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THE USE OF SATELLITE-BASED TECHNOLOGY TO MEET NEEDS IN DEVELOPING COUNTRIES

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ABSTRACT

This project examines trends in the use of satellite-based technologies for needs in developing countries. The results enable a better understanding of the technology and management options that are being pursued in satellite projects. Insights are provided for both developing country policy makers and potential development partners. The satellite applications considered in this research are as follows: 1) remote sensing, to provide imagery and environmental data; 2) communications (including phone, radio, television, and internet); and, 3) navigation, which facilitates services such as air traffic management and surveying. Each of these applications can improve the lives of millions of people. This research centers on an analysis of satellite activities in Africa. Ninety case studies of African satellite projects as well as interviews with African representatives are used to understand the trends in this field. There are myriad satellite "management architectures" or ways that a project can be implemented. There are also many technical levels at which satellite services can be accessed. This research provides valuable observations about a field that is not well documented.

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. There are many examples of programs, organizations and projects that use satellite based technology in developing regions. There is a need for high level analysis of the use of this technology to guide policy makers and development partners. The potential of these technologies is not fully met due to various barriers that challenge developing countries. These barriers include lack of awareness, funding, expertise, infrastructure, equipment and education.

This research explores many examples of satellite enabled activity in Africa in order to observe trends in technology, purpose and management of the projects. Ultimately, this research will provide insight for policy makers in the developing world as well as potential development partners who want to facilitate the use of satellite-based technology.

The paper is organized as follows. Following this introduction, the next section explains how the use of satellite remote sensing, communication, and navigation technology can meet needs in developing countries. The next section explores some of the barriers that prevent developing countries from using satellite-based technology, based on a

literature review. This review is augmented by data from interviews with African embassy officials. The main body of the work centers around ninety case studies of African satellite projects. The fourth section discusses the methodology and results for the case studies. The fifth section discusses some major observations about the use of satellite technology in Africa that can be drawn from the case study analysis. The closing summarizes the paper and provides concluding insights.

HOW SATELLITE TECHNOLOGY CAN MEET NEEDS IN DEVELOPING COUNTRIES

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

Satellite Remote Sensing

Satellite remote sensing allows visual imaging of the earth's surface as well as the collection of scientific data about the earth, sea and atmosphere.

Satellite remote sensing can address needs in developing countries by supporting such efforts as urban planning and disaster management. 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.[i] High resolution satellite imagery used with Geographic Information Systems can provide city planners with much needed information about the growth of their cities.[ii]

A second need of developing countries that can be addressed by satellites is disaster management. Disasters like hurricanes, volcanoes, and fires or long term problems such as famine, drought and disease occur commonly and cause great damage in developing countries.[iii] Satellites can sometimes provide early warning about disasters through remote sensing. Satellites can detect hurricanes, volcanic activity and fires. Projects such as MARA (Mapping Malaria Risk in Africa) use environmental satellite data to understand the spread of disease by animals.[iv] Also, satellite data can give warning of famine or drought conditions before they become severe.[v]

Satellite Communication

Satellites provide many services in the area of communication by providing a platform to transfer data from one point on the globe to another. Satellites play a valuable role in providing phone, internet, and broadcast services in developing countries. These services can improve access to education and medical care.[vi]

There is an urgent need to improve education opportunities in the developing world. Rural schools in developing countries are often understaffed and lack basic resources. There is also concern about the low level of teacher qualification and the high level of teach absence.[vii,viii] To respond to such problems, satellite communication can provide new formal and informal education opportunities through distance education or educational broadcasting.[ix]

Satellite communication technology can improve medical care in developing countries by enabling telemedicine. In rural areas of developing countries, it may be difficult or expensive to get access to medical care. 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 use the system to provide diagnosis, treatment and counseling.[x]

Satellite Navigation

Satellite navigation involves the use of satellites and ground receivers to determine latitude, longitude and altitude. Satellite navigation is relevant to developing countries in various ways. A key benefit of the technology is that the global satellite infrastructure is currently provided for free by several governments. A user of satellite navigation only needs to buy a receiver. Receiver technology is steadily becoming more mature and affordable. [xi] Thus satellite navigation is becoming a cost effective option for areas such as civil aviation and census data collection.

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.[xii] Unfortunately, civil aviation in developing countries suffers from safety concerns. The ground-based infrastructure that is required to maintain air traffic management can be very expensive. The World Tourism Organization (WTO) finds that the air traffic management technology based on satellite navigation can be more affordable than traditional ground based infrastructure, particularly for remote airports that are used infrequently. [xiii]

BARRIERS TO THE USE OF SATELLITE TECHNOLOGY IN DEVELOPING COUNTRIES

There have been many success stories in the use of satellite technology to meet needs in developing countries. Here are just a few examples. The formation of INTELSAT and INMARSAT created opportunities for developing countries to benefit from fixed and mobile satellite communication.[xiv,xv] The work of the United Nations Office of Outer Space Affairs builds capacity and spreads awareness about space technology in developing countries. Companies such as Surrey Satellite Technology Limited work with developing countries. They not only sell satellites, but also provide training in satellite development.[xvi] NASA's SERVIR project is ensuring that all the nations of Central America have access to NASA remote sensing data.[xvii] Meanwhile, a few developing countries, such as India and Brazil, have very accomplished national space programs.[xviii,xix]

Despite these success stories, there is a great deal of unreached potential in the use of this technology in developing countries. There remain several barriers for developing countries that want to use satellites. This section summarizes the barriers often cited in literature that inhibit the use of satellite technology in developing countries. The observations from literature are augmented by data from thirty interviews conducted by the author with African embassy officials. The interviews used semi-structure, open-ended questions to learn about technology policy in Africa.

It is inherent in the definition of developing countries that they have a lower capacity to use technology than more developed countries. With this reality come several problems that impede the indigenous use of satellite technologies. Within developing countries there may be a lack of awareness of the benefits of satellites. Policy makers may not know that satellites 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.[xx] In short, the barriers include lack of awareness, expertise, education, budget and infrastructure.

The results from the embassy interviews provide further insight about these barriers. The level of awareness was probed by several interview questions. Twenty of the thirty countries said that satellite technology is "extremely important" to their country in terms of its potential to meet needs. Meanwhile nineteen of those questioned said that the government agencies concerned with environment in their country use satellite technology. These results suggest a relatively high level of awareness of the value of the technology. With regards to expertise, the interviews showed that most of the African countries do not have a national space agency, but in 26 of the 30 countries is some government agency that deals with space related issues. These agencies may be focused on communication, aviation or defense, for example. Questions about African education showed that twenty-two of the thirty countries mention having engineering and science education available at a national university. While this is encouraging, it does not reveal anything about the quality of the education. Meanwhile twenty-three countries said that government financial resources for science and technology are inadequate. These interview results seem to suggest that the barriers from literature are relevant, but they have different levels of impact.

Due to the lack of indigenous capability in satellite technology, developing countries often collaborate with other countries in order to benefit from the technology. The embassy interviews support this; twenty-four of the thirty officials said that their government ministry for science and technology collaborates with entities outside of their country. These collaborations can be useful, but several challenges limit their effectiveness.

In the area of remote sensing barriers to international collaboration may include national security constraints, limitations on technology transfer and an increase in cost due to commercialization. For communication technology the scenario is a bit different. The entities operating satellites are mostly multinational commercial entities. The barrier that can impede access to satellite technology is sometimes 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.[xxi,xxii] In the area of navigation the barrier is more of a specter than a current reality. Developing countries who depend on the satellite navigation systems of other countries are ultimately powerless to ensure the continuing availability of the resource.[xxiii]

AFRICAN SATELLITE PROJECT CASE STUDIES

To better understand the use of satellite-based technology in developing countries, this study analyzes ninety case studies on satellite-enabled activities in Africa.

Case Study Methods

The Satellite Project Case Studies are a set of ninety summaries of programs, projects and organizations that utilize satellite-based technology in Africa. The case studies are scoped in terms of geography, technical area, project intent and depth. Africa is chosen as a geographic focal point

because it includes a large number of very poorly developed countries while boasting great diversity. This assertion is supported by the country rankings of the United Nations Human Development Report.[xxiv] As for technology area, the Satellite Project Case Studies are limited to satellite communication, remote sensing or navigation projects that involve the direct use of satellite technology. A maximum of 19 questions are considered for each case study. 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. Data for the Satellite Project Case Studies comes from many sources, including conference proceedings, news articles, journal articles, and organizational websites.

Case Study Results

Three types of results are derived from the Satellite Project Case Study data. First is the summary of trends in project purpose. Second is the Master Architecture Matrix, which shows the technical and management scenarios for African satellite projects. Third is a graphical depiction of Roles and Actors in the Satellite Project Case Studies. This is done separately for each of the three areas of satellite-based technology (remote sensing, communication and navigation).

Trends in Project Purpose

The first result is an analysis of Purpose within the Satellite Project Case Studies. The "purpose" is defined based on the user's goal for implementing the technology as explained in the documentation of the case study. This data supports and supplements the discussion from the introduction about ways that satellite technology is helpful in developing countries. The case studies confirm that satellite remote sensing, communication and navigation services are in demand in Africa. They are used to meet very relevant needs. Tables 1 to 3 below show the main purposes mentioned in these three satellite technology areas.

Table 1 – Trends in Project Purpose: 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

Table 2: Trends in Project Purpose: Communication	
Internet	8
Distance Education	8
Radio	6
Television	5
Phone	3
Telemedicine	2
Informal Education	1

Table 3 – Trends in Project Purpose: Navigation	
National Census	7
Surveying/Construction	3
Personal Navigation	2
Aviation Navigation	1
Wildlife Tracking	1

The first table shows the results for remote sensing. Common project purposes are water resource management, natural resource management, and food security. The next table shows the common purposes for communication case study projects. Internet, distance education, radio and television stand out as common uses of satellite communication. Finally, the third table shows the purpose in navigation projects. The use of navigation technology for national census taking is the dominant example.

The numbers in each row show how many case studies refer to a given purpose. Overall, remotes sensing has the largest number of case studies with fifty-eight projects. Twenty-eight projects involve communication, and fourteen use navigation. There is some overlap because a few projects use multiple technologies or have multiple stated purposes.

The relative frequency of project types and project purposes may be significant, but should be treated with caution. Although remote sensing is the most common case study, this does not prove that it is more common in Africa than communication or navigation. The numbers truly reflect the ease with which the researcher uncovered documentation about projects. For example, the most frequently stated purpose among Remote Sensing projects is Water Resource Management. This is due to a large collection of related projects that are all sponsored by the same entity and deliberately address the same topic. The documentation for all of these projects is conveniently located on one website. Similarly, with the Navigation projects, national census data collection dominates numerically because all of the examples come from presentations at a single conference held by the United Nations. In both of these cases, an organization has highlighted the given purpose as important and brought together considerable resources to address it and document it. From one perspective, this does imply that the water resource management and census data collection are considered very important. On the other hand, it does not give definite information about how these purposes compare to the others.

Master Architecture Matrix

The second result is the Master Architecture Matrix, as shown below. The information from the case studies is organized to show the “Mission” and “Management” Architectures used in the projects. Mission Architectures show what technical activities were accomplished. Management Architectures show who executed the project. Using the Mission and Management Architecture categories, all the Satellite Project Case Studies are counted on a Master Architecture Matrix with “Mission” and “Management” as the vertical and horizontal 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. The Matrix is color coded to show the “spectrum” of technical and management options. Red always represents the highest level; violet is the lowest. The total number of projects for each row and column are shown in parentheses along the top row and far left column.

Consider observations from the Matrix about the Management Architectures. There are three major modes of management for the projects that directly involve African entities. The most common mode is that an African country or organization collaborates with an external partner. Columns #4 to #6 show that thirty-nine projects are in this mode. The second most common mode is that an African entity manages the project alone. Column #1 shows thirty-seven such projects. Only six projects

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

Figure 1: Master Architecture Matrix

are in the third mode – collaboration between African partners. These fall in columns #2 and #3. The predominant trend is thus bi-modal. Most African satellite projects are either managed by one African entity or are the result of intervention from partners from outside of Africa. Further scrutiny within the external partnerships in columns #4 to #6 shows that in most collaborative projects, the external partner is bringing satellite expertise. Sometimes the African partner brings it as well, as shown in the 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 column #4 in which the external partner brings some other resources such as funding or coordination. These results show that many of the case study projects could not happen without the help of external partners. Now focus on the Mission Architecture trends in the rows of the matrix. The numerically largest rows are #7 and #8. The thirty-one projects in row #8 involve processing satellite data, and the twenty-two projects in #7 involve operating satellite-enabled ground equipment. These Mission Architectures are relatively low in the spectrum. Despite this concentration near the bottom, there is an optimistic concentration near the top as well. Notice the high numbers in rows #1 and #3. 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 bottom-right quadrant has the most consistently high numbers. This quadrant represents projects enabled by external partners that result in low levels of technical execution. It represents the least accomplishment for Africans in terms of both management and technical effort. By contrasting the top and bottom 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 sources. 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.

Roles and Actors Analysis

The third result is the Roles and Actors analysis. The purpose of the Roles and Actors analysis is to add to the understanding provided by the Master Architecture Matrix by giving more information about the organizations involved. The term "Actor" 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. Note that only relationships observed in the ninety case studies are documented here.

The first graphic shows the various roles seen in the remote sensing Satellite Project Case Studies. The Roles, such as Satellite Builder, are listed on the far left without boxes. Each colored box gives a category of Actors. Below the category, examples of specific organizations from the case studies are listed. These organizations are the Actors. Note that a given Role may include the Roles below it as well. The key insights that can be drawn from these diagrams are the roles played by African organizations and the role of the government and commercial sectors.

Within the Role of Satellite Builders, there are Non-African Space Agencies, Non-African Companies and African Entities. In these ninety case studies, the only two African entities that have truly demonstrated independent expertise in building satellites are the company Sun Space and Information Systems and the Electronic Systems Laboratory (ESL) at Stellenbosch University. Both are in South Africa. Consider now the role of Satellites Owners and Operators. Within Africa, there are two major types of entities that do this - national space agencies and a few national remote sensing agencies. Not many African countries have official national space agencies. This diagram shows most of the strong government organizations in Africa with remote sensing satellite operation expertise. The African countries that are active at this level include Nigeria, Algeria, Egypt, South Africa and a few others. 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. 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 Interview data. Thus, the Satellite Operator and Data Processor Roles are dominated by government. The Coordinating Organizations are in two categories and they can be government, inter-government or

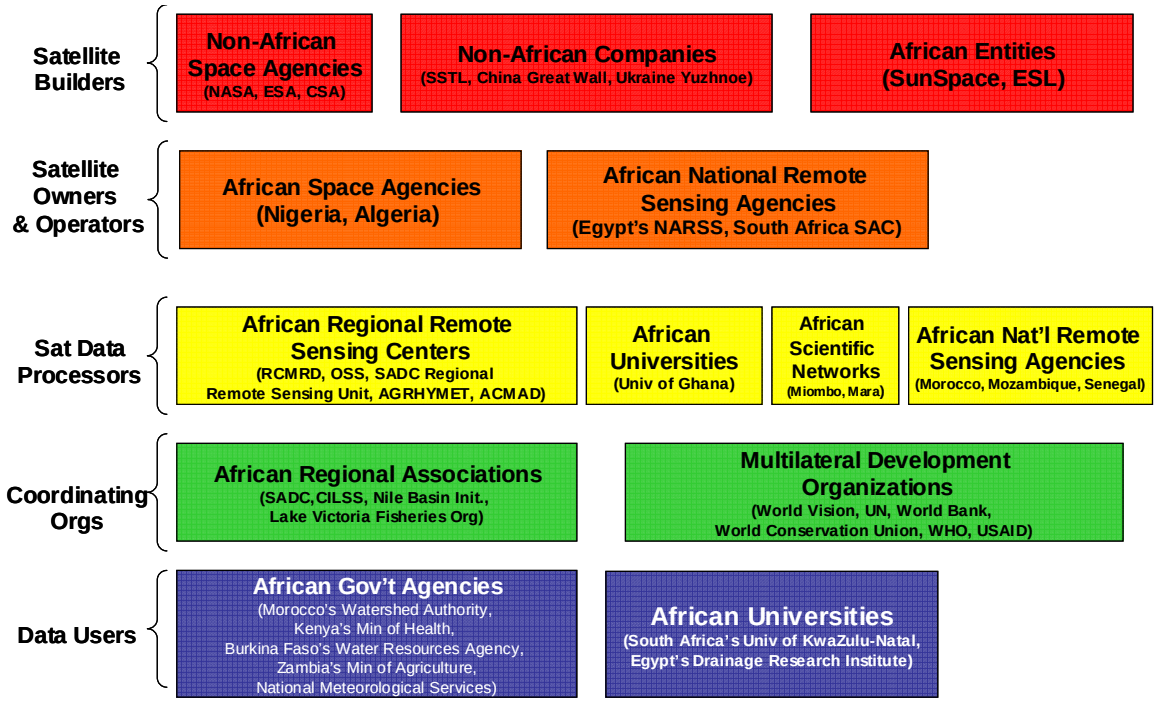

Figure 2: Remote Sensing Roles and Actors Analysis

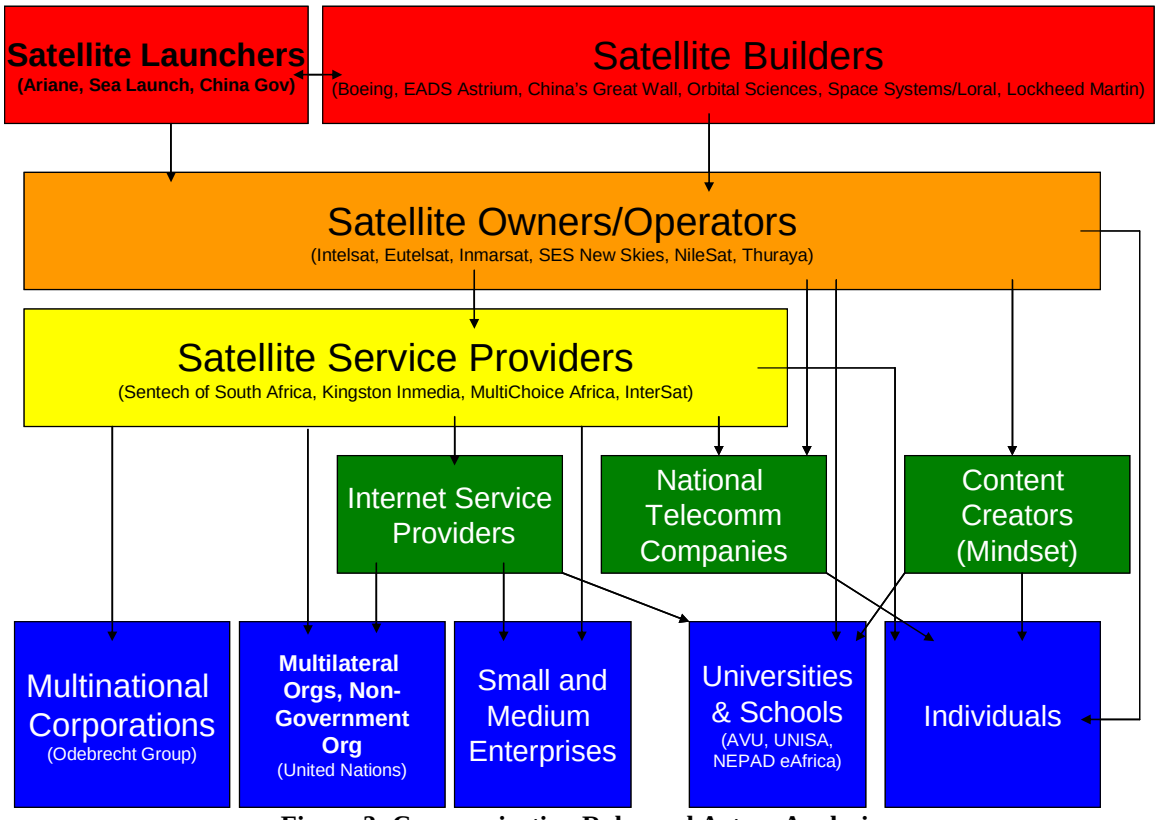

Figure 3: Communication Roles and Actors Analysis

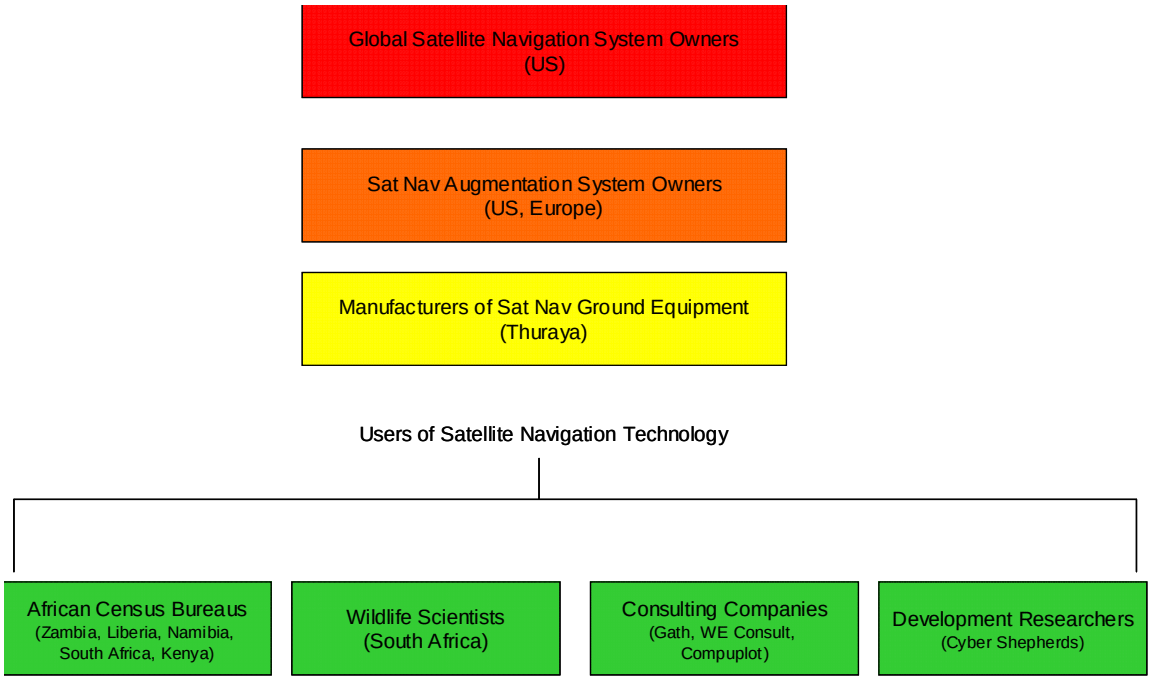

Figure 4: Navigation Roles and Actors Analysis

private, non-profit organizations. In these categories many more examples can be added. 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. Also note 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.

Consider the figure showing the Roles and Actors analysis for the Communication Case Studies. The top level of Roles holds the Satellite Launchers and Builders. None of the Satellite Launchers or Builders in the twenty-seven Communication Case Studies are African; they are European, Chinese and American. Of the seven Satellite Owners listed, only one is African. This is the Egyptian agency NileSat. Africans do not make a strong appearance in the Communication network 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 Multilateral Organizations. 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 Navigation Roles and Actors diagram is simple. There are three levels of non-African roles, and there is one level at which Africans work. The organizations who own the global satellite navigations systems, who own the satellite augmentation systems and who manufacture satellite navigation ground equipment are all non-African.

The bottom row shows African users of the ground segment of satellite navigation systems. Only the African Census Bureaus are government entities; the rest are private.

OBSERVATIONS FROM SATELLITE PROJECT CASE STUDIES

The following section reviews observations that can be gleaned from the Satellite Project Case Studies. Specifically, it will focus on the role of government, trends in collaborative projects, and some of the strengths and weaknesses observed in African satellite activity.

The Role of African Governments

The function of government is different for each of the three satellite areas – remote sensing, communication and navigation. This section discusses some of the trends seen in government activity for each of these areas.

African governments play a pivotal role in the remote sensing case study projects. The Roles and Actors analysis reveals the dominance of government and government-funded actors in the field. Government agencies, inter-government agencies and national universities appear in every Remote Sensing Role, from Satellite Builders to Data Users. This is not true for Communication and Navigation. The Purpose analysis shows that the goals for remote sensing projects in Africa are logical activities for government agencies. Many of the purposes relate to managing the environment for the common good. Some of the purposes given for remote sensing projects are highly scientific. It is understandable that the government would be in the lead in such areas. A few remote sensing applications could also be commercially relevant, especially agriculture and natural resource management. Commercial farmers can use satellite remote sensing data to make better decisions about fertilization and pest control. This can ultimately increase crop yield. Meanwhile, companies engaged in extracting mineral resources can also benefit from satellite remote sensing data. This set of case studies does not reveal any examples of such commercial remote sensing usage. This does not mean that such activities are not occurring in Africa, however. An element of this puzzle that may be important is the extent to which industrial farming, mineral extraction and other industries are done by state owned enterprises in Africa. Some of the comments from embassy interviews suggest that throughout Africa there are countries currently in the process of transitioning form state-centered industry to private industry. Though it is beyond the scope of this study, the authors suggest that the role of satellite remote sensing for commercial use in Africa merits further research. The important role of government in remote sensing is better understood and documented.

The role of government in satellite communication in Africa is not straightforward. The government of each country clearly plays a role in making policy about telecommunication providers. In the embassy interviews, twenty of the thirty officials noted that one government agency that deals with space issues in their country is the ministry for communication that licenses satellite service providers. The Roles and Actors analysis shows that there are many ways through which customers get satellite communication service. There are also many kinds of customers with different needs. Consider the example of Intelsat, an important provider of satellite communication in Africa. The Roles and Actors analysis shows that Intelsat is a Satellite Owner and Operator. The Satellite Project Case Studies show that Intelsat interacts with many kinds of customers and partners. Intelsat has

donated satellite television broadcast services to the non-profit Mindset Network in order to facilitate distance education.[xxv] Intelsat has also leased satellite capacity to Sentech, a state-owned communication company in South Africa.[xxvi] Sentech in turn provides internet, radio, television and phone services. The governments of forty-five African countries are part of the international consortium that oversees Intelsat.[xxvii] Many of those governments are also customers of Intelsat. The example of Intelsat's relationships shows that the role of government in African satellite communication is not static. At times, the government ministry for communication is a service provider, at other times it is a gate-keeper for data or a policy maker. African governments do not have the expertise to build their own communication satellites. Only a few African countries own communication satellites. Nigeria and Egypt are two notable examples. Most African governments involved in satellite communication are dealing with a foreign, commercial entity such as Intelsat, Eutelsat or SES New Skies. The satellite communication market in Africa has developed intricate relationships. Some governments simultaneously act as policy maker and customer or run publicly owned, profit-making enterprises.

The area of navigation shows the weakest role for African governments. The Roles and Actors analysis shows that African governments are not driving the technology via policy, as customers or as technology producers. They are simply users of the technology, just like their private sector counterparts. The Purpose analysis shows two motivations for using satellite navigation that are clearly in the purview of government. These are aviation management and data collection for the national census. In the case studies on census-taking African governments demonstrate a wide range of capability in the use of satellite navigation data. Some are in the process of transition from creating maps by hand to using computer-based systems. Some are integrating satellite imagery and satellite navigation data in Geographic Information Systems. In the area of aviation navigation, there is just one case study. It shows a partnership between the African continental aviation agency (ASECNA) and the European Space Agency to demonstrate the effectiveness of augmented satellite navigation techniques for safe flight in Africa. There is currently very little incentive for African governments to produce their own navigation satellites. Non-trivial effort is required in order for many African governments to use satellite navigation data while taking advantage of the free services provided by other countries. In the short term, it is logical for African governments to focus on growing expertise in using the ground segment of satellite navigation systems. In the long term, other strategies may be required.

Trends in Collaboration

The Master Architecture Matrix shows that collaboration between African entities and non-African partners is a key enabler of satellite activity in Africa. There are several sides to this statement. A few African countries seek additional expertise to meet their satellite technology goals via contracts. The top left quadrant of the Master Matrix shows 16 projects led by one African entity in which a satellite is bought or built. In most of these cases the actual fabrication and design of the satellite is done by a non-African contractor. There are several examples in which this contractor also provides hands-on training and knowledge transfer to African personnel as part of the contract. Nigeria, Algeria and Egypt have benefitted from such technology transfer contracts.

All the countries of Africa, except two small island countries are represented on the Master Matrix because they are affiliated with the projects. The majority of these countries are not involved with projects defined by commercial contracts. They are collaborating with a non-African partner. In many cases this partner is the European Space Agency or an agency of the United States government. Often these European or US agencies are sharing remote sensing data tools that will benefit an African country. As mentioned above, such collaborations tend to lead to low mission architectures. Higher mission architectures correspond to more control over the satellite system. This is understandable in some ways. It is logical that advanced country governments would share primarily the products of their technologies rather than the satellite technology itself. The collaboration trends reveal a high level of dependence on outside satellite expertise. Some collaborative projects include training or technology transfer. In others, the African partners bring expertise about the local conditions or problems but do not participate in the satellite-related work. There are times when this is exactly what is needed to meet a need for information in Africa at a reasonable cost. It may not be a sustainable, long-term solution to Africa's remote sensing needs, however.

A final note about collaboration in African satellite projects is that there are very few examples of collaboration between African countries. This is true despite the great diversity of accomplishment in satellite technology among Africans. There are certainly African countries who can accomplish more together than they could apart. The best example of this is the RASCOM communication satellite project in which about 35 African countries collaborate. The Master Matrix shows six African collaborations. Of the six, two involve launching a satellite and four use satellite ground equipment or data.

African Strengths and Weaknesses

The Satellite Project Case Studies are not a conclusive description of satellite activity in Africa. They do provide evidence, however, of the strengths and weaknesses that African countries exhibit in satellite technology.

Consider the weaknesses first. One weak area is in launch capability. The ninety case studies provide no examples of African countries with launch capability. To authors' knowledge, no African country has indigenous launch capability at this time. The Roles and Actors diagram shows that in the communication area launches are provided by foreign companies and governments. This is an area that is very costly and leaves Africans dependent on outside capability. Another weak area is satellite design and manufacture. Close examination of the African contribution to the Satellite Project Case Studies reveals only two cases in which an African entity independently designs and builds a satellite. The satellites that have been built by Africans, independently or with the support of contractors, have been remote sensing projects. Communication satellites are more complex. Africans do not have expertise in developing communication satellites. While a few Africans own or operate communication and remote sensing satellites, none of them have navigation satellites. Among the three areas of satellite technology, Africa is least involved with navigation spacecraft.

Now consider the strengths of African satellite activity. Africans do frequently harness the benefits of satellite technology, even if they are not controlling the spacecraft. The Roles and Actors analysis shows many well established organizations with remote

sensing expertise. The embassy interviews suggest and the case studies confirm that African governments have some awareness of the benefits of satellite remote sensing. In the area of communication, a complex market structure exists with many African companies benefiting from the sale of satellite service. Finally, though some of the navigation applications may be simple, they are very creative and effective.

SUMMARY AND CONCLUSION

Satellite technology is being used to meet needs in developing countries. This study reviews trends in ninety case studies of satellite-enabled projects. The case studies focus on satellite remote sensing, communication and navigation. The analysis of project motivation or purpose shows that Africa is using satellites for many of the goals recommended in literature. Meanwhile, an architecture analysis shows two common modes for satellite projects. In one mode, individual countries or organizations accomplish projects at many technical levels. In the other mode, African countries collaborate with external partners who bring satellite expertise or resources; these collaborations tend to lead to low levels of technology. There is comparatively little inter-African collaboration.

This study considers ninety examples of projects and programs that use satellite-based technology in Africa. A tacit assumption is that if the project occurred it was effective, however, no rigorous method is used to measure effectiveness. The barriers discussed earlier in this paper suggest that some satellite projects face challenging obstacles to effectively meeting needs. Satellite technology does have potential to meet needs in Africa and other developing regions. There are agencies and governments who are aware of this and willing to invest time and money into implementing projects. While it is encouraging to find so many examples of satellite technology in Africa, more research is needed to understand the impact this technology is having on people's lives.

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