to use the GPS signals for airplane navigation because it increases the fidelity of the signal. The next architecture is using the data from a navigation satellite signal receiver in a Geographic Information System (GIS). This means that the location data is collected and stored and transferred to a computer. GIS software is used to put that information data in a format that can be easily integrated with other information and visualized on maps. The lowest Architecture level involves simply using a navigation satellite signal receiver and finding the location of an individual.

This is a very sparse matrix and it does not reflect the overall shape of the previous ones. Most of the projects involve individual countries using satellite navigation data and GIS. Focus on the box in the first column that has eight projects. Five of these projects are from national governments recording their use of satellite navigation technology and GPS to facilitate the execution of their national census. The other three projects in that box are from commercial African companies that use satellite navigation data and GIS in construction or contracting work for clients.

The one project in the middle column warrants mention. The project uses a specially designed, small device that can be attached to a bird for tracking purposes. The device includes a receiver to get position information from navigation satellites. It also uses cellular technology to send that information to the researchers. Only one example of this kind of animal tracking was found, but these methods are likely used often.

This concludes the review of the Mission and Management Architectures that are found in the various Project Architecture Matrices. The next section shows the Roles and Actors of the Space Project Case Studies.

Roles and Actors

The purpose of the Roles and Actors analysis is to add to the understanding provided by the Architecture Matrices. It is yet another way to organize the data from the ninety Space Project Case Studies. The Management Architectures only show whether African or non-African entities are involved in the projects. The next analysis gives more concrete information about the organizations involved. The term "Actors" simply refers to the entities that are doing the action. The term "Roles" is based on the highest technical activity of the Actors. Separate analysis is done for each of the three satellite technology areas – remote sensing, communication and navigation.

Remote Sensing

The graphic below shows the various roles seen in the Remote Sensing Space Project Case Studies. The Roles are listed on the far left without boxes. They include Satellite Builders, Satellite Owners and Operators, Satellite Data Processors, Coordinating Organizations and Data Users. Each colored box gives a category of Actors. Below the category, examples of specific organizations from the case studies are listed. These examples are the Actors.

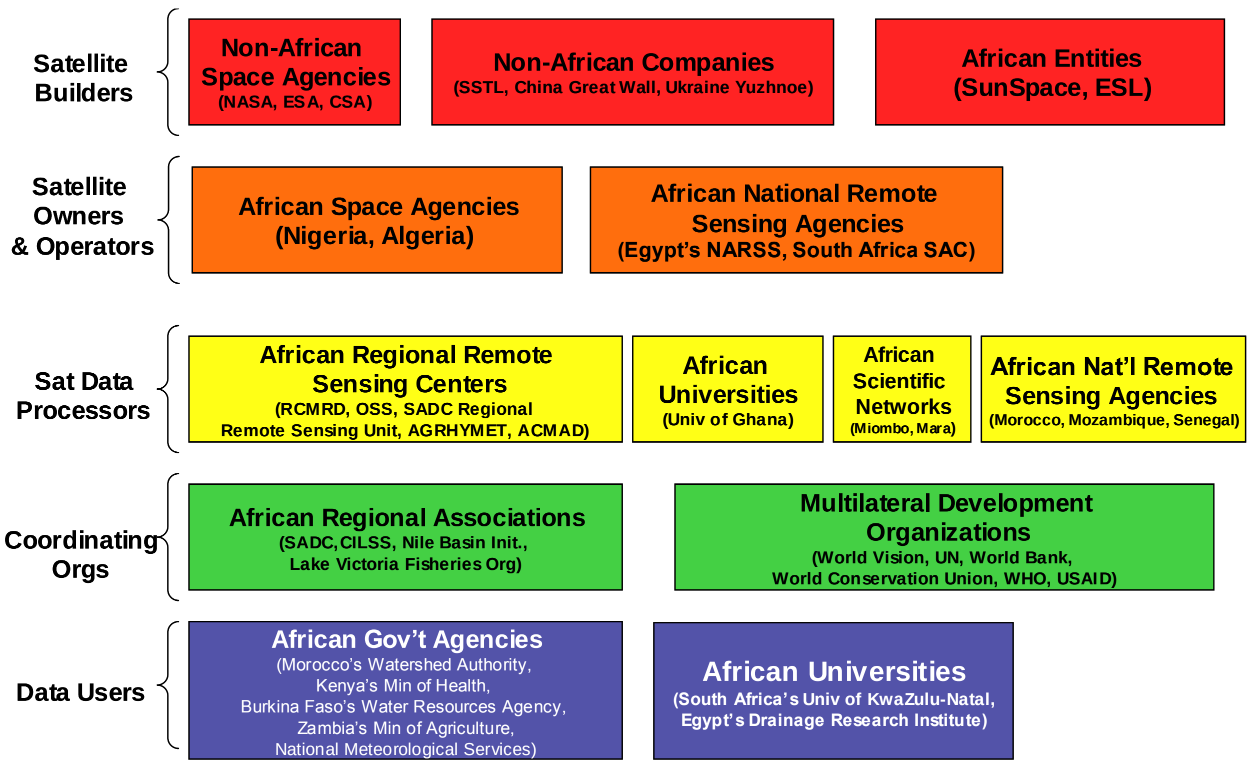

Figure 10: Roles and Actors in African Remote Sensing

Coordinating Organizations is the vaguest Role label. This refers to groups that do not necessarily bring satellite expertise, but they do provide leadership in projects that use satellite technology. They bring together the partners, sometimes provide funding or help to secure it and disseminate information that is produced as a result of the projects. The Roles and Actors diagram is color coded in a manner similar to the Matrices. The Role that is most involved with the satellite technology is red. The colors continue down the spectrum as the roles move away from direct involvement with the satellite. It can be argued that Data Users are more closely involved with the technology than Coordinating Organizations. That is true in the technical sense, but in the context of executing the projects, the Coordinating Organizations have more influence than the data users. Note also that the diagram is designed so that each role can include the roles below it. Thus Satellite Builders are often Satellite Owners and Operators. They also process and use satellite data. Some times they even coordinate projects. With this in mind, it also makes sense to have Coordinating Organizations above Data Users. They do sometimes use the data as well.

The key insights that can be drawn from this diagram are the locations of African organizations and knowledge of whether they are public or private institutions. Within the Role of Satellite Builders, there are Non-African Space Agencies, Non-African Companies and African Entities. This means that the builders for satellites in the Space Project Case Studies came from these three sources. The two African entities that have truly demonstrated independent expertise in building satellites are the Sun Space and Information Systems company and the Electronic Systems Laboratory (ESL) at Stellenbosch University. Both are in South Africa. Sun Space actually is a spin off company from the ESL. It functions as an independent commercial corporation. The ESL is part of a government university. It is easy to see that there is very limited capacity for building satellites in Africa. A few other countries are pursing the capability, including Nigeria, Algeria and Egypt. Several case studies show that when they buy remote sensing satellites, they also pay for training in satellite design from the contractor. None of them have independently built a satellite at this time.

Consider now the role of Satellites Owners and Operators. Within Africa, there are two major types of entities that do this. They are the national space agencies and the national remote sensing agencies of a few countries. Not many African countries have official national space agencies, as is evidenced by the Embassy Data and the Space Program Case Studies. Only Nigeria and Algeria have officially named Space Agencies. The satellite projects of these space agencies are part of the Space Project Case Studies. Egypt has a clear space policy, led by two distinct entities. One of them is NileSat, which deals with satellite communications. The other is the National Authority for Remote Sensing (NARSS). Both NileSat and NARSS are reviewed in Space Project Case Studies, and they appear as examples in the cooresponding Roles and Actors Diagram. South Africa is in the process of creating a space agency, but it is not yet established as of early 2008. A strong South African organization with satellite expertise is the Space Applications Center of the Council for Scientific and Industrial Research. The SAC is also one of the Space Project Case Studies. This diagram, then, shows most of the strong government organizations in Africa with remote sensing satellite operation expertise. Those with communication expertise are shown in the next diagram.

In the Role of Satellite Data Processors many more examples could be listed. This task is done by many Actors, as shown in the diagram. The category "African Scientific Networks" refers to non-institutionalized groups that work together on a common problem from disparate geographic locations. Two case studies, Miombo and MARA, show this type of collaboration.

The other three categories of Actors generally refer to governmental organizations. The Regional and National Remote Sensing Agencies are supported – at least in part – by African governments. This is also true for most universities in Africa, according to the Embassy Interviews. Thus, the Satellite Operator and Data Processor Roles are dominated by government.

The Coordinating Organizations are in two forms, African Regional Associations and Multilateral Development Organizations such as the United Nations. In these categories many more examples can be added. The African Regional Associations are government collaborations. They work closely with the Multilateral Development Organizations. Finally, there are two kinds of Data Users. Both of them are government related – the agencies and the universities.

It is easy to conclude that the Actors in the Remote Sensing area are largely government institutions. The other conclusion is that Africans overall are most active starting at the level of Satellite Data Processors and below. They do not have a strong presence as Satellite Builders, Owners or Operators yet. Notice also that it is easy to see a linear progression through the Roles in the field of Satellite Remote Sensing. Each Role can neatly encompass the roles below it, and each role is the logical step above the roles below it. This makes sense in terms of both technology and project execution. The same linear flow is not present in the Communication Roles and Actors Diagram in the next section.

<u>Communication</u>

This section shows the Roles and Actors for the African Satellite Communication community. In this case, boxes show Roles and the specific Actors that are observed in the Case Studies are shown in parentheses. It is not easy to make a linear progression through the roles from the Satellite Builders to the Data Users. There are many paths through the diagram, as shown by the arrows between boxes. These arrows show how the technical service and the data flow from the source to the final user. The colors have the same meaning as in other analyses. They are red for the highest level of satellite technology and flow downward through the spectrum toward blue to represent weaker connections to the satellite technology. See the diagram below.

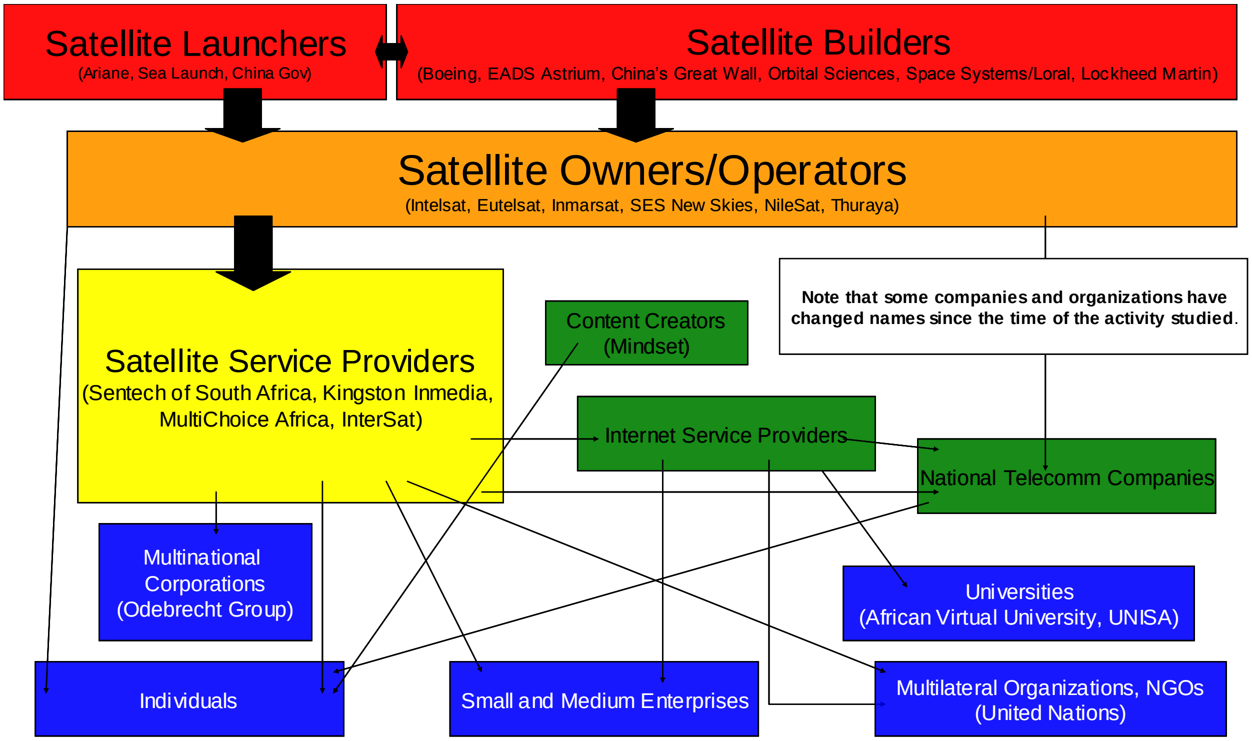

Figure 11: Roles and Actors in African Satellite Communication

The top level of Roles holds the Satellite Launchers and Builders. Both groups are mentioned in the Space Project Case Studies; thus, they are shown here as well. None of the Satellite Launchers or Builders in the twenty-seven Communication Case Studies are African. The Launching Companies and Satellite Builders shown in the boxes here are European, Chinese and American. Of the seven Satellite Owners listed, only one is African. This is the Egyptian agency NileSat, which is mentioned above. Africans do not make a strong appearance in the Communication market until one moves down in the diagram to the yellow and green levels below Satellite Owners and Operators. Several of the Satellite Service Providers are African – Sentech, MultiChoiceAfrica and InterSat. Sentech operates as a commercial company but it is owned by the state government of South Africa. MultiChoice Africa and InterSat are commercial companies that operate in many countries in Africa. Organizations such as these lease satellite capacity and package content to sell to the many groups in the lowest level (blue). They sell directly to individuals, to Small and Medium Enterprises, to Universities and to Multilaterals. Some groups, like Mindset, do both content creation and distribution via satellite. In some cases, the Service Providers reach the end customers through National Telecommunication Companies that may be government run.

The challenge of diagramming the interactions within the Communication community is that the services can have many different pathways. Consider the example of MultiChoice Africa. They sell satellite television, audio, data and video services to individual homes. Meanwhile, Afsat is an African company that leases satellite service and sells V-Sat communication services. Their customers are mainly small enterprises, internet service providers and corporations. The Embassy Interviews and Literature Review revealed that the National Telecommunication Companies and the government ministries that oversee them play an important role in this market. They influence the openness and competitiveness of the market. The African Virtual University is an interesting Case Study as well. It is a program to send educational material via satellite from all over the world to Africa. The satellite service is actually provided by Intelsat, a Satellite Owner, directly to this User.

The Communication Roles have much more diversity than the Remote Sensing Roles. There is quite a mix of government, quasi-government and commercial organizations involved.

Navigation

The Navigation Roles and Actors diagram is simple. There are three levels of non-African roles, and there is one level at which Africans work. See the diagram below.

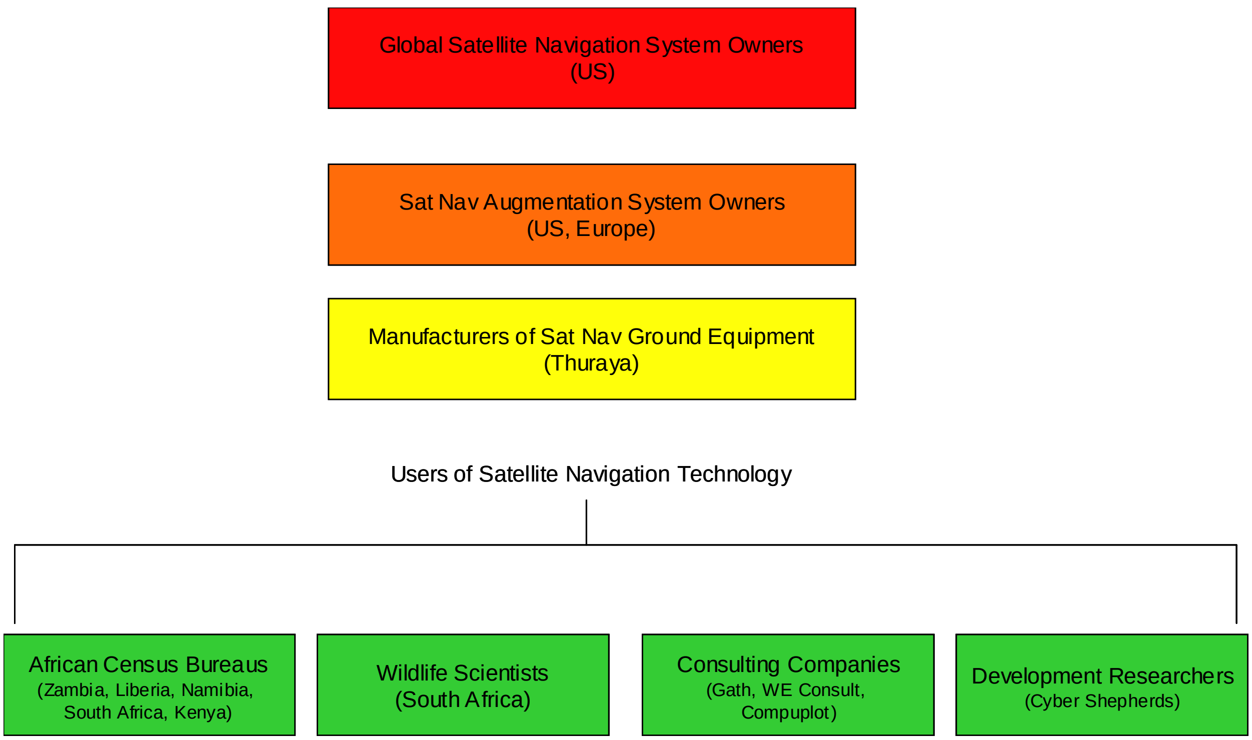

Figure 12: Roles and Actors in African Satellite Navigation

The organizations who own the global satellite navigation systems, who own the satellite augmentation systems and who manufacture satellite navigation ground equipment are all non-Africa. Several groups from the Project Case Studies rely on the services of these external service providers. The groups are African National Census Bureaus, Wildlife Researchers, African Consulting Companies and Development Researchers. The Census Bureaus are government organizations. The other groups are private.

Purpose

This section summarizes the results of an analysis of Purpose within the Space Project Case Studies. The Purpose is defined based on the user's goal for implementing the technology as explained in the documentation of the Space Project Case Study. The three charts below show the main purposes mentioned in the three satellite technology areas – remote sensing, communication and navigation. This is not an exhaustive list, because some stated purposes do not fit neatly within a single category. It does show the important trends, however. It is also not mutually exclusive because some projects list more than one purpose.

The first chart shows the results for Remote Sensing.

Table 23: Trends in Project Purpose for Remote Sensing Case Studies

Remote Sensing	
Water Resource Management	13
Natural Resource Management	7
Agriculture/Food Security	6
Monitoring Desertification	2
Meteorology	2
Wetlands Management	2
Land Cover	1
Pollution Management	1

The largest set of projects is aimed at Water Resource Management. Note, however, that most of these projects are under the same umbrella program. This is the TIGER program of the European Space Agency. Through TIGER, ESA funds a series of projects on Water Resource Management in Africa. Many of the TIGER projects are included in the case studies because their information is so readily available in one place. Their prevalence, however, may skew the data. Other common project purposes are natural resource management, food security, monitoring desertification, meteorology and wetland management.

The next chart shows the common purposes for communication Case Study projects. Internet, distance education, radio and television stand out as common uses of satellite communication systems.

Table 24: Trends in Project Purpose for Communication Case Studies

Communication	
Internet	8
Distance Education	8
Radio	6
Television	5
Phone	3
Telemedicine	2
Informal Education	1

Finally, see below for the chart showing the purpose in navigation projects. The use of navigation technology for national census taking is the dominant example. Note that the dominance of this example is partly due to data collection methods, as in the case of the TIGER projects. All the case studies on the use of satellite navigation data for a national census are from an online record of a United Nation's conference on Census Cartography and Management in Africa.[clxx] Despite the danger of skewing the data, the author chooses to include all of these examples because they provide valuable information.

Table 25: Trends in Project Purpose for Navigation Case Studies

Navigation	
National Census	7
Surveying/Construction	3
Personal Navigation	2
Aviation Navigation	1
Wildlife Tracking	1

Time Trends

The analysis on the initiation dates for the Space Project Case Studies is done to see if anything can be learned from the data available. The results are mostly inconclusive. The method is to divide the Space Project Case Studies into bins based on initiation data and Mission or Management ranking from the Master Space Project Matrix. The outcome is that most of the Chi-Squared tests are invalid due to small numbers in the Expected Values. These low Expected Values imply that the results of the Chi-Squared test can not be trusted.

The charts below show which combinations of binning methods are valid. The top table is for the Mission tests; the bottom shows the Management tests. The top row of each table shows the methods used to bin the time data. The far left columns show the methods used to bin the space project data. Blank boxes in the tables mean that no test is done in that combination. If a test turns out to be both Valid and Significant, it shows that there is a meaningful difference in the type of Architectures used at different time periods.

Table 26: Results of Mission Architecture Time Trend Tests

Mission Architecture Time Trend Tests	*Range of Time Bin*	*Decade Bins*	*Three Equal Groups*	*Four Equal Groups*	*Historical Events*	*Two Time Periods*
Four Bins	INVALID	INVALID	INVALID	INVALID	INVALID	****
Three Bins	****	INVALID	**Valid not Significant**	**Valid not Significant**	INVALID	****
Two Bins	****	INVALID	****	****	****	Several Valid Tests; some Significant

Table 27: Results of Management Architecture Time Trend Tests

Management Architecture Time Trend Tests	*Range of Time Bin*	*Decade Bins*	*Three Equal Groups*	*Four Equal Groups*	*Historical Events*	*Two Time Periods*
Seven Bins	****	****	INVALID	INVALID	****	****
Five Bins	****	****	INVALID	INVALID	****	****
Three Bins	****	****	INVALID	INVALID	****	****
Two Bins	****	****	**Valid, not Significant**	**Valid, not Significant**	****	****

The first issue is the invalidity of so many tests. The suspected reason for this is the lopsided nature of the data. The Space Project Case Studies are not constructed to be an historical representation of the evolution of space activity in Africa. Most of the projects in the Case Studies are currently active or were active within the past decade. The projects that have early initiation dates are mostly well-established organizations that have existed for decades and still exist. Thus, the data set used in these Chi-Squared tests does not represent well the true picture of how Mission and Management practices changed over time. In order to do a more complete analysis of this type, an intentional literature review is needed to find data about past projects. The current analysis is done in an exploratory manner to see what can be learned from the data that is available.

The plot below provides a visual explanation of the limited nature of the data. It shows the Mission Architecture scores or rankings for the Project Case Studies plotted against the initiation date for each project. Note that a set of redundant projects are left out, for visual clarity. These are the TIGER Projects. They are all projects sponsored by the same organization, the European Space Agency. Most of them have the same Mission Architecture scores and the same initiation dates. Two of these projects are used to represent the whole group in the graph below.

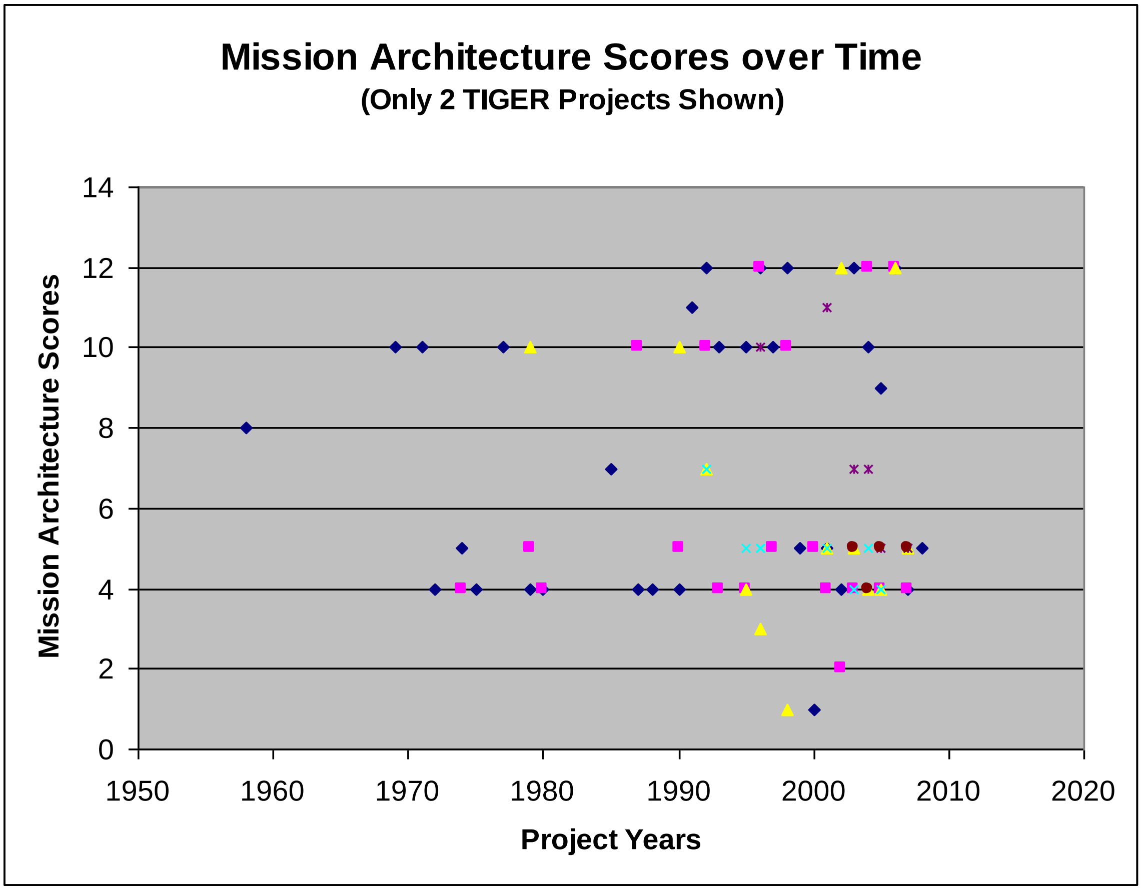

Figure 13: Mission Architectures versus Initiation Dates, Space Project Case Studies

The graph clearly shows that the majority of its projects start after the year 1990. Some of the binning methods lead to invalid tests because they create bins with only three or four projects. Chi-Squared methods do not handle such unsymmetrical data well. Note that the binning method that is based on historical data uses the years of several major space conferences as breakpoints. The three UNISPACE Conferences occurred in 1968, 1982 and 1999[clxxi]; the World Summit for Sustainable Development was in 2002.[clxxii]

Do not use this plot to conclude that most space activity in Africa occurred after 1990. This data is not at all exhaustive in a historical sense. It is better used to notice how many current projects started decades ago.

Consider now the tests that are valid, but not statistically significant. The first of such tests uses three equally sized bins for the time data and three bins for the Mission Architecture data. The test is valid in the sense that the Chi-Squared result is believable. The table below shows the observed data from this Chi-Squared test. The italicized numbers show the indices of the Space Project Case Studies in each Time Data bin. The lowest indices, from 1 to 30, show the earliest projects. Projects #60 to #88 are the latest projects. In the first column under Mission, the three levels represent bins of low, medium and high Mission Architectures. There is no clear trend in the observed numbers. The row of Low Mission Projects decreases then increases. The row of Medium Mission Projects increases then decreases. The Chi-Squared result shows that the probability of achieving such a result by chance is about 19%. Thus, these values are inconclusive. The null hypothesis that there is no different in Mission Architectures over time can not be rejected. This is also true for the other valid and insignificant tests.

Table 28: Results from Valid Time Trend Chi-Squared Test

Observed	*Early Projects*	*Middle Projects*	*Late Projects*	
Mission	*# 1 to 30*	*# 31 to 59*	*# 60 to 88*	**Total**
Low Mission Projects	12	8	16	36
Med Mission Projects	7	11	8	26
High Mission Projects	11	10	5	26
Total	30	29	29	88

The most informative tests are the ones that divide the time data and the Mission Architecture data each into two bins. Here a series of Chi-Squared tests are attempted and each one is valid. The only difference between each test is the year that serves as the cut-off point between early and late projects. The result is that a range of years is found that lead to valid and significant Chi-Squared tests when used as a cut-off point. The cut-off years that lead to significant tests are from 1996 to 2000. For this data set, there is a statistically significant difference in projects before 1996 and projects after 1996 in terms of their Mission Architecture. The same is true for the years 1997 to 2000. The observed results from the test using 1998 as the cut-off year are shown below. Early projects are those before 1998; late projects are from 1998 or later.

Table 29: Results from 2x2 Chi-Squared Time Trend Tests with 1998 as Cut-Off Year

Observed	*Early Projects*	*Late Projects*	**Total**
Low Tech Projects	20	36	56
High Tech Projects	21	11	32
Total	41	47	88

This data actually shows that the number of high tech projects is much lower in the later period than in the earlier period. Also, the ratio of high tech to low tech projects decreases. This preliminary result, then, shows an increase in the number of overall projects, but not in the level of technology over time. The author notes again that this should not be considered conclusive, merely suggestive.

4.3 Q3: Architectures versus National Development Level

The results in this section contribute toward an answer to the third Research Question, "How does national development level influence the Mission and Management Architectures used by developing countries in satellite-based technology projects?" In this analysis, some of the methods from Question 1 and some of the methods from Question 2 are combined to crown the study. This section helps in reaching the second goal of the thesis: to understand how development level impacts satellite activity.

4.3.1 Summary of Analysis

The analysis has two main stages. In the first stage, the ninety African Space Project Case Studies are categorized and ranked based on the methods of Question 2 analysis. In order to do meaningful tests that are neither redundant nor vague, the categorization schemes from Question 2 are reworked into 5 Ladders. Each Ladder measures a different aspect of the Space Project Case Study. Projects are ranked on the Ladders. The rankings are applied to the appropriate African countries that participate in the projects. The second stage is to do statistical analysis about the countries by using the rankings as a measure of space activity and the Development Indicators as measures of national development.

4.3.2 Results and Discussion

The results for each Ladder analysis are shown below. The overall result is that virtually all of the Chi-Squared Tests show a significant difference in the Ladder rankings of countries on different development levels. This parallels the results of Question 1. It is further evidence that national development level is a strong determinant of space activity. Note also that almost all the Chi-Squared tests performed in this section are valid and therefore, believable.

Project Technology Ladder

The Project Technology Ladder ranks projects according to the level of the technical accomplishments in the project. Thus, it shows what is achieved, without regard to whether it is achieved by an African entity, a contractor or an external partner. The first result is the breakdown of projects on the Project Technology Ladder; this is essentially a frequency analysis. The chart below shows the number of projects in each level of the Ladder. Recall that about 12 Space Project Case Studies are excluded from some parts of the Question 3 analysis because of poor applicability to these methods. In this Ladder, seventy-nine out of ninety projects are analyzed.

Table 30: Project Technology Ladder with Frequency Analysis Results

Rank	Color	Level	Projects	# of Projects
9	**Red**	*Design, Build, Launch, Operate Satellite*	SunSat, Sumbandilasat, NigeriaSat-1, ALSAT-1, NX Nigeria, Alsat -2A, Alsat - 2B, EgyptSat-1, DMC	9
8	**Red**	*Design and Build Satellites*	Sunspace, ESL at SU	2
7	**Orange**	*Buy and Operate Satellite*	NARSS, Nilesat 102, Nilesat 101, NigeriaSat-2, NigComSat, NileSat, RASCOM, ARMC,	8
6	**Orange**	*Lease and Operate Satellite*	Nilesat 103	1
5	**Orange**	*Operate others' satellites*	SAC	1
4	**Yellow**	*Lease sat capacity and distribute service*	Sentech, MultiChoice Africa, Intersat, AFSAT, Mindset	5
3	**Green**	*Operate ground segment to send/receive sat data*	RCMRD, UNISA, Botswana V-Sat, WE Consult, Zambia Census, Liberia Census, Namibia Census, South Africa Census, Kenya Census, Gath, Compuplot, Sierra Leone Census, Ethiopia Census, GPS Crane Track, Uganda Telecentre, NePAD eAfrica, Senegal Telemed, AVU, River Blindness, EGNOS, Cyber Shepherds, AIDS Telemed	22
2	**Blue**	*Process Sat Data and create data products/decision tools*	CENACARTA, CERGIS, AGRHYMET, Geo-AQUIFER, Centre de Suivi Eco, RECTAS, Miombo, TIGER Ghana, TIGER GIS River Man, TIGER WADE. IWAREMA TIGER, Lake Victoria TIGER, FEWSNET, AFRICOVER, LEWS, GMES, NileRiver, Tiger Morocco, Malaria Risk TIGER, TIGER ARBRE, TIGER StereoSAat, TIGER SHARE, EPIDEMIO DUE, GlobWetland DUE, Lake Quality Egypt TIGER, Coasts Tanzania, Intsormil CRSP	27
1	**Violet**	*Participate in Regulatory Action regarding Sats*	Tampere Conv, Space and Major Disasters, Inmarsat, Intelsat	4
			Total	79

In the table above, Rank refers to the level on the Ladder. A higher rank means a higher level of technical achievement. The Levels are defined in a similar manner to the Mission Architectures in this and the next Ladder. The important difference is what is being ranked.

The most populous levels of the Ladder are 2 and 3. Most projects involve operating ground technology or processing satellite data. In the next step of this analysis, countries receive credit for the rankings of their projects. If a country is involved in the project called CENACARTA, for example, it has an instance of a Level 2 project. The Chi-Squared tests do not sum these rankings. Rather a frequency analysis counts the instances of each ranking.

The rankings from all of the Space Project Case Studies are compared to the seven Development Indicators in Chi-Squared tests. The Indicators are Human Development Level, Human Development Index, GDP, GDP per Capita, Education Expenditures, Internet Users and Cellular Subscribers. The Chi-Squared tests are performed in two different ways. One method counts the number of projects for countries in various development and space activity levels. The second method counts the number of countries represented in various space activity and development levels. Counting projects means that a country gets credit for every project it has in a particular level. Counting countries means that the test just checks to see whether a given country appears in a level at all.

In almost every test, the Chi-Squared analysis shows significance when counting the number of projects, but not when counting countries. This implies that there is a significant difference in the number of projects in different rankings associated with countries of different development levels. More briefly, counting projects shows that development level influences the level of the space activity. Why does counting countries not show the same thing? This is probably because most countries are involved in at least one project. When countries are counted the numbers do not appear different enough to trigger statistical significance.

Consider now an example from the Chi-Squared tests for the Project Technology Ladder and Human Development Index. The first table shows the values for counting projects; a later table shows the values for counting countries. Both tables show two technology bins, Low and High. Low is considered a rank from 1 to 5 on the Ladder. High is for ranks from 6 to 9 on the Ladder. There are four bins for HD Index. HDIndex4 is the lowest bin and HDIndex1 is the highest bin.

Table 31: Results from Project Tech Ladder vs HD Index Chi-Squared, Counting Projects

Chi-Squared Test for Project Technology Ladder Rankings vs Human Development Index – **Count Projects**					
Observed	*HDIndex4 (Low)*	*HDIndex3*	*HDIndex2*	*HDIndex1 (High)*	**Total**
Low Tech	84	93	60	52	289
High Tech	9	17	7	24	57
Total	93	110	67	76	346
Expected	*HDIndex4 (Low)*	*HDIndex3*	*HDIndex2*	*HDIndex1 (High)*	
Low Tech	77.68	91.88	55.96	63.48	
High Tech	15.32	18.12	11.04	12.52	
Chi-Squared Result	**5.38×10^{-4}**	Result is valid and significant.			

This table above shows the number of projects counted for countries in each of the HD Index bins. The number of countries in each HD Index bin is between 11 and 13. The lowest category of countries, HDIndex4, has ninety-three projects. Eighty-four of these ninety-three projects rank as Low Tech on the Ladder. Nine rank as High Tech. The highest set of countries (HDIndex1) has seventy-six projects. Note that this number is lower than the number of projects for the low group. There are fifty-two Low Tech projects and twenty-four High Tech projects among these seventy-six. The result of the Chi-Squared test shows that the groups are significantly different. What does the data show about how they are different?

There are two ways to look at the data to see how development influences Project Technology Ranking. One can first ask whether more developed countries do more projects overall than less developed countries. This is possible to determine since the columns represent approximately equal numbers of countries. In looking at the column totals, it is not strictly true that more developed countries do more projects. The lowest development level of countries shows ninety-three projects; the next shows one hundred and ten projects. Then there is a drop to sixty-seven and finally seventy six projects. Development level does not seem to increase the number of projects completed. Next ask whether the ratio of high technology to low technology projects is higher for more developed countries. These ratios are shown in the table below. The countries with the lowest development indices are on the left; the highest are on the right. Now it is clear that, while more developed countries may not do more projects overall, they do more projects in the High Technology category. The most highly developed countries show a higher ratio of high to low technology projects in this case. This is evidence that higher development leads to more activity in high tech projects. The raw numbers show the same idea when only the high technology projects are considered. Look back at the Chi-Squared table above and focus just at the high technology row. Notice that the numbers increase from nine to twenty-four high technology projects. There is a slight dip at HDIndex2, but this is dip is not seen when only three HD Index bins are used.

Table 32: Ratios of High Tech to Low Tech Projects for Project Technology vs HD Index Bins (Count Projects)

Ratio of High Tech to Low Tech Projects (Proj Tech vs HD Index - Counting Projects)			
HDIndex4 (Low)	*HDIndex3*	*HDIndex2*	*HDIndex1 (High)*
0.107	0.183	0.117	0.462

The previous set of tables show the results when projects are counted. Now look at the results when countries are counted. These results are not statistically significant, so one can not infer anything from the number patterns. The Chi-Squared result means that there is almost a 50% likelihood of them occurring by chance.

Table 33: Results from Project Tech Ladder vs HD Index Chi-Squared, Counting Countries

Chi-Squared Test for Project Technology Ladder Rankings vs Human Development Index – **Count Countries**					
Observed	*HDIndex4 (Low)*	*HDIndex3*	*HDIndex2*	*HDIndex1 (High)*	**Total**
Low Tech	40	38	30	29	137
High Tech	9	11	7	13	40
Total	49	49	37	42	177
Expected	*HDIndex4 (Low)*	*HDIndex3*	*HDIndex2*	*HDIndex1 (High)*	
Low Tech	37.93	37.93	28.64	32.51	
High Tech	11.07	11.07	8.36	9.49	
Chi-Squared Result	**0.482**	Test is valid and not significant.			

The Chi-Squared tests are also done with Project Technology Ladder rankings versus Gross Domestic Product (GDP). The table below shows the observed data and results.

Table 34: Results from Project Tech Ladder vs GDP Chi-Squared, Counting Projects

Chi-Squared Test for Project Technology Ladder Rankings vs Gross Domestic Product – **Count Projects**					
Observed	*GDP4 (Low)*	*GDP3*	*GDP2*	*GDP1 (Low)*	**Total**
Low Tech	29	69	112	79	289
High Tech	10	6	9	32	57
Total	39	75	121	111	346
Expected	*GDP4 (Low)*	*GDP3*	*GDP2*	*GDP1 (Low)*	
Low Tech	32.58	62.64	101.07	92.71	
High Tech	6.42	12.36	19.93	18.29	
Chi-Squared Result	**1.06×10^{-05}**	Test is valid and significant.			

The Chi-Squared test result shows that it is highly improbable that these results happened by chance. It is statistically significant. Once can say that more developed countries are doing more projects overall, even though the second highest GDP group is slightly higher than the highest GDP group. The ratio of High Tech to Low Tech projects is shown below. Interestingly, the highest GDP group, #1, does have the highest ratio, but the lowest GDP group is in second place. Overall, the evidence does favor the trend that higher GDP leads to higher technology rankings, but the relationship is not completely consistent.

Table 35: Ratios of High Tech to Low Tech Projects for Project Technology vs. GDP, Count Projects

Ratio of High Tech to Low Tech			
GDP4 (Low)	*GDP3*	*GDP2*	*GDP1 (Low)*
0.34	0.09	0.08	0.41

A total of thirty-seven Chi-Squared tests are performed just for the Project Technology Ladder, and there are five Ladders with parallel tests. For the sake of brevity, the results of the Project Tech Ladder are summarized in the chart below. The Development Indicators are listed on the far left column; the binning methods for these indicators are listed on the second row. The HD Level Chi-Squared tests are not shown because their bins are based on the three Human Development Levels defined by the Human Development Report.

Note that similar results are seen with the other development indicators as were seen with Human Development Index and GDP. Counting projects generally leads to statistically significant differences; counting countries generally does not. Each indicator has at least two significant tests in which projects are counted. All the tests are valid except one. The evidence is clear from this section that development level does influence the level of projects in which countries participate. There is slightly weaker evidence that higher development level leads to higher technology rankings.

Table 36: Summary of Results from Project Technology Ladder Chi-Squared Tests

	Counting Projects			**Counting Countries**		
Project Tech Ladder Chi-Squared Results	*Four Equal Bins of Countries*	*Three Equal Bins of Countries*	*Range of Data/Order of Magnitude*	*Four Equal Bins of Countries*	*Three Equal Bins of Countries*	*Range of Data/Order of Magnitude*
HD Index	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	******
GDP	Valid and Significant	Valid and Significant	INVALID	**Valid, Not Significant**	**Valid, Not Significant**	******
GDP per Capita	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Education Exp.	Valid and Significant	Valid, Not Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Internet Users	**Valid, Not Significant**	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Cellular Subscribers	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**

Country Technology Ladder

The analysis for the remaining Ladders is very similar to the first Ladder. The Country Technology Ladder ranks projects and their associated countries according to what the African entity achieved. This is a specialized form of Mission Architecture rankings, as is the Project Technology Ladder. In this case, the African countries only receive credit for what they are clearly documented to contribute to the project. The benefit of this distinction is that it shows the technical expertise of the African countries and organizations. The table below shows the Country Technology Ladder with the projects at each level.

Table 37: Country Technology Ladder with Frequency Analysis Results

Rank	Color	Level	Projects	# of Projects
10	**Red**	*Design, Build, Operate Satellite*	SunSat, Sumbandilasat, Alsat - 2B	3
9	**Red**	*Design, Build Satellite*	Sunspace; ESL at SU	2
8	**Red**	*Buy and Operate satellite; Train in sat design*	DMC, NigeriaSat-1, ALSAT-1, NX Nigeria, Alsat -2A, EgyptSat-1	6
7	**Orange**	*Buy/Lease and Operate Satellite*	NARSS, Nilesat 102, Nilesat 101, NigComSat, NileSat; NigeriaSat-2, RASCOM, ARMC, Nilesat 103	9
6	**Orange**	*Operate others' satellites*	SAC	1
5	**Yellow**	*Lease sat capacity and distribute service/content*	Sentech, MultiChoice Africa, Intersat, AFSAT, Mindset	5
4	**Green**	*Operate ground segment to send/receive sat data*	UNISA, Botswana V-Sat, WE Consult, Zambia Census, Liberia Census, Namibia Census, South Africa Census, Kenya Census, Gath, Compuplot, Sierra Leone Census, Ethiopia Census, GPS Crane Track, Uganda Telecentre, NePAD eAfrica, Senegal Telemed, AVU, EGNOS, Cyber Shepherds, AIDS Telemed; RCMRD,	22
3	**Blue**	*Process Sat Data and create data products/decision tools*	CENACARTA, CERGIS, Geo-AQUIFER, Centre de Suivi Eco, RECTAS, Miombo, IWAREMA TIGER, Lake Victoria TIGER, FEWSNET, AFRICOVER, AGRHYMET,	11
2	**Blue**	*Use/Help Define sat data product*	GMES, NileRiver, Tiger Morocco, Malaria Risk TIGER, TIGER ARBRE, TIGER StereoSAat, TIGER SHARE, EPIDEMIO DUE, GlobWetland DUE, Lake Quality Egypt TIGER, Coasts Tanzania, Intsormil CRSP, TIGER Ghana, TIGER GIS River Man, TIGER WADE, LEWS,	16
1	**Violet**	*Participate in Regulatory Action regarding Sats*	Tampere Conv, Space and Major Disasters, Inmarsat, Intelsat,	4
			Total Projects	79

Consider three key differences between the Project and Country Technology Ladders. First, the highest category in each Ladder is different. In the Country Project Ladder, the highest category is "Design, Build, Operate a Satellite". In the Project Technology Ladder, the highest category is "Design, Build, Operate and *Launch* a Satellite." The difference is that there are Space Project Case Studies that include all four steps. The African partners are only directly involved in three steps, however. There are no Project Case studies in which Africans launch a satellite. There are three case studies, however, in which Africans design, build and operate a satellite. The second difference between the Ladders is that the number of categories is different. The Country Technology Ladder needs an additional category to show how some African countries participated in the projects that work toward data analysis. Look at levels 2 and 3. All of these twenty-seven projects are in one level in the Project Technology Ladder because the project accomplishes satellite data processing. In 16 projects, however, there is no evidence that the African partner work on satellite data processing. They work as data product users, and they help to define the requirements of the data products being developed. The third difference between the two Ladders is that there is a category in which the African countries buy a satellite but also receive some training in satellite development. For some of the projects that achieve designing, building and operating a satellite, the Africans are directly involved in each stage, but they do not achieve it independently. This Ladder shows an accurate picture of the African accomplishments in the Space Project Case Studies.

The same sets of Chi-Squared tests are done using the Country Technology Ladder as were done using the Project Technology Ladder. The same Development Indicators are used to measure national development level. The chart below summarizes the results of the Chi-Squared tests for this Ladder. There is no major difference from the results in the Project Technology Ladder. Although there are subtle differences in the ways the countries participate in the project, most countries did not move from the High Tech bin to the Low Tech bin. Thus the statistical results are generally the same.

Table 38: Summary of Results from Country Technology Ladder Chi-Squared Tests

	Counting Projects			**Counting Countries**		
Country Tech Ladder Chi-Squared Results	*Four Equal Bins*	*Three Equal Bins*	*Range of Data/Order of Magnitude*	*Four Equal Bins*	*Three Equal Bins*	*Range of Data/Order of Magnitude*
HD Index	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
GDP	Valid and Significant	Valid and Significant	INVALID	**Valid, Not Significant**	**Valid, Not Significant**	INVALID
GDP per Capita	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Education Exp.	Valid and Significant	**Valid, Not Significant**	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Internet Users	**Valid, Not Significant**	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Cellular Subscribers	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**

The statistical results show that there is a relationship between development level and space activity. Is there evidence that higher development leads to higher levels of technology? Consider the observed values in the HD Index Chi-Squared test. This test is significant and valid.

Table 39: Observed Values from Country Tech Ladder vs HD Index Chi-Squared, Counting Projects

Chi-Squared Test for Project Country Ladder Rankings vs Human Development Index – **Count Projects**					
Observed	*HDIndex4 (Low)*	*HDIndex3*	*HDIndex2*	*HDIndex1 (High)*	**Total**
Low Tech	79	89	58	51	277
High Tech	9	17	7	25	58
Total	88	106	65	76	335

The HD Index increases from left to right. HDIndex4 is the lowest; HDIndex1 is the highest. The total number of projects does not increase as Development Level increases. The number of high tech projects does increase, and the number of low tech projects decreases as development increases. This can be said to support the idea that higher development is associated with higher levels of technology. This is supported by the ratio of high to low technology; see below. The ratio is much higher for the countries in the top level of HD Index. All of this provides evidence that the more developed countries have more technically advanced space activities.

Table 40: Ratios of High Tech to Low Tech Projects for Country Technology vs HD Index Chi-Squared (Counting Projects)

Ratio of High Tech to Low Tech Projects			
HDIndex4	HDIndex3	HDIndex2	HDIndex1
0.113924	0.191011	0.12069	0.490196

Leadership Ladder

The Leadership Ladder is the first of the three Ladders derived from the Management Architectures. This Ladder ranks projects according to the level of initiative or leadership shown by African entities. The Leadership Ladder is shown below with the projects.

Table 41: Leadership Ladder with Frequency Analysis Results

Rank	Color	Level	Projects	# of Projects
6	Red	Single African country or organization	Sunsat, Sunspace, ESL, Sumbandilasat, NigeriaSat-1, NigeriaSat-2, NigComSat, CENACARTA, Botswana V-sat, ALSAT-1, CERGIS, UNISA, Mindset, AFSAT, MultiChoice, InterSat, NX Nigeria, ALSAT-2A, ALSAT-2B, EgyptSat-1, NileSat-101, NileSat-102, NileSat-103, NileSat, NARSS, Compuplot, Gath, Kenya Census, ZA Census, Ethiopia Census, Sierra Leone Census, Namibia Census, Liberia Census, Zambia Census, WE Consult, Sentech,	36
5	Orange	Non-regional Group of African countries or organizations	MARA	1
4	Green	Regional group of African countries or organizations	ARMC, Geo-Aquifer, RASCOM, AGRHYMET	4
3	Blue	External Collaboration, Initiative from Africa	GPS Crane Track, NePAD	2
2	Indigo	External Collaboration, Initiative from African and external partners	RCMRD, Cyber Shepherds, Uganda Telecentre,	3
1	Violet	External collaboration, initiative from external partner	GMES, Nile River, TIGER Morocco, GIS River Man, Malaria Risk TIGER, TIGER ARBRE, TIGER StereoSat Africa, TIGER SHARE, TIGER WADE, EPIDEMIO DUE, GlobWetland DUE, TIGER IWAREMA, Lake Quality Egypt TIGER, Lake Victoria TIGER, FEWSNET, AFRICOVER, DMC, Miombo, LEWS, Coasts Tanzania, Intsormil CRSP, RECTAS, Centre de Suivi Eco, Senegal Telemed, EGNOS, River Blindness, Space and Major Disasters, Tampere Converntion, AIDS Telemed, Intelsat, Inmarsat, African Virtual University, SAC	34
			Total	80

The projects are largely seen in the highest and lowest Ladder Levels. Thirty-six projects involve only one African country or organization. Thirty-four projects happen because of the initiative of a non-African partner.

The Chi-Squared tests for the Leadership Ladder are performed with the same methods as the tests described above. The table below shows the results.

Table 42: Summary of Results from Leadership Ladder Chi-Squared Tests

	Counting Projects			Counting Countries		
Leadership Ladder Chi-Squared Results	*Four Equal Bins*	*Three Equal Bins*	*Range of Data or Order of Magnitude*	*Four Equal Bins*	*Three Equal Bins*	*Range of Data or Order of Magnitude*
HD Index	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**	******
GDP	Valid and Significant	**Valid, Not Significant**	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	*****
GDP per Capita	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	*****
Education Exp.	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Internet Users	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Cellular Subscribers	**Valid, Not Significant**	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**

The results of the Chi-Squared tests show that all of the Development Indicators show at least two significant results except the Internet Users Indicator. All of the significant tests comes when counting projects, not countries. Internet Usage is not shown to relate to leadership in satellite activities. Since many other Development Indicators do show a significant relationship, however, the overall result follows the same trend as seen above. The table below shows just the ratios of High Leadership projects to Low Leadership projects as evidence that higher development countries tend to demonstrate more leadership. This table uses the data from the HD Index test with four equal bins. The results from the GDP per capita test with four equal bins show similar trends. Note, however, that not all of the sets of ratios are monotonically increasing. Most, though, do show that the highest development level has the highest ratio.

Table 43: Ratios of High Leadership to Low Leadership Projects for Leadership Ladder vs HD Index Chi-Squared Tests (Counting Projects)

Ratio of High Leadership to Low Leadership			
HDIndex4 (Low)	*HDIndex3*	*HDIndex2*	*HDIndex1 (High)*
0.430769	0.459459	0.358491	0.897436

Table 44: Ratios of High Leadership to Low Leadership Projects for Leadership Ladder vs Per Capita GDP Chi-Squared Tests (Counting Projects)

Ratio of High Leadership to Low Leadership			
PCG4 (Low)	PCG3	PCG2	PCG1 (High)
0.39	0.40	0.58	0.91

Finance Ladder

The Finance Ladder is the second of the Management Architecture Ladders. It ranks projects according to the source of the financial support. A project gains higher ranking if more support comes from an African source. The Ladder is shown below.

Table 45: Finance Ladder with Frequency Analysis Results

Rank	Color	Level	Projects	# of Projects
6	Red	Single African country or organization	SunSat, SunSpace, ESL at SU, Sumbandilasat, NigeriaSat-1, NigeriaSat-2, NigComSat, CENACARTA, Botswana V-Sat, ALSAT-1, UNISA, AFSAT, MultiChoice Africa, InterSat, NX Nigeria, ALSAT-2A, ALSAT-2B, EgyptSat-1, NileSat-101, NileSat-102, NileSat-103, NileSat, NARSS, Compuplot, Gath, ZA Census, Ethiopia Census, Sierra Leone, Namibia Census, Liberia Census, Zambia Census, WE Consult, Sentech, SAC	34
5	Orange	Non-regional Group of African countries or organizations	ARMC	1
4	Green	Regional group of African countries or organizations	Geo-Aquifer, RASCOM, AGRHYMET	3
3	Blue	External Collaboration, Funding from Africa		
2	Indigo	External Collaboration, Funding from African and external partners	RCMRD, DMC, MARA, RECTAS, Centre de Suivi Eco, CERGIS, NePad eAfrica, Mindset, Space and Major Disasters, Uganda Telecentre, Kenya Census, Intelsat, Inmarsat, AVU	14
1	Violet	External collaboration, Funding from external partner	GMES, TIGER Ghana, Nile River, TIGER Morocco, GIS River Man, Malaria Risk TIGER, TIGER ARBRE, TIGER StereoSat, TIGER SHARE, TIGER WADE, EPIDEMIO DUE, Globewetland DUE, TIGER IWAREMA, TIGER Lake Quality Egypt, TIGER Lake Victoria, FEWSNET, AFRICOVER, Miombo, LEWS, Coasts Tanzania, Intsormil CRSP, GPS Crane Track, Senegal Telemed, EGNOS, River Blindness, Tampere Conv, AIDS Telemed, Cyber Shepherds	28
			Total	80

Observe that Finance tends to line up with Leadership. Most projects are still at the extreme ends of the spectrum.

Table 46: Summary of Results from Finance Ladder Chi-Squared Tests

	Counting Projects			**Counting Countries**		
Finance Ladder Chi-Squared Results	*Four Equal Bins*	*Three Equal Bins*	*Range of Data/Order of Magnitude*	*Four Equal Bins*	*Three Equal Bins*	*Range of Data/Order of Magnitude*
HD Index	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**	******
GDP	Valid and Significant	**Valid, Not Significant**	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	*****
GDP per Capita	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Education Exp.	Valid and Significant	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**
Internet Users	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**	******
Cellular Subscribers	**Valid, Not Significant**	Valid and Significant	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	**Valid, Not Significant**

The Chi-Squared tests for Finance are almost identical to those for Leadership. Financial support seems to be coupled with Leadership in this context.

Expertise Ladder

The Expertise Ladder is the third and final Management Architecture Ladder. It ranks countries according to the source of the expertise. See the Ladder below.

Table 47: Expertise Ladder with Frequency Analysis Results

Rank	Color	Level	Projects	# of Projects
6	**Red**	Single African country or organization	SunSat, SunSpace, ESL at SU, Sumbandilasat, CENACARTA, NileSat, NARSS, Compuplot, Gath, ZA Census, Ethiopia Census, Sierra Leone Census, Namibia Census, Liberia Census, Zambia Census, WE Consult, Sentech, SAC, Kenya Census	19
5	**Orange**	Non-regional Group of African countries or organizations		0
4	**Green**	Regional group of African countries or organizations	Geo-Aquifer, AGRHYMET, MARA,	3
3	**Blue**	External Collaboration or contract, Expertise from Africa	RECTAS, Centre de Suivi Eco, CERGIS, GPS Crane Track, Cyber Shepherds	5
2	**Indigo**	External Collaboration or contract, Expertise from African and external partners	ARMC, RCMRD, NigeriaSat-1, TIGER Ghana, GIS River Man, TIGER WADE, TIGER IWAREMA, RCMRD, Lake Victoria TIGER, FEWSNET, AFRICOVER, ALSAT-1, DMC, Miombo, LEWS, Space and Mjor Disasters, Tampere Conv, NX Nigeria, ALSAT-2A, ALSAT-2B, EgyptSat-1, Intelsat, Inmarsat	22
1	**Violet**	External collaboration or contract, Expertise from external partner	NigeriaSat-2, NigComSat, GMES, NileRiver, TIGER Morocco, RASCOM, Malaria Risk TIGER, TIGER ARBRE, TIGER StereoSat Africa, TIGER SHARE, EPIDEMIO DUE, GlobWetland DUE, Lake Quality Egypt TIGER, Coasts Tanzania, Intsormil CRSP, Senegal Telemed, EGNOS, NePAD eAfrica, Mindset, River Blindness, AIDS Telemed, Uganda Telecentre, AFSAT, MuiltiChoice Africa, InterSat, NileSat-101, NileSat-102, NileSat-103, AVU	29
			Total	78

This Ladder has a different distribution of projects than the other two Management Ladders. There are more projects away from the extreme ends. The main change is that many projects are in Level 2, where expertise comes from both African and External Partners. The next table summarizes the results of the statistical tests.

Table 48: Summary of Results from Expertise Chi-Squared Tests

	Counting Projects			**Counting Countries**		
Expertise Ladder Chi-Squared Results	*Four Equal Bins*	*Three Equal Bins*	*Range of Data/Order of Magnitude*	*Four Equal Bins*	*Three Equal Bins*	*Range of Data/Order of Magnitude*
HD Index	Valid and Significant	**Valid, Not Significant**	**Valid, Not Significant**	INVALID	INVALID	**Valid, Not Significant**
GDP	INVALID	**Valid, Not Significant**	INVALID	INVALID	**Valid, Not Significant**	*****
GDP per Capita	Valid and Significant	**Valid, Not Significant**	Valid and Significant	INVALID	**Valid, Not Significant**	*****
Education Exp.	Valid and Significant	Valid and Significant	Valid and Significant	INVALID	**Valid, Not Significant**	**Valid, Not Significant**
Internet Users	Valid and Significant	Valid and Significant	**Valid, Not Significant**	INVALID	**Valid, Not Significant**	******
Cellular Subscribers	Valid and Significant	Valid and Significant	Valid and Significant	INVALID	**Valid, Not Significant**	******

This summary of Chi-Squared tests shows the most mixed results. HD Index and GDP are not shown to have meaningful relationships with expertise. The Development Indicators GDP per capita, Education Expenditure, Internet Users and Cellular Subscribers do seem to have a relationship with expertise as demonstrated in these projects. It is fitting that the only Development Indicator that is consistently significant is Education Expenditure. Consider these results in more detail in the two tables below.

Table 49: Observed Values from Expertise Ladder vs Education Expenditure Chi-Squared, Counting Projects

Chi-Squared Test for Project Country Expertise Rankings vs Education Expenditures – **Count Projects**					
Observed	*EDU4 (Low)*	*EDU3*	*EDU2*	*EDU1 (High)*	**Total**
Exp Low	74	106	73	52	305
Exp High	2	8	11	12	33
Total	76	114	84	64	338

This first table shows that the highest education level has a lower number of projects than the lowest level. The number of low expertise projects decreases from left to right, though this is not monotonic. The number of high expertise projects monotonically increases. This is strong support that higher education yields the ability to be involved with projects at a higher level of expertise.

Table 50: Ratio of High Expertise to Low Expertise Projects for Expertise Ladder vs Education, Count Projects

Ratio of High African Expertise to Low African Expertise Projects			
EDU4 (Low)	*EDU3*	*EDU2*	*EDU1 (High)*
0.03	0.08	0.15	0.23

The ratios of high expertise to low expertise projects clearly increase as Education Expenditure increases.

4.4 Embassy Interviews

Representatives from 30 African countries are interviewed as part of this study. Recall that the purpose of the Embassy Interviews is to provide background information about the National Innovation Systems of African countries. There are two sections in the analysis of the information from the Embassy Interviews. The first section, a Frequency Analysis, shows the most commonly stated answers and discusses their import. This shows common trends in African countries from different parts of the continent. The second section, a Statistical Analysis, uses Chi-Squared tests to find whether there is any significant difference between countries that make different statements in the interviews. Here, instead of looking for common trends, the analysis shows distinctions between countries.

4.4.1 Frequency Analysis

There are ten questions in the Embassy Interviews. This section shows the responses to each question in turn. In some cases, information from one question can also be applied to other questions. The responses are kept separately here, however. The presentation is true to the way the speaker gave the information. In each question, the most commonly cited answers are shown. A cut off is subjectively chosen for each question. In some questions, there is very little agreement; if 3 countries make a comment, this is a high score. In most questions, a response is mentioned if more than 5 people say it.

Note that the comments below must be read with some caution. Most questions in the interview are open ended. If a particular interviewee does not make a comment, this does not imply that the comment does not apply to their country. A few questions are directly asked to each country. These are used in the statistical analysis in the next section. In most cases, seeing a given set of countries make a comment only shows that there are *at least* that many countries for which it is true. There may be more that did not say it. Given the open-ended nature of the interview, any convergence in the responses is very significant.

<u>Questions 1 and 2</u>

The table below shows the first two interview questions. These two questions are analyzed together because the information in their responses is so overlapping. Question 1 is, "Are there one or more central government bodies that are responsible for national science and technology policy?" Question 2 is, "What is the relationship between the government and other entities such as universities, industry or national laboratories?" Question 1 has a number of sub-questions that guide the speaker in their description of the government bodies. The table below shows the most commonly stated remarks; any answer mentioned at least 10 times is shown here.

Table 51: Results of Embassy Frequency Analysis, Questions 1 and 2

Question 1: Are there one or more central government bodies that are responsible for national science and technology policy? Question 2: What is the relationship between the government and other entities such as Universities, Industry or National Laboratories?	
Responses to Questions 1 and 2	**Frequency**
There is a government ministry that promotes science and technology	30
At least some universities are government funded	28
The minister in charge of science/technology is part of the cabinet	27
The minister for science/technology reports to Prime Minister or President	26
There is at least one national university	26
Science/Technology ministries collaborate with entities outside of country	24
Financial Resources for science/technology ministry are inadequate	23
There is a regulatory body for industry	22
There are national laboratories or research institutions	21
The Ministry for Communication deals with science/technology issues	18
Education/Science/Technology has recently been a high priority of the country	18
Ministry in charge of science/technology is very large (hundreds of employees or more)	18
There are some private tertiary schools	15
The ministry in charge of science/technology collaborates with multilaterals	14
The ministry in charge of science/technology was recently created or re-organized	11
University research is funded by the government	11
Most industry is private or government is encouraging privatization	11
The body for science/technology financially supports research	10

These responses are full of interesting information. First consider the information about the government body in charge of science and technology. Note that every single country that is interviewed states that there is a government ministry whose job it is to promote science and technology. Furthermore, 27 of the 30 countries note that the minister in charge of this ministry is part of the cabinet. In 26 cases this minister reports directly to the Prime Minister or President. The purpose for asking these questions is to look for evidence that priority is being placed on science and technology in the government. The fact that all 30 countries claim to have a ministry concerned with science and technology that operates at the highest level of government shows at least some effort toward putting emphasis on the topic. Eighteen of the countries stated directly that education, science and technology are currently a high priority in their country. This is very optimistic given the many international calls for more emphasis in these areas. A less optimistic observation is that 23 of the countries say that the financial resources allocated to the ministry for science and technology is inadequate.

Some other common remarks about the science/technology ministries are that they collaborate with foreign entities (24 countries); they are relatively large (18 countries); they work with multilateral organizations such as the United Nations (14); and they give financial support to research (10). What can be concluded from the large size of many of the ministries for science and technology? This is not clear. The interviewees do not seem to equate size with effectiveness. Consider the result that 18 of the countries say that the Ministry for Communications deals with science and technology issues. This potentially shows the importance of information and communication technology in Africa.

Some of the answers in this section speak directly about the university system. Twenty-six of the countries state that they have at least one national university. Twenty-eight say that at least some of the universities are government funded. Fifteen mention that there are some private tertiary schools in their country. Eleven countries note that research within the universities is funded by the government. From these observations several conclusions can be drawn. First, government funding is very important to the universities in these countries, both for existence and for research. Private universities may not be as common as government schools; although this is subject to further investigation.

What do the responses tell about other parts of the National Innovation System, such as research laboratories and industry? The interview prompts directly ask about the existence of national laboratories. Twenty-one countries say that there are national laboratories or research institutions in their country. Note that six countries answer that most research laboratories are in the universities; they are not independent entities. Four countries say that there are no or few national labs. It seems from this sample that most African countries do have some government-based research organizations. In a few cases, they are missing or limited.

The state of industry in the countries is also addressed in an interesting manner with Question 2. Twenty-two countries respond that the government relates to industry through a regulatory body, such as a Ministry of Industry. Note that eleven countries say that most industry is private or the government is encouraging privatization. Four countries mentioned that industry is gradually moving toward privatization. Six countries say that most industry is under the government. In these last three sets of comments there is a common idea. This data reflects the trend in African countries to move from a more centralized, government run economy toward a more privatized model; and the move is certainly not complete.

How do these observations relate to the use of satellite technology in Africa? First, consider the data regarding the ministries for science and technology in Africa. It is good that there are institutional structures in all the sample countries that are relevant to science and technology. The Remote Sensing Space Project Case Studies show that many of the users of satellite data are government agencies that fall under the leadership of such ministries. It is also good that collaboration with external governments and multilaterals is common. The Remote Sensing Roles and Actors analysis shows that African regional collaborations and multilateral agencies often serve as coordinating organizations in satellite projects. Most countries say it is common for them to collaborate externally. This could lead to more opportunities to benefit from satellite technology. The importance of the communication technologies clearly relates to satellites, which are an example of communication technology. If African countries are placing great emphasis on communication technology, they are well positioned to increase their benefit from satellites.

Second, the data about universities and national laboratories relates to satellite technology. These research institutions play the role of Data User and Data Processor in the

Remote Sensing Roles and Actors analysis. These actors have a key role in achieving benefit from satellite technology.

Third, consider the transitional state of industry in some African countries. Many African countries are working towards a more privatized economy. There is evidence for this in both the Embassy Interview data and the Literature Review. This trend toward privatization has potential impact on the use of satellite technology. In the field of Remote Sensing, most Actors from the Space Project Case Studies tend to be government related. In the areas of Communication and Navigation, there is a mix of commercial and government Actors. In all three areas, most Africans are involved by operating ground equipment or processing and using data. There is not presently an industry in Africa for building satellite hardware. Only one commercial entity does this; it is in South Africa. How will a trend toward privatization affect the opportunities for an African satellite industry? In Remote Sensing, it may not be very pivotal whether the economy transitions to being more privatized since many of the uses of satellite technology (as referenced in the Purpose Analysis) relate to public works that are appropriate roles for government. In the area of Communication, an increase in privatization is very important. The Literature Review in this thesis points out that a potential barrier to satellite communication projects is a closed or highly regulated market. Navigation can be affected in various ways by privatization. On one hand, government is very involved with the issues of using satellite navigation for air traffic management. One the other hand, the commercial airlines are certainly affected by technical advances. The Case Studies show several examples of purely private companies using satellite navigation.

Question 3

Questions 1 and 2 have the most in-depth set of questions and issues to consider. The remaining questions have much less scope. As seen in the table below, Question 3 asks, "Is there a central government body that is responsible for national space related issues?" At the heart of this question is a desire to know whether there is an official government space agency in the country. The question is purposely worded very generally to include possible variations from the space agencies of the western world. The question acknowledges that there may not be a dedicated office with concern only for space. There may, however, be an office whose role includes handling national space related issues. The table below shows the responses.

Table 52: Results of Embassy Frequency Analysis, Question 3

Question 3: Is there a central government body that is responsible for national space related issues?	
Response to Question 3	**Frequency**
The ministry for communication licenses satellite providers	20
No or Not sure	11
The Ministry for Infrastructure or Transport	7
The National Aviation Authority	5
The Ministry for Science and Technology	4

Twenty countries say that the Ministry of Communication is one office concerned with space issues because it grants licenses to satellite communication providers. This reflects the idea from Questions 1 and 2 that the Communication Ministry has an important role to play in overall technology policy. Eleven countries answer with "no" or "not sure". In some cases, this clearly reflects a discomfort with the question and a desire to not answer incorrectly. Recall that the interviewees are diplomats and thus are very careful in their wording. Other ministries are mentioned that deal with space issues, including Transport, Infrastructure, Aviation and Science/Technology. It may be that some mention the Aviation Authority because they associate space with air travel. Another reason may be because the Aviation Authority is concerned with satellite navigation for air travel. This is not specified. Overall, these responses show that, even if there is not a clear space agency in a country, issues related to space are handled somewhere in the government.

Question 4

The table below shows Interview Question 4, which asks, "Does your country have a national space program?" This is meant to be a straightforward question with a binary response. It actually generates a variety of responses, as seen in the table below.

Table 53: Results of Embassy Frequency Analysis, Question 4

Question 4: Does your country have a national space program?	
Responses to Question 4	**Frequency**
No/Not aware of one	20
Yes, within Min of Communication	3
Not sure	3
Yes	2
Space Technology is not a priority	2
We are in the process of creating one	1

The majority of the countries (20) say they do not have a space program or agency. A few say this by carefully stating that they are not aware of such a program. Yet another three countries avoid answering by saying they are not sure. Interestingly, three countries repeat the emphasis from Interview Questions 1 through 3 on the role of the Ministry of Communication. This ministry is said to house within it the space program or policy. This is quite a claim. The personal interpretation of the researcher is that this simply means the same thing that is stated in Question 3. The Minister of Communication deals with regulations relating to the use of satellites for communication. Two countries, Nigeria and Algeria, say that they do have a space agency. South Africa is the country that says they are in the process of creating one. Egypt, which does have a clear commitment to a long term space policy, is not interviewed. These interview results fit the conclusions drawn in the African Space Program Case Studies. Note that two countries explain why they do not have a space agency by saying that "Space is not a priority." Several other comments are made by individual countries along the same lines. One country says they can not afford to fund a space program. Another says their country only has space policy with regard to national security and foreign policy issues. These comments are understandable given the notion of a space program presented by agencies such as NASA or ESA. Part of the goal of this research is to expand the image of what an African space program means and how it can serve needs.

<u>Question 5</u>

Interview Question 5 asks, "If your government wanted to have a satellite launched into space, how might they obtain this service?" For some countries, this is a purely hypothetical question. A few countries answer it based on past experience. This few includes Nigeria, Algeria, and South Africa. For several other countries, there is an established answer for their government. For example, Kenya suspects that its first option is to use the launch site that Italy maintains in its territory. For the rest of the countries, what is presented is really the opinion of the interviewee. It should be taken as such.

Table 54: Results of Embassy Frequency Analysis, Question 5

Question 5: If your government wanted to have a satellite launched into space, how might they obtain this service?	
Responses	**Frequency**
Work with Russia	6
Work with China	4
No response/Unsure	4
Work with US	4
Regional collaboration with other African countries	3
Government wants to launch satellite	3
Hire services from else where	4
Question is too hypothetical to answer	3

The box above shows the question, and below it is a table with the responses. As can be expected, most countries answer by saying they would work with another country that has launch capability. These countries include Russia (6), China (4), and the United States (4). Note that a given interviewee may mention more than one such partner. Another kind of collaboration mentioned is with African partners. This calls to mind the efforts of the Regional African Satellite Communications Organization (RASCOM). In this case, about forty African countries are working together; they have seen the launch of their first satellite in December 2007. The launch for RASCOM's satellite is done by Arianespace. This is outlined in one of the Space Project Case Studies. Four countries give the more general answer that they would hire the launch services from somewhere. Seven of the thirty countries refuse to answer, either because they do not know or because they think the question is too hypothetical to answer. Even though some of the answers show the best guess of the interviewee, overall, they agree with other parts of the data. In the Space Project Case Studies, launch services for African satellites are provided by Chinese, US and European launchers. This can be seen in the Roles and Actors analysis.

<u>Question 6</u>

Question 6 asks, "What are some ways your government uses satellite based technology to meet national needs?" The question assumes that many of the satellite applications are government activities. The answer takes a slightly broader scope. See the table below.

Table 55: Results of Embassy Frequency Analysis, Question 6

Question 6: What are some ways your government uses satellite based technology to meet national needs?	
Response	**Frequency**
Communication	23
Weather/Meteorological	22
Environment/Natural Resources	15
Satellite Television	12
Phone	10
Internet (including commercial service)	8
Air Traffic Control	7
Navigation	6
Agriculture/Drought/Food Security	7
Radio	4

The most frequent answer is that satellites are used for communication. Twenty-three out of thirty interviewees mention this. Recall that in the Space Project Case Studies, the number of Remote Sensing Case Studies outweighs the number of Communication Case Studies with a ration of 53 to 27. The reader is cautioned above to not assume that communication is less important than remote sensing because of these numbers. Results like this are part of the reason to not underestimate the importance of communication. Weather is also a frequently mentioned satellite application. It may be that communication and weather are the most common-place satellite applications, both in Africa and around the world. People who are not experts on satellite technology are still aware of how their in these areas.

All of the areas mentioned by interviewees in this question also appear in the analysis on Purpose for the Space Project Case Studies. This agreement is very positive; it shows some level of awareness about satellites among these government officials. It also gives credence to both sets of data.

Question 7

Question 7 is very subjective, but it also is framed in a way that is easily summarized. The question asks, "On a scale of 1 to 5, how important would you say that satellite-based technology is to your country?" The interviewees are told that 1 means "Not Important at All," and 5 means "Extremely Important". The responses are shown in the table below.

Table 56: Results of Embassy Frequency Analysis, Question 7

Question 7: On a scale of 1 to 5, how important would you say that satellite-based technology is to your country?	
Response	**Frequency**
Only answered “5”	17
Answered “5” and a lower number (1-3)	3
“4” only	3
“3” only	2
“2” only	2
“1” only	0
We believe technology is a major tool for change and development	8
There is a lot of potential to benefit from satellite tech	8
Satellite technology is a high priority; we are investing heavily in it	7
Sat technology is not being used much	6
Current impact of satellite technology on our country is small	5

In several cases, the interviewee wants to make two different points. They consider that importance can be measured in more than one way. It can state how much impact the technology is having or how much impact is has the potential to have. In order to accommodate both interpretations, some countries give two answers. As seen in the table, three countries state that the theoretical importance of the technology is at 5, but they give a lower score between 1 and 3 to represent the actual impact of the technology. Otherwise, seventeen of the countries give a straightforward answer of 5. To them satellite technology is extremely important. No one says the importance is just at 1.

In addition to the numerical scores, some countries add qualitative comments. On the positive side are comments about how technology is a major tool for development (8); and there is great potential to benefit from satellite technology (8); and the country is investing in satellite technology as a priority (7). Two other sets of countries say that the technology is actually not being used much (6) and the impact of the technology is small (5). Note that these positive and negative comments sometimes come from the same countries. This set of opinions demonstrates well the motivation for this thesis; there is great potential for satellite technology to meet national needs in Africa. Unfortunately, the impact is not being fully realized.

Question 8

Question 8 asks, “How do government bodies concerned with the environment use satellite technology?” This question is designed to be a follow on to Interview Question 6. It asks a slightly more specific question in the same vein. The answers are shown below.

Table 57: Results of Embassy Frequency Analysis, Question 8

Question 8: How do government bodies concerned with environment use satellite technology?	
Response	**Frequency**
These agencies do use satellite technology	19
These agencies do not seem to use satellite technology	4
These agencies may use satellite technology, I am not sure	3
Satellites are used for Air Traffic Control or Air Navigation	3
They use satellites for remotes sensing	2
Satellites used in mining sector	2

Although this question is specific, the answers are not. Most responses simply indicate the person's understanding of whether or not the agencies do use satellite technology. Nineteen countries mention that the agencies do use satellite technology. Four clearly say that they do not think the agencies use it, and three are not sure. This leaves four countries unaccounted for. The examples most frequently stated for how the agencies use satellite technology include air traffic management, remote sensing and in the mining sector. This question is somewhat disappointing in its lack of examples. The Space Project Case Studies show that African agencies concerned with environmental issues frequently use satellite data.

Question 9

Question 9 asks, "What is the relationship between the government, industry and academia with respect to science and technology issues?" This question is a follow on to Questions 1 and 2. The question is also somewhat vague and produced vague responses. The goal of the question is to learn about how money, technology and information flow among these sectors. Some of the most informative comments are shown below.

Table 58: Results of Embassy Frequency Analysis, Question 9

Question 9: What is the relationship between the government, industry and academia with respect to science and technology issues?	
Response	**Frequency**
Government provides most or some research funding	14
Government and universities collaborate on research	11
University and Industry need better ties	7
Government and Industry need better ties	6
Government and academia are close	6
Universities get some funding from foreign organizations	5

Fourteen countries say that the government provides most or at least some of the research funding to universities and other agencies that do research. Eleven show that universities and government collaborate on research; this includes cases in which the government sponsors specific projects. Seven countries say that University and Industry need better ties. Six countries mention that Government and Industry need better ties. The responses seem to show that the triangle made of the government, university and academia has two weak sides and one strong side. The Government-to-Academia link is strong. The Government-to-Industry link is weak; and the Academia-to-Industry link is weak. The Government, Academia and Industry are key players in a National Innovation System. These ideas are expressed in the diagram below.

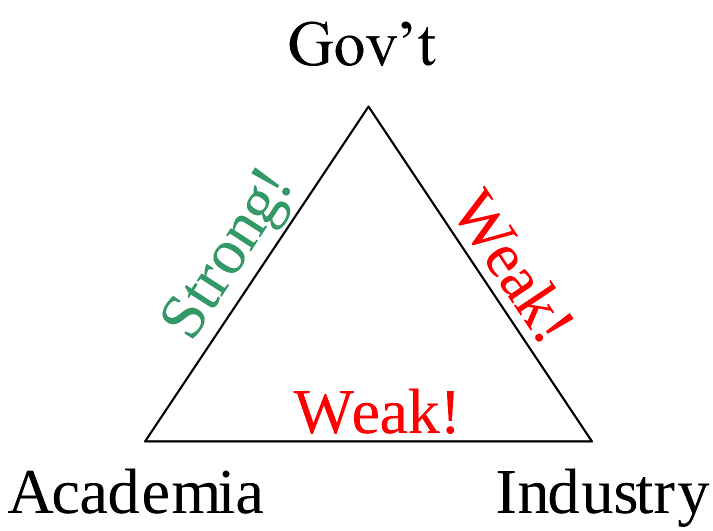

Figure 14: Diagram Depicting Weak and Strong Relationships in African NIS

A weak link between Industry and Academia or between Government and Industry does not bode well for the future of satellite technology in Africa. Recall that Sun Space, the only example of a commercial company in Africa that builds satellites, opened as a result of a strong link between Industry and Academia. If Africa wants to advance in its technical abilities, this triangle must be strengthened on all sides. The weak link between government and industry is interesting given the information in Question 2 about how many African governments are transitioning from a centralized economy toward more privatization. Does the transitional status cause the weak link? This thesis does not have enough data for a complete answer. Of course, the number of countries that make these comments is small; thus the comment can not be taken as universal truth.

Question 10

The final Interview Question asks, "What educational resources are there in the country to train potential entrants into technical careers?" The goal of this question is to learn specifically about the educational system in each country and about the opportunities for technical training. See the table below.

Table 59: Results of Embassy Frequency Analysis, Question 10

Question 10: What educational resources are there in the country to train potential entrants into technical careers?	
Response	**Frequency**
There are scholarships from government or government supported education	23
Engineering and Science are available in a national university	22
Government funds at least some universities	14
There are local technical training schools	11
There are national or regional technical training schools	11
Internships are common or required for graduation	9

Twenty-three of the thirty countries say that the government gives scholarships for education or that education is government supported. Almost as many countries say that engineering and science curriculums are available at a national university. In parallel to Question 2, fourteen countries mention that government funds at least some universities. This supports the conclusions from Questions 1 and 2 about the importance of government funding in African education. There is also more information about the role of private schools. Only two countries say there are more private than public schools. Only one country says that engineering and science education are only available in private schools. This appears to suggest that African countries do not depend on private universities for their science and engineering education. Other literature should be consulted for verification of this.

There is also mention of local and regional technical training schools. These refer to schools that offer degrees that are lower than university degrees. These technical schools train students to work as technicians, mechanics and other trades in technical fields. The question of internships shows interesting results. Internship here refers to jobs taken by students while they are in university to learn about their field. The prompt for the question includes internships; so, many countries address them in their answer. Nine countries think of them as common. Four countries think they are not common. One country says internships are a new trend. Overall, internships do not seem to be a common practice, based on this sample.

Conclusion: Frequency Analysis for Embassy Interviews

There is clearly a great deal of data contained in these interviews. It is not within the scope of this thesis to completely analyze and compare all the comments. The main benefit of this frequency analysis is to give a sense of context for the scientific and technical institutions in Africa. These institutions – the government ministries and agencies, the universities, the laboratories, the private companies – are the partners that can make use of satellite technology.

4.4.2 Statistical Analysis

The Embassy Interview data is also analyzed in a very preliminary way with statistical tests. The goal is to see whether some of the interview responses divide the countries in a statistically meaningful way when compared to those countries' performance in some of the other data sets in this thesis. Specifically, the Embassy data is compared to the Human Development data, the Space Participation data and the Project Technology Ladder data. The embassy data is chosen because it clearly divides the countries into two groups.

Agencies Using Satellite Technology

This data is drawn from Question 8, "How do government bodies concerned with environment use satellite technology?" Nineteen of the countries say that the relevant agencies in their country do use satellite technology. Call this group of countries #1. The remaining eleven do not say this, and are assumed to imply a negative answer. Call this group of countries #2. Note that each country is directly asked about this issue. Three sets of Chi-Squared tests are done based on these two groups of countries. All three show at least one valid test.

The first test asks whether there is a significant difference between the Human Development Indices of Group 1 and Group 2 countries. Two methods are used to bin the HDIndex data – based on the range of data for the 30 countries and based on dividing the countries into two equal groups. Only the latter method leads to a valid result. It is not significant. This means that the null hypothesis – that there is no difference in HDIndex between Group 1 and Group 2 countries – can not be rejected. This test shows no evidence that the HD Index between Group 1 and Group 2 countries are systematically different.

The second test asks whether there is a significant difference in Space Participation for Group 1 and Group 2 countries. For simplicity, the Aggregate SPM data is used; it describes SPM in one number. The valid test in this case bins the SPM data based on two equally sized groups of countries. This test is also not significant. The null hypothesis – that there is no difference in SPM for Group 1 and Group 2 countries – can not be rejected. This test shows no difference in SPM data for Group 1 and Group 2 countries.

The third Chi-Squared test compares the Group 1 and Groups 2 countries according to their Project Technology Ladder rankings from the Space Project Case Studies. One test counts projects that the countries participate in; the other test counts countries in the various bins. This is similar to earlier methods for the Ladder Chi-Squared Tests. Both tests are valid and not significant. No mathematically important difference is found in the rankings of Group 1 and Group 2 countries.

In all three examples, Group 1 and Group 2 prove to not be a meaningful division. This could be because some of the interviewees are mistaken in their answers.

Large Ministry for Science and Technology

This data comes from Question 1. Eighteen countries say that their government ministry in charge of science and technology is large and has hundreds of employees or more. The remaining twelve countries do not call the ministry large. Every country is asked about the size of this ministry. A parallel set of Chi-Squared tests are done with the same binning methods for the HD Index, SPM and Ladder data. Again, there is at least one valid test for each combination of variables. None of them are significant. This means that the current data set does not show a meaningful division of countries based on the size of their ministry of science.

Financial Resources are Inadequate

This comes from the supporting question within Question 1 that asks each country if the financial resources are adequate for the ministry concerned with science and technology. Twenty-three countries say that the resources are inadequate. This is probably an indicator of low development. In the same three sets of Chi-Squared tests, only the tests comparing Embassy Data versus the Technology Ladder data produce valid results. Again, none are significant. This is not surprising since Group 1 and Group 2 are so different in size. Thus the response to this question is not a statistically significant way to divide the countries in this data set.

Body for Communication deals with Science/Technology Issues

This is the one set of tests that produces a valid and significant result, but only one of the six tests with this data is significant. This information comes from Question 1. All the countries are asked if there is a national government body that deals with science and technology issues. Eighteen say that it is the ministry for communication (or information technology or broadcast). The remaining twelve countries answer in another way that indicates it is not the communication ministry.

The same set of six Chi-Squared tests is performed. For the Project Technology Ladder data, both results are valid and not significant. For the Human Development data, one result is invalid; one is valid and not significant. For the SPM data, one result is valid and significant; one is invalid. The valid result bins the SPM data into two equally sized groups of countries that are sorted by SPM. The observed data is shown below.

Table 60: Results of Embassy Chi-Squared Analysis,

Embassy Data versus Space Participation Metric			
Observed	*Emb1 (Comm)*	*Emb2 (Other)*	**Total**
High SPM	6	9	15
Low SPM	12	3	15
Total	18	12	30

In the table above, the breakdown of countries in each category is shown. The category "Emb1" refers to the countries that do say that their communication ministry is the main government body to handle science and technology issues. The label "Emb2" refers to countries that do not say this. The data shows that a greater percentage of the High SPM countries are in the Emb2 category; meanwhile, a greater fraction of the Low SPM countries are in Emb1. This implies that countries that score higher for space participation are not likely to have the Communication Ministry function as the most important government body for science and technology issues. This may be explained by looking at some of the countries in the High SPM category. This high SPM group includes countries like South Africa, Nigeria, Algeria and Kenya who all have strong, specialized government agencies for space and other scientific topics. All of these countries are in the Emb2 category.

4.5 Summary of Results

This section provides a brief summary of the results discussed this chapter. In the analyses for Question 1, Chi-Squared tests are performed to compare Space Participation to seven Development Indicators. The results of the Chi-Squared tests clearly show there is a meaningful difference in the space activity of countries in different development levels. There is also strong evidence that the more developed countries do more space activity and do more space activity at higher technical levels. These points can be seen in the number trends, but are not proven with statistics.

The analysis for Question 2 takes the ninety Space Project Case Studies and categorizes them in several ways. The Master Space Project Matrix organizes the case studies based on their Mission and Management Architectures. This matrix shows that most Space Project Case Studies involve individual African countries and organizations or involve external collaborations. There is not as much collaboration between African countries. The Roles and Actors study shows what kinds of positions African entities hold in the Space Project Case Studies. For Remote Sensing projects, African entities are usually Data Processors, Coordinating Organizations or Data Users. They are very rarely satellite builders. There are a few organizations with satellite operation ability, but this is very limited. In Communication projects, Africans are Service Providers, Content Creators, Internet Service Providers, and System Users. The National Telecommunication companies also play an important role. In Navigation, Africans use the ground based equipment in a variety of ways and at different levels of sophistication. Some analysis is done to see if there are discernible Time Trends in the Space Project Case Study data. The question is whether the Mission and Management Architectures have changed over time. Most of the Chi-Squared tests are invalid. The main exception is a series of tests that use two bins for time and two bins for Mission Architecture. These 2-by-2 tests show that the years from 1996 to 2000 each create a meaningful cutoff in this data set. The tests also suggest that the number of projects has increased over time, but the level of technology has not. This result is not conclusive.

The analysis for Question 3 creates five Ladders on which to rank the Space Project Case Studies. The Ladders compare the projects on the basis of Project Technology, Country Technology, Leadership, Finance, and Expertise that can be credited to the African countries. Chi-Squared analysis is done to compare the space activity to the seven Development Indicators. In almost all the Ladder Chi-Squared tests, there is a valid difference for most Development Indicators when counting projects, but not when counting countries. The least consistent Development Indicator is the number of Internet Users. The tests results with Internet Users are sometimes significant, but not always. There is evidence that higher development leads to more activity at higher levels on the Ladders. It is not always a monotonic relationship, however. It is not clear that higher development leads to doing more projects, but higher development seems to lead to a higher percentage of advanced projects.

In the Embassy Study, thirty representatives from African Embassies are interviewed. The results include the following ideas. There is a science policy infrastructure in most African country governments. Most representatives say the ministry that makes science policy is not adequately funded. The university systems in Africa are closely tied to government for funding. Government agencies and universities work frequently with external and multilateral organizations. The lists offered by the embassy personnel of the ways that satellite technology is used agree in content with the Purpose trends from the Space Project Case Studies. Most African countries do not have a space agency, but many do have an office to handle various space related issues. Most interviewees say that satellite technology is extremely important to their country, although some note that it is not being used to full its potential. There is evidence in the interviews of transition in many African economies from centralized to more privatized markets. These may be affecting relationships between government and industry as well as between academia and industry. There is government-funded technical education at various levels in most countries.

Several Chi-Squared tests are done with the Embassy data to see if it produces meaningful results. Most tests are valid, but not significant. The Embassy responses do not provide meaningful distinction among countries. One exception may be the comment that the Ministry of Communication is the most important government body for science and technology issues. This does lead to one significant statistical test, but the tests are not consistently significant.

[clxx] "2010 World Programme on Population and Housing Censuses: Sub-regional Workshop on Census Cartography and Management." http://unstats.un.org/unsd/demographic/meetings/wshops/Zambia_8Oct07/list_of_docs.htm Accessed June 27, 2008.

[clxxi] Report of the Third United Nations Conference on the Exploration and Peaceful Uses of Outer Space. http://www.unoosa.org/oosa/en/unisp-3/index.html Accessed on June 26, 2008.

[clxxii] Home Page for World Summit on Sustainable Development. http://www.un.org/jsummit/ Accessed June 26, 2008.

5 Conclusions

This chapter shows how the results defined in Chapter 4 answer the three Research Questions of the thesis. Each Research Question is discussed in turn.

5.1 Q1: National Space Activity versus National Development Level

Research Question 1 asks, “How does national development level relate to national space activity?” The specific analyses that address this question are Chi-Squared tests that compare Space Participation and Development Indicators for all sovereign countries. In short, the Chi-Squared tests show definitively that there is a meaningful difference in space activity for countries at different development levels. The data also includes strong evidence that more highly developed countries are more active with space technology and have more advanced space projects. The tests that use the Aggregate version of the Space Participation Metric imply that more developed countries have higher Aggregate scores. This suggests that they do more space-related activities. Recall that the Aggregate score is simply the total number of activities for each country. The tests that use the Categorized version of SPM imply that more developed countries show greater participation in technically advanced space-related activities.

Note that “development level” is measured with multiple Development Indicators. Each indicator shows the same overall results, though with different levels of significance. This implies that the conclusions are true for development level as defined by this set of indicators. It does not prove that every Development Indicator will show the same results.

The Development Indicators used in this analysis are Human Development Level, Gross Domestic Product, GDP per Capita, Education Expenditure, Internet Users and Cellular Subscribers. The consistency of the results among the Development Indicators is noteworthy. All of the Development Indicators produce at least one Chi-Squared test that is significant for both Aggregate and Categorized SPM. The only clear exception that is valid and not significant comes from the tests on Cellular Subscribers, which is a limited data set. The statistics thus show that development level is related to space activity. The numerical patterns in the observed data, further suggest that space activity increases in quantity and quality with development level.

The results from the Categorized SPM analysis show that the four Categories chosen to divide the twenty-one Space Activities are valid Categories. The Categories are designed to distinguish the Space Activities into four technical levels of space participation. They range from membership in a space society to operating space hardware. This classification of activities is shown to create meaningful differences between countries.

All of these conclusions confirm the theory discussed in the Literature Review. They specifically confirm the theory on the importance of technology to national development. This theory argues that pursuit of technological capability building is a key step to national development. Countries that are active in Categories 3 and 4 are demonstrating technological capability. This analysis also confirms the motivation for the thesis. It shows that developing countries are not accessing the benefits of satellite-based technology as much as more developed countries. Note that the number patterns in the data support a two-way relationship between space activity and development. More developed countries are more active in high level space technology. At the same time, more advanced countries in space are more developed.

There are, of course, exceptions to the theories. The trends in the observed data are not completely monotonic. For example, the Categorized SPM versus GDP test shows that more of the lowest GDP countries are in the low Category 1 activities than the high Category 4 activities.

This follows the theory. Meanwhile, there are also more of these low GDP countries in Category 3 than 2 activities. This does not follow theory. Note also, that countries like Nigeria and India have low Human Development Index scores but high Aggregate Space Participation scores. These countries are exceptions to the theory. These examples show that the pursuit of satellite technology does not by itself guarantee national development. Nor does high development always imply that a country is using satellite technology. Countries like Iceland and Luxembourg are in the highest Human Development Level and the middle Aggregate SPM level. Despite these exceptions, the trends are statistically sound. This research does show that national development level is related to national space activity.

5.2 Q2: Mission and Management Architectures

Research Question 2 says, "What Mission and Management Architectures are developing countries using to apply satellite-based technology to national needs?" The answer to this question is complex. It is drawn from the Master Space Project Matrix as well as the Ladders from Question 3.

Consider first the Management Architectures. These Architectures show who is directly involved with executing a project. The Master Space Project Matrix shows trends based on ninety case studies. The three most common scenarios are listed below.

- One African Country or Organization (37 projects)
- External Collaboration; Satellite Expertise from External Partner (23)
- External Collaboration; Satellite Expertise from Both Sides (13)

This list of Management Architectures shows that two extremes are common. African countries do many projects independently; they also do many projects based on partnerships with external experts. There are fewer examples of projects involving partnership between African countries or organizations. Only six of the Space Project Case Studies show inter-African collaboration.

These trends lead to several conclusions. First, many African countries, companies and scientific organizations are pursuing satellite-enabled projects without external partners. In some of the 37 examples the African entity contracts some of the work of the project, but the leadership and financing is African. This large number of projects is encouraging when one considers the commonly cited barriers of using satellite-technology in developing countries. Some of the common barriers are lack of finances and lack of awareness. In these thirty-seven cases, the African entities are aware of the technology and have the financial resources to pursue the project. This is confirmed by the Leadership and Finance Ladders from the Question 3 analysis. In each Ladder, over thirty projects show Leadership or Finance coming from an African entity. The Expertise Ladder is quite different. It has only nineteen projects in which one African entity gets credit for the all the satellite expertise. This suggests that the biggest barrier for some countries is not money or awareness, but expertise.

Second, consider the two categories of projects that involve an external partnership with at least some satellite expertise from outside of Africa. Adding up the projects in the second and third most common Architectures shows that thirty-six projects have this scenario. Thus there is a rather bi-modal behavior in African Space Project Case Studies. About thirty-seven happen with African Management while another thirty-six happen due to external collaboration. There is a balance between independent African action and dependent African effort. This situation leaves much room for improvement. Analysis for Question 3 shows that many countries are only working in the lower Management Architectures.

Consider now the Mission Architectures. These can be considered from two points of view. First, the Master Space Project Matrix shows what Architectures are used in general in space projects that involve Africa. The three most common technical activities are listed below.

- Process satellite data (31 projects)
- Operate ground segment of satellite system (22)
- Buy and operate a satellite (15)

A different set of activities summarizes what African countries and organizations specifically accomplish in the Space Project Case Studies. The most common cases are listed below.

- Operate ground segment of satellite system (22 projects)
- Use or help define satellite data product (16)
- Process satellite data to create decision tools (11)

These lists show what is most commonly accomplished in African countries using satellite-based technologies. The data only considers Africa, not the entire developing world. Thus it is not a complete answer to the question, but it is a good start.

The Literature Review for this thesis discusses the issue of Technology Choice for developing countries. Poorly developed countries need to invest in technological capability. As part of this process, they must decide what level of technology to pursue. The literature on Technology Choice suggests that developing countries should pursue the most advanced technology that is available. The Mission Architectures that are most common for African countries are not the most advanced options. Most African countries are not pursuing the highest level of space technology. Both lists of Mission Architectures above show that the predominant activities involve using ground technology enabled by satellites. The nature of satellite technology dictates that different expertise is needed to operate satellite ground equipment than to develop spacecraft. This means that the effort of Africans to use ground equipment or process satellite data does not automatically help them move toward working with spacecraft directly. Africans must make a conscious choice to gain technological capability in higher level satellite technology if they want to move up in Mission Architecture.

5.3 Q3: Architectures versus National Development Level

The third Research Question reads, "How does national development level influence the Mission and Management Architectures used by developing countries in satellite-based technology projects" This question is answered based on the Chi-Squared tests using the rankings of the five Ladders and the Development Indicators. The statistical tests prove that there is a meaningful difference between the Ladder rankings of countries in different development groups. The data also suggests that the percentage of projects with high Mission and Management Architectures is likely to be higher for more developed countries. This is true even though the overall number of space-related projects may not increase.

For both the Mission and Management Architectures, significant results are seen when the Chi-Squared tests count the total number of projects for each country. There is no significant difference when countries are only counted once per category. The statistical difference does not just come from which countries are using satellite technology. It comes from how involved various countries are with satellites.

The Mission Architecture Ladders suggest that higher development leads to more advanced technology. Evidence from the number trends shows that more highly developed countries are likely to have a higher fraction of their projects in the high technology category.

This trend is not always consistent or monotonic in the data, however. In both the Project and Country Technology Ladders, the number of high technology projects increases and the number of low technology projects decreases as development increases. Neither relationship is monotonic. There is very little difference between the results of the Project Technology Ladder and the Country Technology Ladder in their statistical results. Some difference can be seen in the distribution of countries along the Ladder. For example, the Country Technology Ladder has nineteen projects in its top 3 categories; the Project Technology Ladder has only eleven projects in it top three categories. Many countries do move down in the Country Technology Ladder because the African contribution in the project is lower than the overall project achievement. The changes are not very well captured in the statistical analysis, however, because most projects do not move from the "High Tech" bin to the "Low Tech" bin in the Chi-Squared test. Most move within the same bin. Thus, the two ladders do have different results, but the differences are small.

The three Management Ladders have slightly more variation in their results, but they all show that the ratios of high to low Architecture projects increase with as development increases. This suggests that higher development is associated with higher Management Architectures. There are very bi-modal results for the Leadership and Finance Ladders. The projects are piled at the extreme ends of these two Ladders. Most projects are led and financed by either one African entity or by an external partner. Leadership and financial sponsorship seem to be very closely linked. The statistical tests show significant results for all the Development Indicators except for Internet Users. In these significant tests, the ratios of high leadership projects to low leadership projects increase with development level, but not monotonically. Meanwhile, the results of the Expertise Ladder rankings show a slightly different picture. There is not longer a bi-modal distribution of projects at the extreme ends of the ladder; more projects have moved to the middle of the ladder. Only Education Expenditure has consistently significant tests. Education emerges with a strong relationship to Expertise, as would be expected.

These results are consistent with theory in the same way that the results from Research Question 1 are consistent. Theory suggests that higher development should correspond to greater use of technology. These results are noteworthy, however, because the number of countries under consideration is much smaller than in Question 1. Research Question 1 compares about one hundred and seventy-five countries. Research Question 3 only compares fifty-three countries and the statistical results are significant. The analysis from Question 3 shows that there is measurable diversity among African countries. The results from Question 2 show that there may be two groups of African countries, those who manage their own projects and those who tend to collaborate. This suggests that there is untapped potential for African collaboration.

6 Policy Recommendations

This chapter builds on all the previous chapters and presents a set of policy recommendations that flows out of the study results. Most of the recommendations address observations of the Mission and Management Architectures in the ninety Space Project Case Studies. The distribution of the projects on the various Matrices and Ladders suggest ways that possible improvements can be made in how African countries pursue satellite projects. The recommendations are made primarily to African policy-makers and other stakeholders that participate in satellite projects in Africa. This is because the recommendations respond to data from Africa. It may be useful as well to policy-makers and stakeholders in other developing contexts.

All of the recommendations build on the idea – as outlined in the introduction – that it is to the benefit of developing countries to increase their use of satellite technology in remote sensing, communication and navigation. The responses to the Embassy Interviews show that African representatives are also aware of the potential for satellite technology to meet needs in their countries.

Recommendation #1: Take initiative in developing external collaborations in remote sensing projects.

This recommendation is directed toward African government representatives, particularly in those countries that are frequently involved in low Mission Architecture projects at the initiative of external partners. The Project Technology Ladder from Question 3 analysis shows that twenty-seven of the ninety Case Studies involve processing satellite data. Many of these same projects appear among the thirty-four Case Studies for which the initiative comes from an external partner. This recommendation does not discourage collaborations with external partners. The Literature Review clearly shows that one way for developing countries to increase their technological capability is to learn from other countries. The recommendation thus states that African policy makers should look for opportunities to collaborate and design the collaboration in a way that best meets their short and long term needs. Specifically, they should keep three goals in mind. First, design the collaboration such that their country receives training or technology transfer that they can use in the future. Second, design the collaboration such that it is feasible for the work to continue after the help from the partner is gone. Third, design the collaboration such that the work reflects the needs of their country, not just the resources of the partner. If African policymakers initiate the collaboration, they will have a greater opportunity to define it.

Two project case studies, Geo-Aquifer and AFRICOVER show examples of projects that meet these goals. AFRICOVER is initiated by an external partner, but it is done in a beneficial way. The United Nations Food and Agriculture Organization initiated AFRICOVER, and the United States and Italy financed it. The goal of the project is to create remote sensing data products for land management. The implementation model is wise because it involves local expertise from the beginning. The work is done by Africans with the help of external experts. At the end, the African partners own the databases created during the project. The Geo-Aquifer project is lead by Algeria, Tunisia and Libya with the goal of using satellite data for natural resource management. It is follows a project initially lead and funded by the European Space Agency. The three countries are able to continue the work started in the ESA project.

There are challenges to such a recommendation. An African country may not feel able to freely negotiate the terms of a partnership in which they are primarily a recipient. If an opportunity to benefit from satellite technology does not meet the three goals described above, that does not mean that it should not be taken. The recommendation only suggests that African policy makers consciously pursue these goals as often as possible.

Recommendation #2: Look for opportunities to fund projects based on African expertise.

This recommendation is directed to African policy makers as well as donor organizations that invest in African technological capability building. The Remote Sensing Architecture Matrix shows that very few projects are done in which an external partner provides only funding and an African partner provides expertise and funding. The Remote Sensing Roles and Actors Diagram reveals many centers of knowledge in Africa about remote sensing. These include National Remote Sensing Agencies, African Space Agencies, Regional Remote Sensing Centers, Scientific Networks, and Universities. This recommendation suggests that external partners should seek to underpin these organizations with funding and avoid funding only projects in which the partner provides expertise. The goal of this recommendation is to increase the opportunities for these African centers of knowledge to use and improve their skills.

The examples in the Case Studies of projects that achieve this Management Architecture are centers for remote sensing. Consider RECTAS, the Centre for Training in Aerospace, which provides training and consulting in remote sensing for countries in western Africa. The center is funded by the UN Economic Commission for Africa. The African countries that participate in the center also supply funding and handle the operations.

The challenges to implementing this recommendation may arise from the unwillingness of a funder to give money to a project with which they are otherwise uninvolved. Because of this, it may be more palatable to attempt such an Architecture between an African partner and an external partner that have worked together in the past with successful results.

Recommendation #3: Pursue advanced Mission Architectures with African collaborations.

This recommendation is directed towards African policy makers. It responds to the fact that only two projects on the Master Space Project Matrix involve Africans collaborating on projects in the upper half of the Mission Architectures. These projects are the African Resource Management Satellite Constellation and RASCOM. This excludes the Disaster Monitoring Constellation in which Nigeria and Algeria collaborate with England, China and Turkey. The recommendation suggests that African policy makers look for more opportunities to work together on advanced missions. For countries that already own satellites, this could include new satellite projects. For countries that do not have satellite design or operation experience, this could begin with a mid-level architecture such as leasing time on another country's satellite. The goal here is to find ways that Africans can help each other climb the Mission Architecture ladder. There has been little of this so far.

The African Resource Management Satellite (ARMS) Constellation project is an ambitious example of such effort. It includes Nigeria, Algeria, and South Africa – who have had satellites in space before – as well as Kenya who has not. The goal is to develop four satellites with the same payload that will work together to observe the entire African continent. This is a project that is not yet complete, thus its success can not be rated. It is an admirable effort, however.

The ARMS project highlights some of the difficulties of such collaboration. The four countries are not in the same region of Africa. They face cultural and language differences. They also bring different levels of expertise to the project. Part of the challenge is to teach partners while completing work. A project like ARMS is very liable to derailment by political or economic instability. Both of these are common in Africa.

Recommendation #4: Look for opportunities to do mid-level Mission Architecture projects.

This recommendation is for African policy makers. The Master Space Project Matrix shows that there are few projects that involve Africans leasing satellite time from other satellite owners. In the communications area, several large companies lease satellite capacity and distribute satellite service. In these cases, the leasing company does not operate the satellites. Meanwhile, Egypt leases a satellite for national communication. Some data from the Embassy Interviews suggest that it is common for African countries to lease time on communication satellites. There are no examples of satellite leasing in the remote sensing Case Studies. There are similar trends for some of the other mid-level Mission Architectures such as satellite operation and down linking satellite remote sensing data. This recommendation encourages African policymakers to consider pursuing projects like these in the middle of the Matrix. This is directed especially to countries that have satellite data processing capability for remote sensing. This could be a feasible next step that can increase both technological capability and the benefit from satellite data.

The Satellite Applications Center (SAC) in South Africa is an example of a facility that benefits from the capability to operate satellites even when no national satellite is in orbit. The SAC is able to serve other countries with this capability, and they use these skills at home when they launch indigenous satellites.

The challenges with implementing such a recommendation depend on the goal. If a country wants to begin to down link data directly from a satellite, this is very doable. The Regional Centre for Mapping of Resources for Development in Kenya has the capability to down link data from other countries' satellites by agreement. Indeed, as stated in the Literature Review, the United Nations' principles governing remote sensing establish that countries with satellites should support the right of other countries to access and downlink their data.[clxxiii] Another example of this is the PUMA Case Study Project in which the European Space Agency attempts to provide every country in Africa with equipment for down linking meteorological satellite data. There may be greater challenges in starting to operate a satellite for the first time. The skills needed for satellite operation are specialized; they are not taught in general education programs. This may require collaboration with African or external partners in order to gain the expertise. Finally, note that this recommendation can be equally useful to countries that have only worked at low Mission Architectures as well as countries that already have national satellites. In both cases, it can expand their access to useful data.

Recommendation #5: Look for opportunities to collaborate with external partners on satellites.

This recommendation is directed to African policy makers. The Master Space Project Matrix shows that only one project involves an African partner working with an external partner on a project to launch and operate satellites. This recommendation encourages Africans to look for opportunities to collaborate with external partners on high mission architecture projects. It can mean contributing to a satellite constellation, building an instrument for another country's satellite, co-sponsoring a satellite with another country or many other scenarios. The only relevant project in this set of Case Studies is Nigeria and Algeria's participation in the Disaster Monitoring Constellation. In this project the Surrey Satellite Technology company invites several countries to contribute satellites to a constellation that can be used for natural resource management and disaster monitoring. Each country owns its one satellite in the constellation, but agrees to use some of the satellite time for disaster response. Consider also some examples from Latin America. Argentina frequently works with other countries on its satellite projects.[clxxiv] Brazil has a series of earth observation satellites jointly developed with China.[clxxv]

This recommendation may seem applicable only to African countries that have their own satellites, but it does not have to be limited to this set. There are a number of ways that an African country can contribute to a satellite project, from funding to personnel to expertise.

Recommendation #6: Use the Mission Architectures. Try to go up to the next level, even if it requires collaboration.

This recommendation is for African policy makers and policy makers in other developing countries. It responds to the results of Research Questions 1 and 3, which show that less developed countries tend to have lower levels of space participation. In Question 1, less developed countries show lower quantity and technical quality of space activities. In Question 3, there is evidence that less developed countries are less likely to be involved with high technology projects, even if they do a comparable number of projects. How can poorly developed countries respond to this discouraging data? This recommendation presents a way forward to any developing country, no matter where it tends to find itself on the Master Space Project Matrix.

The Introduction and Literature Review establish that developing countries can benefit from a greater use of satellite technology. The use of this technology also increases the technological capability of the country. This increase is a step toward national development. Thus, it is argued that investing in satellite technology has a two-fold benefit. First, it helps to address problems in the environment, in communication and in navigation. Second, when a country learns how to use this advanced technology, they develop skills that can help improve their development level.

The recommendation suggests that no country should complacently remain where they are on the Master Space Project Matrix. If a country tends to do projects at a certain technical level and does not have expertise in higher Mission Architectures, they should consider opportunities to do more advanced Mission Architectures. This may require moving down in Management Architecture. That is fine as long as the project experience is a learning opportunity. Consider developing Country A, for example. Perhaps Country A's National Remote Sensing Agency has widespread competence in data processing but there is only limited expertise in satellite operation. This agency may consider partnering with a partner to learn about satellite operation. Such knowledge can ultimately lead to more control over the data and services available to them.

There is a compelling counter argument to this recommendation. In the case of Country A as described above, the leaders may argue that they are meeting all of their current needs by using satellite data from other sources. They may say that the data processing skills they have are adequate for present activities. Country A may not be able to afford to launch its own satellite at the present time and thus may not see any benefit in having satellite operation skills. This kind of philosophy is very near-sighted. Though Country A does not have current opportunities to operate their own satellite, it is certainly in their long term benefit to gain these advanced skills. It may be possible for Country A to use these skills in a future partnership. Perhaps if Country A contributes satellite operation effort to a project, they can receive access to more frequent or more relevant data as a result. There is no guarantee that the data sources that Country A currently relies on will always be available. It is also likely that the needs of Country A will change and require new kinds of data or better quality data. To not prepare for such eventualities is dangerous as well as near-sighted. Of course, the challenge for policy makers in developing contexts is how to invest in long-term welfare when so many short term crises dominate the resources.

Several comments made by African officials during the Embassy Interviews show that there is an awareness of this tension. They also show that these officials believe in the need to increase their technical capability and their level of satellite use. These comments confirm the wisdom of the recommendation and disagree with the counter argument. Several examples follow. When asked how important satellite technology is to their country, one interviewee says, "We do not have many people who have been trained in science and technology. We normally rely on technical expertise from other countries. It would be good to use satellite technology more." This comment acknowledges the country's current dependence on foreign partners and the need for more training in their local personnel. Another country responds to the same question by saying, "Technology is important and is a major tool for change. We believe in this but we do not have the tools to use it." A third country answers the same question this way, "You cannot be developed without good communication; to have good communication is the tool for everything. But it will be very hard for poor countries to achieve it because of the lack of financing." This recommendation suggests a small, practical step to improve such situations.

[clxxiii] Abiodun, Adigun Ade, Camacho, Sergio, Oesberg, Rolf-Peter, Zhukov, Vladimir. "Development of Indigenous Capability in Remote Sensing." *Space Policy*. 1988, pp. 122-130.

[clxxiv] National Commission for Space Activities. www.conae.ar Accessed June 14, 2008.

[clxxv] **INTERNATIONAL ASTRONAUTICAL FEDERATION. "FOCUS ON BRAZIL." HTTP://WWW.IAFASTRO.ORG/INDEX.PHP?ID=57&NO_CACHE=1&TX_IAFMSHOW_PI1[TT_COUNTRY]=BR ACCESSED ON APRIL 6, 2007.**

7 Suggestions for Future Work

This section presents several questions that are raised in this study but are not fully answered. Each question is followed by a brief explanation and follow up issues. These questions are suggested as foundations for future research.

Are African countries taking full advantage of available data sources?

The Master Space Project Matrix shows that none of the Case Studies are projects involving just African partners who process satellite data. It is not clear whether this is representative of the reality in Africa or what might cause such a trend. Does this imply that African countries that do not have their own satellites are not able to access satellite data without the efforts of a partner? What resources are available that make satellite data freely available outside of formal partnerships. A future study could investigate these issues. The first step is to find more data to confirm the trend from this study. The second step is to find examples of sources of satellite data that are freely available for general use. Through documentation or interviews, a study can ascertain who uses this data and what barriers prevent its use.

Why are African countries not collaborating more with external partners on satellites?

The Master Space Project Matrix shows only one project in which African countries mutually collaborate with external partners on a project that involves the design, building and operating of a satellite. This specifically distinguishes contracting projects from collaborating projects. Future study could investigate why this kind of project is so scarce. What are the barriers that prevent African countries from collaborating with space faring nations on satellite projects? One method could be to consider the examples in which Latin American or Asian countries have collaborated with NASA or the European Space Agency. While reviewing these examples, look for the technical contributions from each side and compare these with Africa's capabilities. Also consider the motivations and incentives for such collaborations through documentation and interviews.

Does African have greater expertise in building remote sensing satellites than communication satellites? What are the causes and impacts of this?

The Master Space Project Matrix, along with the Specialized Matrices in Remote Sensing and Communication, imply that Africans have much stronger expertise in satellite development for remote sensing than for communication. This thesis does not completely answer why this is true; it only speculates that this is because communication satellites are more complicated to build. Further study could investigate this trend by focusing on the cases of Nigeria, Algeria, Egypt and South Africa. Through documentation and interviews with personnel in these countries, one could learn about the levels and areas of expertise in their country. Further analysis could consider the economic implications of this by learning about the stakeholders and motivations in the African satellite communication industry.

Why is there little collaboration in the communication case studies?

This question arises from the Specialized Communication Case Study Matrix. It shows that there are few projects involving collaboration of any kind. Only seven out of the twenty-seven communication projects involve collaboration. Further study could investigate why this might be. One could start by understanding the stakeholders and motivations in the African satellite communication industry. One could also consider other geographic areas such as Latin America. Next, explore the examples of collaboration that do appear in Africa. Use documentation and interviews to understand the motivation in these cases. Consider also the economic and policy pressures that influence these projects.

Is there a need for a stronger commercial remote sensing industry in Africa?

The Remote Sensing Roles and Actors Analysis reveals that most Actors in the African remote sensing field are government agencies or universities. This begs the question, what might be the role for a commercial segment to the industry? Is there any economic motivation to encourage commercial activity? What has caused the Actors to form as they are? How does this compare to the US or other commercial remote sensing industries?

What is the status of communication regulation in Africa?

This study finds allusions to the importance of open policy regimes to encourage satellite communication in Africa. Much more could be studied on this topic. The first step would be to learn about the current policy regulations that influence the use of satellite technology in Africa. An economic analysis could evaluate the need for policy changes.

What are the trends in Space Project Architectures over Time?

This study does a very preliminary analysis of space project Mission and Management Architectures over time. The analysis is based only the data collected in this study, which is not a truly historical overview. In order to do a more complete analysis, one must start with an historical literature review to find documentation on African space projects from the 1950s through the present. For each example, find the initiation date, the Management Architecture and the Mission Architecture. One could use the same statistical analysis methods described in this thesis on this larger data set and find more conclusively if there are changes in the Architectures over time.

How do the various Development Indicators compare?

This thesis uses seven Development Indicators as measures of national development level. No effort is made in this study to rigorously compare the indicators and their relative importance in predicting space activity. Several questions could be explored using regression analysis. First, which of these Development Indicators makes the strongest contribution in explaining the results of the Space Participation Metric analysis? Second, which of these Development Indicators makes the strongest contribution in explaining the results of the Space Project Case Study analysis? Third, are there other Development Indicators that should be included? This third question may be addressed by considering other studies that use Development Indicators to predict technology outcomes. A study like this must also consider relationships, such as correlation, between the Development Indicators.

Which comes first – satellite technology or development?

This thesis is written from the point of view that technological capability building is a stepping stone to national development. The basic belief is that if countries pursue satellite technology, they will ultimately improve their development level to some extent. The results of Questions 1 and 3 imply that more developed countries are more involved in satellite technology. It is not clear, however, what causes what. Does higher development level make it easier to participate in satellite technology projects? Or does satellite technology help a country improve its development? This is a question that merits further study, perhaps with a system dynamics model.

What else can be learned from the Embassy Interview Data?

Much data is included in the results from the Embassy Interviews with African officials. The data is analyzed here largely for the purposes of comparing it to the other data sets in the study. It is not used to its full potential. Several other steps can be taken with this data. First, it can be compared to other documented evidence about African National Innovation Systems. How do these responses compare to literature on Africa's ministries of science and technology or Africa's national laboratories and universities? Second, the information can be organized thematically. The analysis done so far organizes the data according to the question to which it responds. Some information, however, should be looked at according to topic. For example, there is insight into the university system in both Interview Questions 2 and 9. This data should be combined and summarized. Once these themes are organized, the data can be more readily compared to published literature on the topic.

How is the emphasis on Communication Technology affecting African countries?

The Embassy data shows that 18 of the countries name the ministry in charge of communication as the most important ministry for science and technology issues. Further study could investigate this trend. Does this imply a real emphasis on communication in these countries? Are other areas of technology suffering or benefitting from this emphasis? How are government and grass roots efforts in the area interacting? It appears from the statistical analysis that the countries with higher technical capacity in space do not have such an emphasis on the communication ministry.

Are African countries in economic transition? How is this affecting technology adoption?

Some Embassy responses suggest that many African countries are transitioning from a centralized to a more privatized economy. Further research and literature review could confirm this. It would then be interesting to explore how this transition is affecting technology adoption in general and satellite activity in particular. Satellite technology often requires strong government activity, particular in remote sensing projects. Are countries with more privatized industry less active in satellite projects? How is this different in the remote sensing, communication and navigation areas?

Is there a weak triangle in African National Innovation Systems?

The Embassy data also suggests that there are weak linkages in the Innovation Systems of some African countries. Several interviewees talked about the weak connection between industry and government or between industry and academia. Further literature review could confirm such trends and clarify them. This could also be cross-referenced with the space activity data. What causes these weak linkages? What are possible solutions? How does this phenomenon influence technology adoption?

Are African students being trained for technical careers with internships?

There is a mix of responses as to whether internships are commonly used to train African students for technical careers. It would be valuable to explore this question more deeply and gain more accurate data on the prevalence of internships. This data could be compared to technology adoption data, education data or space activity data to learn if it seems to influence outcomes in these areas.

8 Closing Reflections

All the conclusions in the previous chapters are founded on literature, data or analysis included in this study. I take the liberty in this chapter to discuss some personal reflections. These may not be rigorously supported by data, but they were learned or observed during the process of conducting this study.

Overall, I am pleased to report that the level of satellite-related activity in Africa far exceeds my initial expectations. Once I expanded my definition of satellite activity to include any project that is enabled by a satellite, I found that it is influencing life in Africa in many ways. This is very encouraging. The comments of many African embassy officials confirm that satellite technology is used frequently. At the same time, my data and their comments confirm that the technology could be used so much more.

The experience of conducting interviews in African embassies deserves some discussion. It was very challenging in several ways. First, I had to convince people at the embassies to meet with me. Some countries simply refused to attempt to answer my questions. When they heard that I had questions about technology, they said that they did not have anyone competent to answer me. I learned that I had to be careful about how I sold myself. Here my dual competences in engineering and policy were an advantage. If I said that I was doing engineering analysis, some people were more overwhelmed. If I said I was doing a policy study, they were often more likely to help me. Some people at the embassies were very bothered by my methods. They assumed that if I was doing a technical study about their country, I should not simply talk to a few officials and call that research. I tried to reassure them that their comments would not be my final source of information and that I only needed high level information about each country. Several embassies suggested that I needed to travel to their country for my research. A few asked me to wait while they contacted the appropriate officials in their home country. This usually led to no response, but 2 countries did send me information in this way. The second challenge was in communicating with the embassies. I generally contacted them initially by phone. Some embassies have sophisticated phone systems with directories and voicemail boxes. Some phone lines would ring ceaselessly if no one was there to answer. I observed that these African ex-patriots used technology at a variety of levels. Even though they are in the United States with all of its resources, many of them are not confidant in using these modern conveniences. Some embassies use e-mail readily. Others asked me to send everything by fax because they did not use e-mail regularly. In some cases, fax was even preferred to postal mail. I found it hard to know who to talk to in the embassy when I first called. Every embassy has a different leadership structure. In some cases, the best person is the education or cultural attaché. Ultimately, I was at the mercy of whoever answered the phone or responded to voicemails. My interaction with the African embassies was very valuable as a way to ground my analysis in the practical realities of African countries.

The main thing I learned in this study is that the barriers that prevent African countries from using satellite technology must be battled simultaneously. The main barriers seem to be lack of finances, lack of technical expertise and lack of awareness of the potential of the technology. Simply addressing any one of these areas will not solve the problem. Partnerships between developing countries or between less developed and more developed countries seem to be a powerful tool for combating these barriers. Such partnerships can bring financial help, technical training, technology transfer and increased awareness all at once. The key need seems to be that partnerships are designed to maximize long term benefit to the developing countries.

There are certainly difficult issues to consider when suggesting that developing countries solve their problems by working with other countries. There is the danger that less developed countries may settle into a rut in which they depend on others for advancement. There is the danger that more developed countries may not find adequate incentives for partnering in a beneficial way. There is the danger that partnerships will depend too much on the ebb and flow of political regimes. Collaboration is certainly not a panacea. It is, however, a practical way to address the reality that developing countries have very limited resources and extremely large problems.

Appendix A: List of Space Activities Used in SPM Definition

List of Space Activities Used in SPM Definition	
Space Activities	**References (Links Accessed on June 19, 2008)**
Members as of 2004 of United Nations Committee on the Peaceful Uses of Outer Space	http://www.unoosa.org/oosa/COPUOS/members.html
Member of Group on Earth Observations	http://earthobservations.org/ag_members.shtml
Hosted an International Astronautical Congress Conference	http://www.iafastro.com/index.php?id=101
Member of International Mobile Satellite Organization	http://www.imso.org/member_states.asp
Member of International Telecommunications Satellite Organization	http://67.228.58.85/dyn4000/itso/tpl1_itso.cfm?location=&id=3&link_src=HPL&lang=english
Member of International Telecommunications Union	http://www.itu.int/cgi-bin/htsh/mm/scripts/mm.list?_search=ITUstates&_languageid=1
Member of International Astronautical Federation	http://www.iafastro.com/?id=55
Member of International Astronomical Union	http://www.iau.org/administration/membership/national/
Signed Outer Space Treaty	http://www.unoosa.org/oosatdb/showTreatySignatures.do
Inclusion in United Nations Directory of Education Opportunities for Space Science	http://www.unoosa.org/oosa/SAP/eddir/index.html
National Space Program (according to *Jane's Space Directory)*	Clark, Phillip. *Jane's Space Directory*. Jane's Information Group, Alexandria, VA, 2005/2006.
Space Institutes or Organizations (according to *Jane's Space Directory)*	Clark, Phillip. *Jane's Space Directory*. Jane's Information Group, Alexandria, VA, 2005/2006.

Participate in United Nations Program on Space Applications	http://www.unoosa.org/oosa/en/SAP/sched/index.html
Report to UNOOSA on nationals space activities or research	http://www.unoosa.org/oosa/en/docsidx.html
Domestic Communication Satellite system (According to CIA World Factbook)	https://www.cia.gov/library/publications/the-world-factbook/fields/2124.html
International Communication Satellite Earth Stations (According to CIA World Factbook)	https://www.cia.gov/library/publications/the-world-factbook/fields/2124.html
Earth Observation Facilities and Equipment (*Jane's Space Directory)*	Clark, Phillip. *Jane's Space Directory.* Jane's Information Group, Alexandria, VA, 2005/2006.
Launch Facilities (*Jane's Space Directory)*	Clark, Phillip. *Jane's Space Directory.* Jane's Information Group, Alexandria, VA, 2005/2006.
Launch Vehicle(s) (*Jane's Space Directory*)	Clark, Phillip. *Jane's Space Directory.* Jane's Information Group, Alexandria, VA, 2005/2006.
Participant in International Space Station	http://www.nasa.gov/mission_pages/station/structure/elements/partners.html
Appear on UN Launch Registry	http://www.unoosa.org/oosa/en/SORegister/docsstatidx.html

Appendix B: List of Space Project Case Studies with References

List of Space Project Case Studies with Full Names and References		
Shorthand Name	**Full Name**	**Reference** (Links Valid as of May 2008)
ACMAD	African Center of Meteorological Applications for Development	http://ioc.unesco.org/goos/Africa/ACMAD.doc
AFRICOVER	Multipurpose Africover Database for Environmental Resources	http://www.africover.org/africover_initiative.htm
AFSAT	Afsat Communications Africa Limited	http://www.afsat.com/index.html
AGRHYMET	Agro-Hydro-Meteorological Regional Center	http://www.agrhymet.ne/eng/centre.htm
AIDS Telemedicine	AIDS Telemedicine	http://www.gvf.org/solutions/studies/index.cfm?fuseaction=more&check=121&row=10
ALSAT-1	AlgeriaSat-1	Cooksley, Curiel, et al. "Alsat-1 First Year in Orbit" 54th International Astronautical Congress of the International Astronautical Federation, the International Academy of Astronautics, and the International Institute of Space Law, 29 September - 3 October 2003, Bremen, Germany
ALSAT-2A	AlgeriaSat-2A	http://www.engineeringnews.co.za/print_version.php?a_id=125912
ALSAT-2B	AlgeriaSat-2B	http://www.engineeringnews.co.za/print_version.php?a_id=125912
AMESD	African Monitoring of the Environment for Sustainable Development	http://www.eumetsat.int/Home/Main/Media/Press_Releases/032117?l=en
ARMC	African Resource Management Satellite Constellation	http://www.sunspace.co.za/programmes/african_resource_managment.htm
ARTEMIS	Africa Real Time Environmental Monitoring Information System	http://gcmd.nasa.gov/records/GCMD_CIESIN0122.html
AVU	African Virtual University	www.worldbank.org/afr/findings/english/find223.pdf
Botswana V-Sat	Using Very Small Aperture Terminal Systems in Botswana	www.btc.bw/News/Articles/JanMarch/BTC%20Pilots%20VSAT%20Services%20Deep%20in%20the%20Seronga.pdf
CENACARTA	National Center for Mapping and Remote Sensing	www.cenacarta.com (with translation by Google.com)

CERGIS	Centre for Remote Sensing and GIS at University of Ghana	Rochon, et al. "Applicability of Near-Real-Time Satellite Data Acquisition and Analysis & Distribution of Geoinformation in Support of African Development" www.uneca.org/codi/Documents/WORD/ECA_CODI_IV_Paper_Rochon.doc. Accessed Feb 27, 2008
Coasts in Tanzania	Tanzania/Kenya spatial information project	http://www.crc.uri.edu/index.php?projectid=46
Compuplot	Compuplot Company	www.compuplot.com
CSE	Centre de Suivi Ecologique	Planchon, F."Land Degradation in Senegal" ftp://ftp.fao.org/agl/emailconf/lada/lada2_fatou_planchon.doc Accessed Feb 27, 2007
Cyber Shepherds	Cyber Shepherds	http://www.idrc.ca/en/ev-47038-201-1-DO_TOPIC.html
DMC	Disaster Monitoring Constellation	Baker, Adam, et al. "NextGen DMC: High Performance Small Spacecraft Based Observation at an Affordable Cost." International Astronautical Congress, Valencia, Spain, 2006.
DUE EPIDEMIO	Earth Observation in Epidemiology	http://dup.esrin.esa.it/projects/summaryp60.asp
DUE GlobWetland	Development and demonstration of a standardised information service based on EO technology to support the implementation of the RAMSAR Convention	http://dup.esrin.esa.it/projects/summaryp61.asp
EGNOS	EGNOS in Africa	http://www.esa.int/esaNA/SEMOZ00DU8E_index_0.html
EgyptSat-1	MisrSat-1	http://www.engineeringnews.co.za/print_version.php?a_id=125912
ESL at SU	Electronic Systems Laboratory at Stellenbosch University	http://esl.ee.sun.ac.za/index.php/Main/SatelliteSystems
Ethiopia Census	Ethiopia Census	Presentation on the Ethiopian Approach in Census Cartography. http://unstats.un.org/unsd/demographic/meetings/wshops/Zambia_8Oct07/list_of_docs.htm Accessed April 24, 2008
Eutelsat	Eutelsat SA	http://www.eutelsat.com/eutelsat/eutelsat-communications.html
FEWS NET	Famine Early Warning Systems Network	http://www.fews.net/Pages/default.aspx
Gath	Gath Management Ltd	http://www.gathkenya.com/
Geo-Aquifer	Geo-Aquifer	http://dup.esrin.esa.it/news/news135.asp
GMES Services Element	Global Monitoring for Environment and Security, Services Element	http://www.esa.int/esaLP/SEM2UV2IU7E_LPgmes_0.html
GPS Crane Track	GPS Crane Tracking	http://www.ewt.org.za/news_fullstory.aspx?status=0&newsID=466
Inmarsat	Inmarsat oversight by	http://www.inmarsat.com/About/?language=EN&textonl

	International Mobile Satellite Organization	y=False
Intelsat	Intelsat, oversight by ITSO (International Telecommunications Satellite Organization)	http://www.intelsat.com/about-us/
International Charter Space and Major Disaster	International Charter, Space and Major Disasters	http://www.disasterscharter.org/main_e.html
InterSat Africa	InterSat Africa Limited	http://www.intersatafrica.com/
INTSORMIL CRSP	International Corn and Millet Collaborative Research Support Program	"Down to Earth: Geographic Information for Sustainable Development in Africa," Report by National Research Council. http://www.nap.edu/openbook.php?isbn=0309084784
Kenya Census	Kenya Census	Ndubi, Joseph. "Use of GIS in Census Management and Mapping: The Kenyan Experience." United Nations Regional Workshop on Census Cartography and Management. Lusaka, Zambia. 2007 http://unstats.un.org/unsd/demographic/meetings/wshops/Zambia_8Oct07/list_of_docs.htm
Kingston Inmedia	Kingston Inmedia	http://www.balancingact-africa.com/news/back/balancing-act_143.html
LEWS	Livestock Early Warning system	http://cnrit.tamu.edu/lews/index.html
Liberia Census	Liberia Census	Mwangangi, Isaac, et al. "The 2008 Liberia Population and Housing Census." UN Regional Workshop on Census Cartography and Management. Lusaka, Zambia. 2007 http://unstats.un.org/unsd/demographic/meetings/wshops/Zambia_8Oct07/list_of_docs.htm Accessed April 24, 2008.
MARA	Mapping Malaria in Africa	http://www.mara.org.za/
Mindset	Mindset Network	http://www.mindset.co.za/corporate/templates/about.htm
Miombo	Miombo Network	http://www.geog.psu.edu/geclab/miombo/ and "Down to Earth: Geographic Information for Sustainable Development in Africa," Report by National Research Council. http://www.nap.edu/openbook.php?isbn=0309084784
Multichoice Africa	MultiChoice Africa Limited	http://www.dstvafrica.com/main.aspx?t=9&s=3
Namibia Census	Namibia Census	Mwazi, Ottilie. "Census Mapping with GIS in Namibia" Regional Workshop on Census Cartography and Management., Lusaka, Zambia. 2007 http://unstats.un.org/unsd/demographic/meetings/wshops/Zambia_8Oct07/list_of_docs.htm Accessed April 24, 2008
NARSS	Egypt's National Authority for Remote Sensing and Space Sciences	http://www.narss.sci.eg/narsspages/home.aspx

NEPAD eAfrica eSchools	NEPAD eAfrica eSchools Initiative Demo Project	http://www.infodev.org/en/Publication.355.html
NigComSat	Nigeria Communication Satellite -1	http://news.bbc.co.uk/2/hi/africa/6653067.stm
NigeriaSat-1	NigeriaSat-1	http://www.sstl.co.uk/index.php?loc=5
NigeriaSat-2	NigeriaSat-2	http://www.spacedaily.com/reports/Nigeria_To_Build_Second_Space_Satellite_999.html
NileSat	The Egyptian Satellite Company	www.nilesat.com.eg
NileSat-101	NileSat-101	http://www.engineeringnews.co.za/print_version.php?a_id=125912
NileSat-102	NileSat-102	http://www.engineeringnews.co.za/print_version.php?a_id=125912
NileSat-103	NileSat-103	http://www.engineeringnews.co.za/print_version.php?a_id=125912
NX Nigeria	NX Nigeria	http://www.engineeringnews.co.za/print_version.php?a_id=125912
PUMA	Preparation for Use of MSG in Africa	http://www.eumetsat.int/Home/Main/What_We_Do/InternationalRelations/Africa/SP_1182256661901?l=en
RASCOM	Regional African Satellite Communications Organization	http://www.rascomstar.com/web/index.html
RCMRD	Regional Centre for Mapping of Resources for Development	http://www.rcmrd.org/
RECTAS	Regional Centre for Training in Aerospace Surveys	http://www.rectas.org/RECTAS%20Brief.htm
River Blindness	Onchocerciasis (River Blindness) Control Programme	http://www.who.int/blindness/partnerships/onchocerciasis_OCP/en/ and United Nations Office for Outer Space Affairs. “Space Solutions for the World’s Problems.” http://www.uncosa.unvienna.org/uncosa/reports/wssdpub/iam/menu.html April 2, 2008.
SAC	Council for Scientific and Industrial Research’s Satellite Applications Center	http://www.csir.co.za/SAC/index.html
Satellife	AED-SatelLife company	http://www.healthnet.org/whoweare.php
Senegal Telemedicine	Telemedicine in Senegal	http://eu.spaceref.com/news/viewpr.html?pid=5399
Sentech	Sentech	http://www.sentech.co.za/
SES New Skies	SES New Skies Satellites	http://www.ses-newskies.com/products.htm

Sierra Leone Census	Sierra Leone Census	Presentation by Statistics Sierra Leone on the Use of GPS to Design Enumeration Areas: A Convenient Solution for Developing National Sampling Frames. http://unstats.un.org/unsd/demographic/meetings/wshops/Zambia_8Oct07/list_of_docs.htm Accessed April 24, 2008.
Sumbandilasat	Sumbandilasat	http://www.sunspace.co.za/programmes/ZA002.htm
SunSat	SunSat	http://centaur.sstl.co.uk/SSHP/micro/micro99.html
SunSpace	Sun Space and Information Systems	http://www.sunspace.co.za/products/index.htm
Tampere Convention	Tampere Convention on the Provision of Telecommunication Resources for Disaster Mitigation and Relief Operations	http://www.reliefweb.int/telecoms/tampere/
Thuraya	Thuraya	http://www.thuraya.com/content/profile.html
TIGER ARBRE	Aquifer and River Basin Resource Evaluation	http://www.space.gc.ca/asc/eng/satellites/tiger_project.asp#arbre
TIGER Ghana	Satellite hydrogeology for water resource management in Northern Ghana	http://www.space.gc.ca/asc/eng/satellites/tiger_project.asp#ghana
TIGER GIS River Man	Remote Sensing and GIS Application in Integrated River Basin Management	http://www.space.gc.ca/asc/eng/satellites/tiger_project.asp#limpopo
TIGER IWAREMA	TIGER IWAREMA Zambia	http://dup.esrin.esa.it/projects/summaryp75.asp
TIGER Lake Quality Egypt	Satellite Monitoring of Lake Water Quality in Egypt	http://dup.esrin.esa.it/projects/summaryp79.asp
TIGER Lake Victoria	Lake Victoria TIGER project	http://dup.esrin.esa.it/projects/summaryp76.asp
TIGER Malaria Risk	Development and demonstration of Earth observation technology for identifying natural mosquito habitats and predicting malaria risk in Africa	http://www.space.gc.ca/asc/eng/satellites/tiger_project.asp#africa
TIGER Morocco	Integrated Decision Aid System for Water Resource management, Sous-Massa Basin, Morocco	http://www.space.gc.ca/asc/eng/satellites/tiger_project.asp#morocco

TIGER Nile River	TIGER Nile River Awareness Kit	http://www.space.gc.ca/asc/eng/satellites/tiger_project.asp#nile
TIGER Share	Operational soil moisture monitoring service	http://dup.esrin.esa.it/projects/summaryp77.asp
TIGER StereoSat	TIGER StereoSat Africa	http://www.space.gc.ca/asc/eng/satellites/tiger_project.asp#stereosat
TIGER WADE	Water Resources Assessment using SAR in Desert and Arid Lands in West African Ecosystems	http://dup.esrin.esa.it/projects/summaryp78.asp
Uganda Telecentre	Satellite Communication for Community Development: Nakaseke Telecentre	http://www.idrc.ca/en/ev-86365-201-1-DO_TOPIC.html
UNISA	University of South Africa	http://www.unisa.ac.za/default.asp?Cmd=ViewContent&ContentID=20555
WE Consult	WE Consulting Company	http://www.we-consult.info/index.html
World Space	World Space Satellite Radio	http://www.worldspace.com/whatisit/overview.html
ZA Census	Census South Africa	"Basson, Carel. "The Use of Geographical Information Systems, Global Positioning Systems and Automated Demarcation Technologies in Surveys and Census Mappingn 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 Accessed April 2008.
Zambia Census	Zambia Census	Zambia, "Census Mapping: A Case of Zambia." United Nations Regional Workshop on Census Cartography and Management. http://unstats.un.org/unsd/demographic/meetings/wshops/Zambia_8Oct07/list_of_docs.htm Accessed April 24, 2008.

Appendix C: Master Space Project Matrix with Projects

The Master Space Project Matrix is shown below with the projects filled in. Because the graphic is so large, it is divided into two parts. First, the left half of the Matrix is shown; next the right half is shown.

Master Space Project Case Study Matrix – (Left Side)	*One African Country + Contractors (37)*	*Non-Regional African Collaboration + Contractors (2)*	*Regional African Collaboration + Contractors (4)*	*External Collaboration; Sat expertise from African partner (3)*
Design, Build, Launch, Operate Satellite (9)	SunSat, Sumbandilasat, NigeriaSat-1, ALSAT-1, NX Nigeria, Alsat -2A, Alsat - 2B, EgyptSat-1			
Design, Build Satellite (2)	Sunspace, ESL at SU			
Buy and Operate Satellite (15)	NigeriaSat-2, NARSS, Nilesat 102, Nilesat 101, NigComSat, NileSat	ARMC	RASCOM	
Lease and Operate Satellite (1)	Nilesat 103			
Operate Others' Satellites (1)	SAC			
Lease Sat Capacity and Distribute Service (6)	Sentech, MultiChoise Africa, Intersat, AFSAT, Mindset			
Operate Ground Segment; send or receive data (22)	UNISA, Botswana V-Sat, WE Consult, Zambia Census, Liberia Census, Namibia Census, South Africa Census, Kenya Census, Gath, Compuplot, Sierra Leone Census, Ethiopia Census			
Process Sat Data; create data products (31)	CENACARTA, CERGIS		AGRHYMET, Geo-AQUIFER	Centre de Suivi Eco., ACMAD, RECTAS
Use Sat Data Products (1)		MARA		
Participate in Regulatory Action (2)				

Master Space Project Case Study Matrix – (Right Side)	*External Collaboration; Sat expertise from both sides (13)*	*External Collaboration; Sat expertise from external partner (23)*	*External Company or Org.; provides sat service in Africa (8)*
Design, Build, Launch, Operate Satellite (9)	DMC		
Design, Build Satellite (2)			
Buy and Operate Satellite (15)			SatelLife, SES NEW Skies, Eutelsat, Inmarsat, Intelsat, Thuraya, WorldSpace
Lease and Operate Satellite (1)			
Operate Others' Satellites (1)			
Lease Sat Capacity and Distribute Service (6)			Kingston Inmedia
Operate Ground Segment; send or receive data (22)	GPS Crane Track	Uganda Telecentre, NePAD eAfrica, Senegal Telemed, AVU, River Blindness, EGNOS, Cyber Shepherds, AIDS Telemed	
Process Sat Data; create data products (31)	Miombo, TIGER Ghana, TIGER GIS River Man, TIGER WADE, IWAREMA TIGER, Lake Victoria TIGER, FEWSNET, AFRICOVER, LEWS	GMES, NileRiver, Tiger Morocco, Malaria Risk TIGER, TIGER ARBRE, TIGER StereoSAat, TIGER SHARE, EPIDEMIO DUE, GlobWetland DUE, Lake Quality Egypt TIGER, Coasts Tanzania, Intsormil CRSP, ARTEMIS, PUMA, AMESD	
Use Sat Data Products (1)			
Participate in Regulatory Action (2)	Tampere Conv, Space and Major Disasters		