International Collaboration on Satellite-Enabled Projects in Developing Countries

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Abstract. There is great potential for satellite technology to meet needs in developing countries. This study investigates ninety case studies of satellite-enabled activities in Africa. The activities all involve at least one of the following three satellite technologies: communication, remote sensing or navigation. A review of the case studies suggests that the majority of the satellite-enabled activity in Africa is the result of collaboration or contracting between African and external partners. Such collaboration often involves technology transfer to Africa. The case studies are analyzed along several parameters, including technical achievement and the source of funding, expertise or initiative. These parameters show the extent and source of technology transfer within the project. Several projects are highlighted to provide concrete examples. The observations from this study lead to recommendations for the structuring of future technology transfer programs that aim to help developing countries use satellite technology.

Keywords: Satellites, Developing Countries, Remote Sensing, Communication, Navigation.
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INTRODUCTION

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. In order to counter this trend, many developing countries seek opportunities to partner with more technically advanced nations on satellite projects. Thus, technology transfer, international collaboration, and contracting are important components of many satellite-related activities in developing countries. As shown in the background section, the desire of developing countries to benefit from outside technology in this way is identified by economic writers as a beneficial activity. This study considers many examples of satellite projects in Africa and shows various patterns in the way external technology is used. The research is inductive; its goal is to observe and categorize the situations under consideration. The results lead to policy recommendations for developing country decision makers and those who partner with them on satellite technology projects.

BACKGROUND

Technological capability building is a key to national socio-economic development. Robert Solow, Nobel Prize winner in Economics, demonstrated the importance of technical progress as a factor in economic progress (Solow, 1957). Within this paper, technology refers to both the physical objects and the knowledge required to apply scientific principles to valuable activities. Technological capability for a country is defined as the ability to understand what its technical needs are, to operate and maintain its technology, and to encourage constant technical learning (Kumar, Kumar and Persaud, 1999). Although technology does not always have positive impacts, it has become widely understood that mastery of technology is an important step toward economic development. With this

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motivation in mind, this section discusses some of the challenges of pursuing technological capability building as a developing country.

One challenge is choosing the level of technology in which to invest. Grieve (2004) explains that in the 1960s and 1970s, development economists recommended that developing countries pursue "appropriate" technology that was highly labor intensive. In contrast, some current development economics encourages developing countries to do their best to implement the same kind of technology that is used in more advanced 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." This does not imply that there is no place for grass-roots, locally motivated technology. It simply means that developing countries should pursue advanced technology as part of their overall strategy.

When developing countries do not have access to technology locally, they can seek to gain access to it through technology transfer from another country that does have the technology. Such technology transfer can be a potential opportunity for developing new capability, but this is not automatic. Successful technology transfer "ensures that the technology is accepted…by someone who has the knowledge and the resources to apply and/or use the technology" (Williams and Gibson, 1990). According to Cohen (2004), the success of technology transfer depends heavily on the initial technological capability of the recipient country. 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. Technology transfer from developed to developing countries 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. One way that a country can increase its ability to benefit from technology transfer is to strengthen its National System of Innovation (NIS). The NIS is the set of institutions that facilitates technological capability building. Such institutions may include universities, firms, research agencies, administrative agencies, financial agencies and consumers. In a strong NIS, the interactions between the organizations are consistent and productive. Some of the founders of this approach are Freeman (1995), Lundvall (1993) and Nelson (1993).

This paper builds on the foundations from the literature presented above. Technological capability building is a key step toward development. The discussion on technology choice argues it is appropriate for developing countries to pursue competence in advanced technology such as satellites. Further, they can gain this competence partly through technology transfer. The transfer process will be more successful if the country invests in strengthening the NIS. Thus there are two motivations for developing countries to use satellite technology. The first is that the technology is relevant to important needs. The second is that the act of learning to use advanced technology is beneficial to national development and strengthens the National Innovation System. The following sections discuss examples of satellite-enabled activity in Africa. The focus is on cases in which African countries worked with non-African partners or contractors on satellite projects. That is, the study looks for examples in which there were opportunities for technology transfer from outside of Africa to inside of Africa, primarily via purchasing, working with foreign experts and the training of African personnel. The data available for the case studies is not precise enough to discern the success of these technology transfer opportunities. What can be analyzed are the organizational and technical elements of the projects.

INTERNATIONAL IMPACTS ON AFRICAN SATELLITE CASE STUDIES

This study centers on Satellite Project Case Studies – ninety summaries of programs and projects that utilize satellite-based technology in Africa. The case studies are limited to examples from Africa in order to provide scope, but this is appropriate given the diversity among countries in Africa. Each case study involves an operational project using satellite remote sensing, communication or navigation. Data was collected for the Satellite Project Case Studies from many sources, including conference proceedings, news articles, journal articles, and organizational websites. For each case, a maximum of 19 questions was considered about the accomplishments and structure of the project. Fifty three of the projects use remote sensing technology. Common project goals in this area are water resource management, natural resource management, and food security. Internet, distance education, radio and television stand out as common uses of satellites in the twenty-eight communication projects. Fourteen projects involve satellite navigation. This technology is used to collect data for the national census or to support construction work is a dominant example. As mentioned above, satellite technology is relevant to many needs in developing countries. Once the data for the case studies was collected, the information was organized to show patterns. The following sections explain two analyses that reveal different aspects of the satellite projects. The first analysis ranks the projects on Mission and Management Ladders to reveal the impact of external technology. The second analysis summarizes the Ladder results in an Architecture Matrix that allows for rapid, visual comprehension of the impact of international collaboration, contracting and purchasing on African satellite projects.

Ladder Analysis

This section compares the Satellite Project Case Studies based on specific project attributes in the areas of "Mission" (or technology level) and "Management." The Ladders are hierarchies that rank the projects and show how many achieve each level. The Ladders are useful because each shows only one element of the case studies at a time. This allows the reader to glean more specific information about the impact of international technology in African satellite projects. The metaphor of a Ladder is used to evoke the image of an upward climb in technology or management accomplishment. Building on the ideas from the background section about the benefits of pursuing advanced technology, the Ladders and Matrix analysis investigate how external partners and contracts affect the ways Africans are using satellites.

Mission Architecture Ladders

The first two Ladders reveal patterns about the level and types of satellite technology used in Africa. The Project Technology Ladder ranks projects according to the level of the technical accomplishments in the project. Thus, this Ladder shows what is achieved, without regard to whether the effort is from an African entity, a contractor or an external partner. Table 1 shows the number of projects in each level of the Ladder. [Note that 79 out of the 90 case study projects are shown in the Mission Ladders because not every data source includes enough detail for accurate rankings.] The most populous levels of the Ladder are 3 and 4. Most projects operate the ground segment of a satellite system or process satellite data. Levels 7 and 9 also hold a large fraction of the projects. By comparing this Ladder to the Country Technology Ladder, the role of external technology can be observed. The Country Technology Ladder, ranks projects according to the technical achievement of the African organizations. In this section of Table 1, the projects are ranked according to what the African groups were clearly documented to accomplish during the project.

Consider three key issues regarding the Project and Country Technology Ladders. First, note that none of the levels list launching as part of the project activities. This reflects the reality that none of the African satellite case studies show examples of Africans launching satellites with indigenous capability. The launch aspect of the mission is purchased from or donated by an external provider. The second issue to note about the Ladders is the number of projects for levels 2 and 3. The Project Technology Ladder shows that 27 projects that process satellite data to create data projects. The Country Technology Ladder shows the different ways that Africans participate in these projects. In 11 projects, the African team members participate in the data processing effort. Meanwhile in 16 of the projects an outside organization does the data processing. The Africans receive the benefits of the data processing, but participate in other ways. In some projects, like those under the European Space Agency's Global Monitoring for Environment and Security program, African partners provide feedback to European partners who do the data processing. Africans also participate by doing field work to validate the satellite results (European Space Agency, "Global Monitoring for Environment and Security," http://www.esa.int/esaLP/SEM2UV2IU7E_ LPgmes_0.html). Another scenario is found in a project in Morocco for water resource management. Funding and technical expertise are provided by Canada. The African partners receive training through the project, but do not execute it (European Space Agency, "TIGER Projects: Integrated Decision Aid System for Water Resource Management," http://www.space.gc.ca/asc/eng/ satellites/tiger_project.asp#morocco). Consider also a project on malaria risk in Kenya. The external partners provide satellite expertise while the Kenyan partners provide medical expertise (European Space Agency, "TIGER Projects: 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). These African satellite projects show a variety of opportunities for international collaboration at relatively low levels on the Technology Ladder. A third issue is the difference between the two Ladders in levels 8 and 9. The Project Technology Ladder shows that 11 projects involve designing, building and operating a satellite. According to the Country Technology Ladder, however, the African contribution varied. In four of the projects, the African country or organization did the design, fabrication and operation. In the remaining 7 projects, the African country was involved in the design process but only in a learning capacity. These 7 projects are examples in which Africans hired a non-African company to deliver a satellite to them, but they also paid to have the company train local engineers about the satellite development process. These are opportunities for technology transfer at a high level on the Technology Ladder.

TABLE (1). Mission Architecture Ladders

Level	Description	Project Technology Ladder	Country Technology Ladder
		# of Projects	# of Projects
9	Design, Build, Operate Satellite	**11**	**4**
8	Buy and Operate Satellite; Train in Satellite Production	**----**	**7**
7	Buy or Lease and Operate Satellite	9	9
6	Operate Others' Satellites	1	1
5	Lease Satellite Capacity; Deliver Service	5	5
4	Operate Ground Segment; Send or Receive Data	22	22
3	Process Satellite Data; Create Data Products	**27**	**11**
2	Use Satellite Data Products	**----**	**16**
1	Participate in Regulatory Action	4	4

Management Architecture Ladders

The three Management Ladders rank the projects according to specific aspects of project execution. First is the Leadership Ladder, which ranks projects according to the level of initiative, shown by African countries or organizations. The Leadership Ladder is shown in Table 2 with the number of projects in each level. [Note that 78 out of the 90 case study projects are shown in the Management Ladders because not every data source includes enough detail for accurate rankings.] Also in Table 2 is the Finance Ladder, which ranks projects according to the source of financial support. Third is the Expertise Ladder. Here projects are ranked according to the source of satellite-related expertise that enabled them. Comparing the three ladders reveals patterns in the nature of external technical assistance in African satellite projects.

Consider first the Leadership Ladder. The results show a bi-modal behavior, with most projects in the highest and lowest levels. Thirty-four projects involve only one African country or organization; another thirty-four projects happen because of the initiative of a non-African partner. There were comparatively fewer projects that were led by a collaboration of African countries or organizations. The Finance Ladder tends to follow Leadership. Most of the projects are at the extremes, though some of the 34 projects at Level 1 for Leadership move up to Level 2 for Finance. This shows that in some projects led by external organizations, the financial burden is shared by both Africans and the external partners. The Expertise Ladder does not show the same bi-modal pattern as Leadership, but it does show more projects at the lower levels than at the higher levels. Levels 1 and 2 of the Expertise Ladder show that over half of these projects are enabled, at least in part, by outside expertise.

Three important observations can be made by considering the rows of Table 2. First, Level 6 shows that there are more examples of Africans independently paying for and initiating satellite projects than of Africans independently providing the satellite expertise to accomplish projects. Notice how the number of projects declines across the Ladders from Leadership to Expertise at Level 6, where all the effort is coming from one African country or organization. Some projects that are at Level 6 for Leadership and Finance drop to Level 2 or 1 for Expertise. These are cases in which the African country or organization buys the satellite service or product. A second observation is about the dynamics of collaborations between African and external partners on satellite projects, shown in Levels 1 to 3 of the Ladders. Most collaborations are initiated by an external partner but there is African involvement in providing funding and expertise. Third, note that Levels 4 and 5 have very few projects in any column. These levels represent collaborations between African organizations or countries.

TABLE (2). Management Architecture Ladders

Level	Description	Leadership Ladder	Finance Ladder	Expertise Ladder
		# of Projects	# of Projects	# of Projects
6	Single African country or organization	34	32	19
5	Non-regional Group of African countries or organizations	1	1	0
4	Regional group of African countries or organizations	4	3	3
3	External Collaboration, Effort from Africa	2	0	5
2	External Collaboration, Effort from African and external partners	3	14	22
1	External Collaboration, Effort from external partner	34	28	29

Architecture Matrix

The discussion on the Mission and Management Ladders shows how projects compare to each other on specific project attributes. In Figure 1, an integrated Architecture Matrix is used to combine the Mission and Management rankings of the Ladders into one graphic. It shows how many projects are in each combined category of Mission and Management Architecture. Note that 6 projects are excluded for this representation because they do not involve any direct effort by African countries or organizations. Instead these are cases in which external organizations sell satellite-based service in Africa.

The vertical axis of the Matrix shows the Mission Architectures, which parallel the rankings from the Project Technology Ladder. The horizontal axis shows the Management Architectures, which combine aspects of the Leadership, Finance and Expertise Ladders. The Matrix is divided into quadrants based on technical and management levels. The two upper quadrants involve space-based technology, while the lower quadrants use satellite-related technology on earth. The two left quadrants involve independent African activity or African collaborations. The right quadrants are for collaborations between Africans and non-African partners. The quadrant with the most projects represents the lowest level of achievements for Africans. This bottom right quadrant has forty projects. These are examples in which Africans work on low level technology with the help of an external partner. More positive are the 25 projects in the top-left quadrant that show African led activity at high levels of technology.

The Master Architecture Matrix combines the observations from the Ladders about the role of external technology in African satellite projects. There are three major opportunities for technology transfer shown in the Matrix – contracts, purchases and external collaborations. The rows and columns that involve these elements are indicated with bold numbers in large font. Contracting is seen in six that projects in which African countries work along side of contractors to design, build and operate a satellite. In the area of purchasing, nine projects in the second row from the top are examples of Africans buying and operating satellites. All except one of the external collaborations are in the bottom right quadrant. In this data set, the collaborative projects lead to lower levels of technology than the contract or purchasing-based projects. Note also that only a few countries and a few organizations are represented in the top-left high performing quadrant. Many more countries work only in the bottom-right quadrant. They depend on external collaborations to help them use even ground-based satellite technology.

Satellite Project Case Studies	One African Country or Organization **(31)**	**ONE AFRICAN COUNTRY + CONTRACTOR (6)**	African Collaboration (6)	**AFRICAN COLLABORATION + CONTRACTOR (0)**	External Collaboration Sat Expertise from African Partner **(3)**	**EXTERNAL COLLABORATION SAT EXPERTISE FROM BOTH SIDES (15)**	**EXTERNAL COLLABORATION SAT EXPERTISE FROM EXTERNAL PARTNER (23)**
Design, Build, Operate Satellite **(11)**	4	**6**				**1**	
BUY/LEASE AND OPERATE SATELLITE (9)	**7**		**2**				
Operate Others' Satellites **(1)**	1			**Space-Based** Technology Project Enabled by **African Leadership (25)**	**Space-Based** Technology Project Enabled by **External Collaboration (1)**		
Lease Sat Capacity/Deliver Service **(5)**	5						
Operate Ground Segment; send or receive data **(22)**	12		1	**Ground-Based** Technology Project Enabled by **African Leadership (18)**	**Ground-Based** Technology Project Enabled by **External Collaboration (40)**	**1**	**8**
Process Sat Data; use or create data products **(32)**	2		3		3	**9**	**15**
Participate in Regulatory Action **(4)**						**4**	

FIGURE 1. The Architecture Matrix combines the information in the five Ladders. The bold rows and columns show opportunities for technology transfer

SUMMARY OF ANALYSIS

The African Satellite Project Case Studies reveal valuable information about the ways that satellite technology is accessed in developing countries. African entities are applying satellite technology to a variety of applications in remote sensing, communication and navigation. The two Mission Architecture Ladders show specific technology areas in which external technology or expertise is important. First, Africans generally depend on external launch providers. Second, while a few African organizations are growing their own satellite development capability, more rely on contractors. Third, many projects that apply satellite data to African problems do not include Africans working directly with the satellite data. Instead, this is sometimes done by external partners. The Management Architecture Ladders showed results about three modes of project execution. First, there are more examples of Africans independently paying for and initiating satellite projects than of Africans independently providing the satellite expertise to accomplish projects. Second, most external collaborations are initiated by the non-African partner. Third, there are very few examples of collaboration between African countries. The Architecture Matrix shows that most of the projects involve either collaboration between African and non-African partners on ground-based technology projects or leadership by an African entity on a space-based technology project. Most African countries are involved in low technology projects with external partners. Based on this analysis, the following section makes recommendations on how to better use technology transfer to increase technological capability in African countries and allow them to meet important needs.

POLICY RECOMMENDATIONS

The following recommendations are presented to two primary audiences: African policy makers and those concerned with fostering the use of satellite technology in Africa. The ideas respond specifically to data from Africa, but stakeholders of other developing regions may also find useful insights.

Recommendation 1:
Design Collaborations Carefully

Both African policy makers and potential partners should look for opportunities to collaborate on satellite projects. They should design the collaboration in a way that best meets the short and long term needs of the African partner. Specifically, they should keep three goals in mind. First, design the collaboration such that the African partner receives training or technology 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 external partner is gone. Third, design the collaboration such that the work reflects the needs of the African partner, not just the resources of the external partner. Two project case studies, Geo-Aquifer ("Geo-Aquifer: African water project supported by space," http://dup.esrin.esa.it/news/news135.asp) and AFRICOVER ("The Africover Initiative: Overview of the Project," http://www.africover.org/africover_initiative.htm) show examples of projects that meet these goals. AFRICOVER was initiated by an external partner in a beneficial way. The United Nations Food and Agriculture Organization started AFRICOVER, and the United States and Italy financed it. The goal of the project was to create remote sensing data products for land management. The implementation model was wise because it involved local expertise from the beginning. The work was done by Africans with the help of external experts. At the end, the African partners owned the databases created during the project. The Geo-Aquifer project was lead by Algeria, Tunisia and Libya with the goal of using satellite data for natural resource management. It followed a project initially lead and funded by the European Space Agency. The three countries were 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 policy makers consciously pursue these goals as often as possible.

Recommendation 2:
Invest in Local Expertise

This recommendation is directed to African policy makers as well as organizations that invest in African technological capability building. The Finance and Expertise Ladders of Table 2 show that very few collaborative projects build on African expertise. The case studies identify many centers of knowledge in Africa about remote sensing. These include national remote sensing agencies, African space agencies, regional remote sensing enters, scientific networks, and universities. This recommendation suggests that external partners should seek to underpin these organizations with funding. They should not be limited to 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 ("RECTAS in Brief," http://www.rectas.org/RECTAS%20Brief.htm). The center receives funding from the UN Economic Commission for Africa. The African countries that participate in the center also supply funding and handled the operations. The challenges to implementing this recommendation may arise from the unwillingness of a funder to give money to a project they are not executing. Because of this, it may be more palatable to attempt such Architecture between an African partner and an external partner that have worked together in the past with successful results.

Recommendation 3:
Look for Opportunities to Collaborate with Developing Country Partners on Satellites

This recommendation is directed to potential external partners. The Master Architecture Matrix of Figure 1 shows fews projects in which Africans partner with non-Africans on high mission architecture projects. This recommendation encourages Africans and external partners to look for opportunities to collaborate on high technology projects. It could mean that a developing country contributes to a satellite constellation, builds an instrument for another country's satellite, co-sponsors 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 (Stephens, Hodgson and Mackin, 2008). In this project the Surrey Satellite Technology company invited several countries to contribute satellites to a constellation that can be used for natural resource management and disaster monitoring. Each country owns its 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 (National Commission for Space Activities, "International Collaboration," (2007), http://www.conae.gov.ar/eng/coopinstitucional/convinter.html). Brazil has a series of earth observation satellites jointly developed with China ("Focus on Brazil," http://www.iafastro.org/index.php?id=57&no_cache=1&tx_iafmshow_pi1[tt_country]=BR). This recommendation may seem applicable only to African countries that have their own satellites, but it does not have to be limited to this small set. There are a number of ways that an African country can contribute to a satellite project, from funding to personnel to expertise.

Recommendation 4:
Use Technology Transfer to Help Developing Countries Move Up in Mission Architecture Spectrum

This recommendation is for African policy makers and potential external partners. The Introduction and Background sections 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 environment monitoring, in communication and in navigation. Second, when a country learns how to use this advanced technology, they develop skills that can help increase their development level. The recommendation suggests that no country should complacently remain where they are on the Master Architecture Matrix of Figure 1. 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.

CONCLUSION

There are myriad examples of satellite technology being used in developing countries. This study reveals the importance of international collaboration and contracting in making many of these projects happen in Africa. While it is clear there are many opportunities for technology transfer of satellite technology, there is room for improvement. Both African and non-African partners have a role to play in leveraging technology transfer opportunities more effectively to allow African countries to increase their technological capability. The African partner can focus on developing a strong National Innovation System while seeking out partnerships that meet their short and long term needs. The non-African partners can look for opportunities to invest in local expertise and help it to grow.

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