Catalyzing Innovation
ANNUAL WORLD BANK CONFERENCE ON LAND AND POVERTY
WASHINGTON DC, MARCH 25-29, 2019

COST-EFFECTIVENESS ANALYSIS OF A SATELLITE–BASED APPROACH TO MAINTAINING A PROPERTY DATABASE

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Paper prepared for presentation at the
"2019 WORLD BANK CONFERENCE ON LAND AND POVERTY"
The World Bank - Washington DC, March 25-29, 2019

Abstract

Maintaining up-to-date and accurate information about all assets and services owned and operated by organisations is essential for good governance. Often insufficient attention or resources are provided to ensure this occurs and in rapidly changing environments, such as exist in the developing world, where increasing urbanisation is a major factor, information about land and property is all too often inaccurate, considerably out of date and not maintained in any meaningful way. The change detection project in Dakar, which uses the analysis of Very High Resolution satellite imagery to identify urban change, provides a means to help keep the database of land and property up-to-date at reasonable cost. However it is only of benefit if, upon the completion of a Cost-Effectiveness Analysis (CEA), the method adopted is also demonstrably shown to be carried out at a lower cost than the alternative approaches, such as a field-only based approach.

Key Words:

Cost-Effectiveness Analysis, Senegal, Change Detection, Satellite Imagery, Property Database

1. INTRODUCTION

Maintaining up-to-date and accurate information about all assets and services owned and operated by organisations is essential for good governance. Although in many cases accurate inventories of assets are undertaken, possibly as part of a specific project, it is often the case that resources are not made available for ongoing monitoring of change. This can be a problem, particularly in areas of rapid change, when a project is completed and then there may be no resources left available for ongoing monitoring.

In rapidly changing environments, such as exist in the developing world, where increasing urbanisation is a major factor, information about land and property can be inaccurate, considerably out of date and not maintained in any meaningful way. This can create significant problems to local or national governments who need to raise revenues to ensure that resources are available for, amongst other things, improving refuse collection, sanitation, public transport and roads. Trying to raise revenue without access to accurate information is likely to lead to resentment and low rates of recovery, thereby missing potential revenue targets.

> *'With well administered property tax, local authorities can count on a predictable, autonomous, and potentially lucrative source of income.'* (Nara Monkam and Mick Moore; How property tax would benefit Africa, Africa Research Institute, January 2015)

The change detection project in Dakar, which uses the analysis of Very High Resolution satellite imagery to identify urban change, provides a means to help keep the database of land and property up-to-date at reasonable cost. However such an approach is only of benefit if, upon the completion of a thorough Cost-Effectiveness Analysis (CEA), the method is demonstrably shown to be carried out at a lower cost than the various alternative approaches, such as a field-only based methods, that are currently available. The CEA of change analysis based on satellite imagery is the main subject of this paper.

The Dakar urban change project is supported by grant funding within the UK Space Agency's International Partnership Programme (IPP). (www.gov.uk/government/collections/international-partnership-programme) The International Partnership Programme is a five year, £152 million programme run by the UK Space Agency. IPP is part of and is funded from the Department for Business, Energy and Industrial Strategy's (BEIS) Global Challenges Research Fund (GCRF): a £1.5 billion fund announced by the UK Government, which supports cutting-edge research and innovation on global issues affecting developing countries. The International Partnership Programme, which also encompasses forestry, land use, agriculture, marine environments, disaster resilience, health and education, and, renewable energy, is being delivered in alignment with UK aid strategy, forming part of the UK's Official Development Assistance (ODA) commitment, and the United Nations' (UN) Sustainable Development Goals (SDGs). So far 33 IPP projects, involving 33 countries, have been commissioned; many of the individual projects, particularly in the sector of environmental monitoring, do span several countries. The co-funded Dakar project has been undertaken by Airbus Defence and Space (Airbus) in conjunction with its technical partner in Senegal, New Africa Consulting, who provided the staff resources and logistics support in Dakar.

This paper examines the costs of the use of satellite imagery to identify change to land and property on a regular basis (every six to 12 months) and compares it with the costs of identifying the same changes using other methods. All the possible alternative methods require data acquisition for land and property and the analysis involves the comparison and subsequent processing of one period against those of another period. Data acquisition for locating changed properties can be obtained by the remote methods of satellite, unmanned aerial vehicles (UAVs) and fixed wing aerial means, or, by extensive field work on the ground.

2. BACKGROUND TO THE PROJECT

The IPP Change Detection Project was originally conceived in order to address issues relating to property data management and to highlight the importance of keeping a database about land and property fully up-to-date; that is identifying and recording the changes to land and property on a regular annual basis. The major application for change detection concerns the identification of newly developed land and extended buildings so that accurate valuations of such developments can be undertaken; all with the aim of ensuring that the right amount of property-based tax revenue will be calculated and, eventually, collected. Although the selected area for testing is Dakar City in Senegal, it was always envisaged that the technology would have wide application in many large cities in several developing countries, thereby meeting one of the main objectives of the UK Space Agency's overall partnership programme.

This change detection project has been developed based upon prior information and the recent experience of Airbus in Senegal and other countries concerning land and property and the wider aspects of land administration. Particularly important in this is the management of information about land and the use of high resolution satellite imagery to monitor changes to the status of land and property which the City of Dakar has, to date, been unable to resource and carry out efficiently. This has had a detrimental effect upon the calculation of property valuation and the collection of revenue, which ultimately means that resources for development of the city are limited.

The project is based upon the principle that “the economic development of the country can be improved by improving domestic capacity for tax and other revenue collection” (Sustainable Development Goal (SDG) 17.1). Specifically the internal goal of the project is therefore to use space technology to address the challenge of ensuring accurate, up-to-date and sustainable information on land and property can be maintained by the local partners and the Dakar City Authorities, and, that the goal is to generate increased tax revenues which can then be used to enhance and improve city-wide services with overall benefits to the wider stakeholder community and citizens. This is particularly important due to a rapidly changing land and property environment in Dakar with significant increases in new land parcels and buildings being developed.

The method developed during this IPP project is based on the regular use of satellite imagery to detect change. This satellite image analysis with directed and targeted field data collection represents an efficient method for monitoring large areas of land and buildings in urban areas. The main characteristics of the satellite imagery are that complete city-wide coverage can be obtained on a single date (or perhaps two dates if cloud-free coverage in wetter seasons is to be provided) and the imagery can be quickly processed to an ortho-correct coverage based on a small number of ground control points. Use of stereo imagery also enables building height information to be collected and fed into the property database. The vertical resolution of the height information is around one metre which is ideally suited to detecting building change of one or more storeys.

Therefore the particular advantage of the use of satellite imagery is to obtain data quickly and efficiently, to obtain and use it on a regular basis (without the organisation of specific data capture campaigns) and to establish a base or benchmark for future comparison. It also provides a chain of independent evidence which can be used in disputes and the avoidance of potential errors and omissions inherent in most field data capture activities. This transparency should also be attractive to citizens thereby, hopefully, increasing the rate of tax recovery.

The analysis of satellite imagery for this purpose includes the following stages:

- Acquisition of tri-stereo very high resolution (50cm) Pleiades imagery covering the target area, once or twice per year, in optimum cloud-free periods. Tri-stereo imagery provides the opportunity to extract accurate height information from the satellite imagery;
- Ortho-correction of the imagery to fit Ground Control Points (a minimum of five points) accurately surveyed on the ground;
- Calculation of a Digital Terrain Model (DTM) and a Digital Surface Model (DSM) for the city area. The differences between DTM and DSM identify building heights within the area of interest;
- Comparison of land parcels in two Pleiades images (acquired at least six months apart) that have been processed to DTM/DSM in order to identify buildings that have increased (or decreased) in height or plan area. This calculation process also includes local corrections for such things as building shadow and parallax (for high buildings), in order to improve the accuracy of building change detection. The final dataset is a classification of land parcels into 'no change' and 'change' with the change sub-divided into building height and/or building footprint increases and decreases. These changed parcels are then the targets for detailed collection of data in the field.

Stages 1 to 3 are routinely undertaken before delivery of data to a user. Stage 4 is the process specifically developed within this IPP project. At the outset it was envisaged that the Stage 4 calculations would be implemented locally in the target countries. However, the process is computationally quite heavy and as Stage 4 does not actually require any locally supplied information in order to run, it is now felt that the change analysis can be most efficiently provided as another data layer; therefore as a service.

So although the means of running the change analysis has been provided to the Dakar team, going forward, for the purposes of calculating costs for the Cost-Effectiveness Analysis, the 'satellite image change service' involves providing the ortho-imagery, DTM, DSM and Change Layer to the implementing agency so that they can fully focus on planning and execution, in the most efficient way, of the field updates to those properties identified as changed.

In the future, and once the principal stakeholders have established a data centre for a city-wide property database, the Change Layer could, if required, be calculated locally. However, there is no operational necessity to do this locally. In the same way that it is now unusual for an end user to undertake their own ortho-correction, as it is routinely provided as part of the image acquisition service, the change layer could also be provided as part of the image acquisition service. The end-users will have, of course, all the data layers to load into their geospatial software/database for any further analyses that they may wish to undertake.

In the following section we outline the key results obtained from the satellite data analysis for Dakar.

3. PROJECT RESULTS AND IMPACTS

The principal technical achievements in the Dakar Change Project can be summarised as follows:

- Tri-Stereo Pléiades Very High Resolution satellite Imagery in Elevation1 (one-metre vertical resolution) product format is sufficient to differentiate with high reliability building height increases/decreases of one or more storeys as well as increases/decreases in building footprints;
- GIS Data collection software tools for parcel mapping (Figure 1) have been developed so that land parcels can be accurately mapped from the ortho-rectified satellite images. These tools have been developed using Open Source GIS libraries and have been provided to the data capture team in Dakar. Training of personnel has been completed and comprehensive user manuals have been provided as part of the 'leave behind' at the end of the project. Leave behind is defined as the tools, expertise and knowledge provided to the local partners to enable the urban monitoring process to continue after completion of the initial IPP project, thereby forming the basis for long-term sustainability of data maintenance;
- Fieldwork updates and verification for property attributes have been undertaken with the assistance of mobile tablets with drop-down menus for key building variables (such as age, type of construction and condition). The information is collected in a central database. Such property information can be input to a revenue generation model. Training and comprehensive manuals for field data collection have been provided to local personnel;
- A methodology for urban change detection has been developed using software that compares the height information contained in pairs of satellite images (acquired at least six months apart) to detect changes in building height and footprint (Figure 2). The land parcels are then classified as 'not changed' or 'changed' (Figure 3). The changed parcels are labelled according to the type of change (as listed below). These analyses have been tested to ensure that performance targets are met; in general errors of omission (missed changed) are well below the target of 5% and errors of

commission (false positives) are slightly above this target. This means that very little real change is being missed, but the fieldwork on the ground will be visiting some parcels where there is no actual change; false positives mean that the subsequent planned fieldwork is slightly less efficient because more parcels are visited on the ground;

- From the height and area change detected parcels the detailed field work, collecting property attributes, can be planned. In Dakar, for well-established urban areas around 3% to 5% of parcels exhibit change in a 12-month period (Figure 4); rates in development areas are much higher at 15% to 20% (Figure 5).

The specific categories of identified change can be summarised as follows:

1. **Bare ground to building**, i.e. new buildings;
2. **Building decrease in height**, for example if a building is replaced and re-built;
3. **Building increase in height**, a very common occurrence in Dakar where new storeys are added to existing buildings;
4. **Building increase in plan area**, where the building footprint is increased;
5. **Building to bare ground**, where demolition has occurred prior to possible re-build;
6. **No change, building exists,** this is the normal 'no change' scenario;
7. **No change, No building**, these are urban open spaces.

However the technical results from this project are only part of the achievement. As indicated in the introduction above, these IPP projects are part of the UK's Official Development Assistance (ODA) commitment. As a consequence all the projects are assessed in relation to their overall development impact, and not just on the technical successes achieved, and so each of the IPP projects has made use of the Logical Framework (LogFrame) approach to project design. The LogFrame is a method used in designing, monitoring and evaluating international development projects and has been used to define the impacts, outcomes and outputs of each IPP project. The Dakar Change Project was planned in detail using the LogFrame approach to identify and subsequently monitor the development impacts.

It is therefore emphasised that although the project has a technical base, it has been set up and delivered to ensure that the principal evaluation criteria of the Organisation for Economic Co-operation and Development, Development Assistance Committee (OECD/DAC) have been met. That is, the process of project Monitoring and Evaluation (M&E) has been a central part of the work undertaken. This has involved an assessment "to determine the relevance and fulfilment of objectives, developmental efficiency, effectiveness, impact and sustainability" of the project because the OECD/DAC members view these five criteria as essential in guiding development aid: effectiveness, relevance, efficiency, impacts and sustainability. http://www.oecd.org/dac/evaluation/50584880.pdf.

At the end of the Dakar Change Project, an M&E Report has been produced that reviews the work carried out on the project, based upon the DAC five criteria. The overall results of the project set against these development criteria can be summarised as follows.

Effectiveness

The project has identified how a satellite change detection system would operate, and, land parcel plans, change maps and change statistics have been produced with the full support of the local Senegalese partner. In addition, property valuations were developed and discussed with the *Direction Générale des Impôts et des Domaines* (DGID), the principal stakeholder. However some political hurdles were identified with regard to the short-term adoption of the technology and its potential use in identifying properties for raising tax revenues to be used, for example, to provide services to citizens. This is because there is not currently an operational system in place for creating a city-wide property database; in such circumstances it is, of course, difficult to introduce a property monitoring service right now. However, the issue of property-based taxation in Dakar, and throughout Senegal, is high on the current political agenda and it is highly likely that an operational property revenue system will be fully in place in the near future and then data maintenance will be an essential component of this.

Relevance

DGID's property-based revenue remit can only be achieved by the management of its database of land and property. The change detection project is a means of identifying change to that database and keeping it up-to-date. Flowing from this is also the ability to use such an accurate database for a range of other services such as raising revenues, reviewing building developments and ownerships, and, a range of diverse applications using the satellite imagery, such as land use planning, infrastructure projects, mapping and providing some of the base data required for local authority services. Evidence from a literature search on this topic, across many African countries, indicates that the use of such technology for urban monitoring is currently relevant to many other major cities.

Efficiency

The satellite change detection method was developed using software tried and tested after “field trials” involving the analysis of three separate timed imagery sets taken over the two-year project period. This has resulted in maps, plans and statistics created within the six to 12 months of project commencement and further change in the second year of the project; a strategy for annual update is therefore fully feasible. The Cost-Effectiveness Analysis, as described in the next section, has identified how many staff would be required to carry out the annual data maintenance work compared with, for example, alternative field-only methods. It should be noted that the project was essentially about developing a system for the maintenance of a land and property database which is not, however, currently being maintained operationally.

Impacts

The project has provided evidence that an accurately maintained database, based upon change detection, can potentially be used to generate additional revenues which could be used to provide better services to citizens. The requirements for such services, including capital investment and operational maintenance have, for example, been identified in a detailed Dakar Resilience Strategy publication (https://www.100resilientcities.org/strategies/dakar/). Operational data maintenance is not currently carried out by DGID and so additional staff would be required to carry out this activity; these staff increase would be financed by the increased revenue generated. Research and contacts made in Dakar and elsewhere indicate that the change detection methodology would have significant application for other organisations in Senegal and elsewhere globally.

Sustainability

Sustainability has been addressed through knowledge sharing and the training of the local partner’s staff to enable them to undertake most of the future monitoring work in Dakar. The importance of urban monitoring methods have been acknowledged by DGID and accepted by other key stakeholders in Dakar. A roadmap for the roll-out of the technology developed in the Dakar Change Monitoring project has been prepared.

In summary, the satellite-based solution involved software development and the training of local staff to create land parcels over a wide area of Dakar (covering around 60% of Dakar City) together with fieldwork in selected sites to refine the software to detect automatically diverse types of change in both two and three dimensions. The digital solution enabled the creation of approximately 90,000 land parcels and clearly identified the changed features of the urban landscape. These changes to land and property for the areas of Dakar examined varied from 17% over six months for the rapidly developing areas on newly available land near the old Dakar Airport to a 3% change for more established areas.

However, the main focus of this paper is to show how the satellite-based approach compares with alternative methods of database maintenance. This has been achieved by implementing Cost-Effectiveness Analysis (CEA) to demonstrate how using the satellite method compares with a field-based alternative of employing staff to constantly "sweep" the whole of Dakar looking for change.

4. COST-EFECTIVENESS ANALYSIS: BACKGROUND AND METHOD

In accordance with the guidelines for IPP projects, Cost–Effectiveness Analysis (CEA) is the selected means of assessing the impacts of the delivered space-related services. CEA is a type of 'Value-for-Money analysis that compares the costs of alternatives that achieve different amounts of the same impact.' (Her Majesty's Treasury: The Green Book, Appraisal and Evaluation in Central Government.) The particular advantage of CEA compared with, for example, Cost-Benefit Analysis is that CEA provides a means of comparison without the need to put a monetary value to impacts that are difficult to quantify and is, therefore, significantly less time-consuming for comparing alternative development strategies.

The importance of the Cost-Effectiveness Analysis is to examine the principal options for achieving the primary objective of identifying, on a regular basis, change that takes place to development in terms of the area and height of urban property. All this is in order to maintain a database of land and property to create an effective, up-to-date and accurate database of all land and property; important because of the rapid changes taking place in Dakar. Such changes to property are common in developing countries and cities due to rapid urbanisation. What is also common is the lack of existing information and the lack of an administrative structure that can monitor and assess such changes. If the information is not available it can lead to, amongst other things, a lower revenue base, unplanned development, transport problems, and, an overall lack of accurate information about where people live and what local authority services are required to be provided for the benefit of citizens.

The CEA examines the cost of change detection and, in the first instance, the importance of raw data acquisition. The basic data on land and property (and in this case this primarily means data on buildings which have then to be processed and managed) can be obtained either by satellite, by UAVs, by aerial photography or by field methods. These alternative solutions to raw data collection are examined in the CEA and conclusions are presented, as a basis for developing a future operational change monitoring methodology.

The approach takes account of the fact that it is possible to detect change from satellite imagery using automated image processing, thus targeting subsequent detailed field work at properties that have changed, whereas field work on its own has no such facility and therefore extensive effort is required each time to "sweep" the entire area to gather the relevant change information for further analysis. We have also looked at the potential use of the UAVs and aerial imagery for initial data acquisition but suggest that whilst there could be some reduction in field work required to validate and confirm any automatic change detection (because of greater image resolution and, therefore, clarity) the significant additional costs involved for data acquisition on a regular basis puts these methods at a considerable cost disadvantage over the satellite imagery based method. The CEA provides a means of evaluating this cost disadvantage.

4.1. CEA INPUTS

Time Horizon

The Dakar Change project was launched in January 2017 and completed in December 2018. For the CEA a further five-year period of consolidation and operation, until December 2023, is modelled. This latter period (2019 – 2023) represents the proposed ongoing service operational phase of the project, i.e. after the development period during 2017-2018, and when a full assessment of the effectiveness of operation can be made. The cost-effectiveness of the project will therefore be established over a seven-year period from the commencement of the project's development phase in January 2017. All relevant costs and benefits that accrue over this period are considered within this CEA. The analysis also incorporates a potential expansion strategy for other African cities in the period 2022 to 2023. These candidate cities have been selected on the basis of literature search to identify their likely interest in property-based revenue generation.

Project Solution and Alternatives

The project solution is specifically the method developed during this Dakar project based on the use of satellite imagery to detect change. This satellite image analysis with directed and targeted field data collection represents an efficient method for monitoring large areas of land and buildings in urban areas. The particular advantage of the use of satellite imagery is to obtain data quickly and efficiently, to obtain and use it on a regular basis (without the organisation of specific data capture campaigns) and to establish a base or benchmark for future comparison. It also provides a chain of independent evidence which can be used in disputes and the avoidance of potential errors and omissions inherent in most field data capture activities. The transparency of the method should also be particularly attractive to citizens, leading to an anticipated improvement in the rate of tax recovery as a consequence.

The costs included in the CEA for the project solution include the costs for developing and testing the methodology included in the IPP project and, for the operational service, the ongoing annual costs of image acquisition, data processing and field data collection for the 'changed' properties. The development costs also include the development of the software tools for image analysis, parcel mapping and mobile field data capture. The software developed in the project could also be used to assess height differences in imagery derived from either aerial mans or UAVs.

As all costs for five years of potential operations are included, the impacts of inflation are discounted and all costs are compared at 2017 prices. This is the case for all costs for all analysed solutions.

The first alternative solution is to employ field teams on a rolling basis to cover all of Dakar and identify visually any changes to land and buildings in terms of both area and heights of development. This requires the use of field staff to monitor developments without any prior knowledge or information of the changes that are taking place and therefore a continual "sweep" of the Dakar area would be required by field teams employed for the purpose. In preparing the costs for this alternative it is assumed that the field teams have to traverse all streets on an annual basis in order to identify those that have changed. Once the 'changed buildings' have been located, however, it is assumed that the costs for recording the details of change are the same, whatever solution is selected. As this solution for data maintenance is not currently undertaken, we have estimated the costs based upon our knowledge of local conditions, including labour rates, with the assistance of the local partner.

The second alternative is the use of UAVs to acquire the city-wide imagery as an alternative to the collection of imagery from satellites. All other tasks and processes after image acquisition by UAVs are essentially the same as those for the use of satellites, but there are some differences in the acquisition and processing of data from UAVs. These additional costs which are built into the CEA modelling are:

- Significant additional image acquisition time and costs would be incurred because of both technical issues (such as flying UAVs in urban areas with high rise buildings) and increased logistical and management effort;
- Significant additional processing costs are required to "stitch" all these images together to create a seamless ortho-correct image mosaic of Dakar;
- Some of this additional time and cost would be offset by the greater resolution of the imagery (around 5 – 10 cm as against the satellite imagery of 50cm) allowing clearer and easier measurement of buildings and, therefore, some potential for reduced fieldwork. However a field visit will still be necessary in order to obtain all the required information and so the overall reduction in field data collection costs is deemed to be marginal.

Whilst the use of UAVs for initial data capture to high spatial precision in low-rise areas is an accepted methodology, routine use for annual updates over extensive areas does present logistical problems and, potentially a lot of work for little obvious benefit to property data quality. It is suggested, therefore, that the implementation of UAV technology is focused on its use, in suitable areas, for baseline data capture and for updates in new development areas and to support the use of satellite for monitoring change in extensive built-up areas.

Aerial imagery from fixed wing aircraft, the third alternative solution, has the same disadvantages and advantages as for UAVs; i.e. greater time and costs for acquisition with the additional problem of greater susceptibility to weather conditions but with resolutions typically in the range 15 to 25 cm providing better clarity than satellite imagery (but not as good as UAVs) and, therefore, some potential for reduced fieldwork. However, as with UAVs, these savings may not be sufficient to offset the additional costs of imagery acquisition and processing. This is tested through the CEA.

Costs

The costs for development the satellite method include the real costs of acquisition and processing of the satellite imagery and development and testing of the methodology. Specifically they include project management, system design, software development and testing, training and field data collection. Each of these includes labour, capital costs (equipment and imagery), and logistics (office space, utilities, travel and subsistence for field data collection).

The estimated costs for the proposed Service Operations include project management, planning, office operations, imagery acquisition and processing, field operations (including supervision) and IT support. The major activities are:

- Planning – costs are for the planning required to carry out the service operation. This is for the assessment of the results derived from the baseline image analysis (from satellite, UAV or aerial imagery) and the detailed planning of the supporting field data collection. The aim of planning is to ensure the most efficient data collection campaign for amended property values where properties are identified as 'changed' on the baseline imagery;
- Office Operations – the main part of this task is to prepare all the databases ready for the extraction of data and loading on to tablets and then updating after completion of field work;
- Field Operations – collection of property information in accordance with the requirements of the planning team and the data collection instructions issued;
- Imagery Analysis – this includes the 'service' provided to generate processed imagery and a change detection layer.

The Cost-Effectiveness Analysis also takes into account a forecast for the potential extension of the process to other candidate cities. For these analyses the cities of Accra, Nairobi and Abidjan have been selected; it is known that each of these cities does have a current interest in property-based revenues. For the purposes of this illustration it is assumed that these cities could come on-line as listed below, although at this time there are, of course, no contracts in place for such city by city implementation.

- Accra starting 2022 and annually after that;
- Nairobi starting 2022 and annually after that;
- Abidjan starting 2023.

In calculating the likely costs for implementing change detection in these other cities, we have based these on the unit costs, such as labour and transport, currently applicable in Dakar. To calculate precise costs, and revenues, for each of the other cities would require significant effort, including site visits and detailed analysis. This is not possible under this IPP project. Therefore these values have been calculated on a straight ratio basis to the population of Dakar. This ratio has been applied as a multiplier to both the costs and the potential revenues.

The primary statistic used to determine the size of the task in each additional city is total population. This information has been collected from the CIA World Fact Book, as well as United Nations and World Bank publications. Under this working method, the population of Accra, for example, is 1.8 times the population of Dakar, so the task of field data capture is therefore assumed to be 1.8 times that of Dakar. The same statistic is also used for Nairobi (3.3 times Dakar) and Abidjan (3.7 times Dakar).

For the satellite image analysis the cost of the imagery and the processing time is based on area, so the area of each metropolitan city has been used to calculate the image analysis costs involved. Similarly the potential costs of imagery via UAV or aerial means are based on the metropolitan area.

4.2 CEA ANALYSIS

In the LogFrame, the IPP Dakar Change Project identifies four impacts. The primary impact is identified as: 1) evidence that property tax collection can be improved. The impact indicator, therefore, is a potential increase in the total revenue due. For the purposes of the Dakar Change IPP Project, this is quantified in the CEA as additional revenue that can accrue from having a database accurately maintained on an annual basis.

There are other IPP Dakar Change Project impacts but they are not included in the CEA analysis because there is currently no available data to suggest that the value of these impacts varies in accordance with the method of baseline data capture. The key point is that these impacts are most likely to be realised if there is a cost-effective data capture and data maintenance process in place. These specific impacts are: 2) Identification of how improved revenue collection could be used for enhanced services; and, 3) Increases in job opportunities and roles created in local government.

The final identified impact is: 4) Generation of interest from additional cities in using the methodology. This impact is included in the CEA; additional target cities are modelled as coming on-stream during the forecast period 2022-3, as described in the previous section.

Whilst each of these impacts is demonstrated by the IPP project results, the specific financial impacts of change monitoring can more specifically be described as:

1) The revenue due from each household is re-calculated if there is a significant change to a property (e.g. additional storeys on top of existing buildings, expansion of building footprint, demolition and redevelopment, and, new urban expansion in development areas). The benefit of this for the city is that all increases in the quantity and quality of properties are captured and this leads to **an increased total revenue due;**
2) The process, if suitably publicised, provides confirmation to citizens that there is a method for ensuring that the revenue due for each household is calculated accurately and without bias so that all citizens are treated fairly. The benefit of this for the city is an **improved likelihood that people will pay**.

The important question therefore is; how do we assess the value of these impacts for Cost-Effectiveness Analysis?

The Dakar Change Project has clearly identified that approximately 3 to 5 per cent of parcels (in various test areas) exhibit some change over a 9-month period. Not all properties within a parcel will necessarily change (adding a storey might create one change and therefore an additional property, but there may already be several others in that parcel which may have an apartment block in it). However, urban population growth in Dakar (currently 3.6% per annum) also gives an indication of the number of new properties required and therefore probably being built or modified.

For the purposes of comparison, therefore, we have assumed that the impact of ‘change monitoring’ is to increase total annual property revenues by 3% per annum based on the addition of new properties to the database. Each of the additional ‘target cities’ is growing at a similar rate so this figure of 3% growth is used for all of them.

So for Dakar, where the baseline property tax, based on total property values is estimated at around 80M€ per year, the potential maximum annual increase attributable to change monitoring is therefore estimated at 2.4M€ (i.e. 3% of 80M€). This is 'potential' because at the current time there is not yet a complete revenue system (value calculation and revenue collection system) in place; although the IPP project does demonstrate that such a system could be implemented as soon as the baseline data capture for all properties has been completed.

However based on our research of the current literature it seems most unlikely that 100% payment of the revenues due will be achieved in Dakar or any of the other target cities. For example, in a Lincoln Institute publication, "Property Tax in Africa - Status, Challenges and Prospects," by Rie Franzsen and William McCluskey, 2017, suggested that only 15 - 20% of property tax is collected in Niger, although for some municipalities in Zambia and Namibia the equivalent collection rates are well over 70%. (https://www.lincolninst.edu/publications/books/property-tax-africa)

A more realistic 'baseline' therefore is that an initial revenue total of 60% of the perceived potential will be achieved. This figure has recently been achieved in Freetown, Sierra Leone. This baseline figure has been used in the tables for Dakar and all additional cities. From there an increase of 3% per annum for both the satellite-based method and the field-only method has been used in the calculations; it is assumed that the field-only method will also find all changes, but with reduced efficiency.

It is more difficult to quantify 'improved likelihood' of payment on its own, particularly as there is currently no baseline. However, if the baseline is set at 60% payment, a realistic target could be 80% payment after 10 years; i.e. 80% of those required to pay property taxes actually do so. This would confirm an increased confidence in the system amounting to 2% increase in proportion paying year on year. As a result of the independent nature of the satellite-based method, this is regarded as an indicator of the impact of that method over the alternatives.

Based on foregoing remarks, the total impact of the satellite-based method is calculated as 5% (3% plus 2%) of 60% of the maximum potential revenue for Dakar. The total impact of the field-only method is based on 3% of 60% of the maximum potential revenue for Dakar. The costs and impacts for the other target cities are based on Dakar but escalated according to the higher populations of these individual cities.

In these calculations the 'change' in the property database is assumed to be a physical change, i.e. either new construction or demolition. It is recognised that there could also be significant change in the database based on changes of ownership or occupation, and maintaining this is also a major activity. However it is assumed that this information would be maintained by other means, such as through transaction records for property sales or rentals. Unless planning controls are very tightly monitored, the only way to monitor physical changes to property is through observing the change on imagery or through viewing on the ground.

5. CEA RESULTS

The detailed CEA calculations for Dakar have been used to calculate, based on the potential for increased property-based revenue generation due to annual maintenance of property database, a Cost-Effectiveness Ratio (Figure 6) for the satellite supported method to compare with the field-only method CE Ratio. The CE ratio for the use of aerial imaging rather than satellite imagery has also been calculated. The CE Ratio for image acquisition by UAVs has not been calculated because of the potential difficulties of flying these in areas of high-rise buildings which are common in most capital cities. Although it is acknowledged that in the right environment, particularly smaller urban areas without high rise buildings the UAVs could provide appropriate baseline data.

The method also enables similar CE ratios to be calculated for other potential candidate cities in Africa where a data maintenance service could potentially be provided in the future.

Based on the results calculated in the CEA it can be confirmed that the satellite-based method of property data maintenance with targeted field work is a cost–effective solution. Analysis of the CE Ratios highlights some specific observations about the cost-effectiveness of data maintenance by the alternatives**:**

- Based on the costs and impacts listed, the satellite supported method has a CE Ratio of 0.317 for Dakar and the field-only method a CE Ratio of 0.647;
- On this basis, each £500K spent on the satellite-supported analysis would generate £1.6M of additional revenue, whereas the equivalent spend on a field-only method would generate only £770K of additional revenue;

- The aerial method comes somewhere between the other two: CE Ratio of 0.402. This reflects that the aerial method has the same impact benefit as the satellite-based method, but the annual costs of data acquisition are significantly higher;
- These analyses are based on the potential increase in revenue that can be achieved by having an operational data maintenance system on top of a city-wide property-based revenue system for Dakar and the forecast additional cities.
- A key driver of this improvement is the enhanced perception of the independence and fairness of the satellite–based methodology which in turn generates increased confidence amongst citizens and the increased likelihood that revenue bill payments will be improved overall.

This CEA method can therefore be used to demonstrate that the impact of using satellite imagery for change detection, together with targeted field data collection, is an efficient and cost-effective method for routinely identifying property change and maintaining an up-to-date property database for the calculation of revenues for individual properties in the city of Dakar.

The IPP project, with its ultimate focus on providing trained staff and an implemented methodology to ensure the maintenance of a land and property database, will complement the current national strategies in the sector; both to provide national cadastral information and an associated information management system. These recently launched national strategies acknowledge the need to develop a fully digital national database of land and property; a cornerstone being the ability to ensure that the database can be maintained cost-effectively.

This Cost-Effectiveness Analysis provides the detail in a robust and comprehensive manner of why a solution based on satellite imagery analysis provides an efficient method of addressing the problem compared to other methods. In this way the analysis and the conclusions can be communicated and demonstrated as an effective and efficient solution to many of the data problems that beset organisations in Senegal, and worldwide, who are concerned about keeping data up to date; that is the problem of how to maintain essential databases about land and property which can have such a critical impact upon the provision of services to benefit citizens. It is particularly important for the audience in the developing world, including government agencies, the private sector, research institutes, donors and NGOs, who represent the primary audience for project-level CEAs.

6. CONCLUSIONS AND FUTURE

The project was completed in late 2018. It involved the development and testing of software designed to analyse building height and footprint information from satellite imagery, to identify physical change in urban properties as a means of helping the process of maintaining an up-to-date property database for Dakar. The use of imagery to detect change identifies those properties where detailed field data collection is needed to update the individual property records and maintain a property database.

The process was verified by comparing the satellite results with ground survey data to ensure that no building change was being systematically missed and that the 'false positives' of change did not add significantly to the process of detailed field data collection. The process was tested for two periods of change in 2017 and 2018 and it was found that the observed errors are within acceptable limits; an error rate of below 5% was stipulated at the beginning of the project.

In parallel with the technical work there was also a continuing monitoring and evaluation activity designed to determine the impacts of the methodology on the availability of property-related information for Dakar. This is complementary to the sustainability of the IPP-related activities to be achieved by the transfer of technical skills, the use of the software tools developed, the concepts of database maintenance and a recognition of the value of a rigorous, accurate and complete database which can be used as the basis for government self-funding revenue generation and the provision of other services.

The detailed Cost-Effectiveness Analysis for Dakar has been used to calculate, based on the potential for increased revenue due to annual maintenance of property database, a Cost-Effectiveness Ratio for the satellite supported method to compare with the field-only method CE Ratio. The CE ratio for the use of aerial imaging rather than satellite imagery has also been calculated. The method also enables similar ratios to be calculated for other potential candidate cities in Africa where a data maintenance service could potentially be provided in the future.

This CEA method has demonstrated that the impact of using satellite imagery for change detection, together with targeted field data collection, can be an efficient and cost-effective method for routinely identifying property change and maintaining an up-to-date property database for the calculation of revenues for individual properties in the city of Dakar. The satellite method is also identified as fair and unbiased approach that is equally applicable to all citizens, thereby contributing to ensuring that the city can benefit from increased revenues for assisting in maintenance of the urban infrastructure.

The IPP project for Dakar, with its ultimate focus on providing trained staff and an implemented methodology to ensure the maintenance of a land and property database, will complement national strategies in the sector; both to provide national cadastral information and an associated information management system. Such national strategies are under consideration in several countries which acknowledge the need to develop a fully digital national database of land and property; a cornerstone being the ability to ensure that the database can be maintained cost-effectively.

A further outcome is a methodology that can be rolled out to similar cities, across Africa and the wider developing world, where city infrastructures and services, always under pressure, can be improved and enhanced by raising local revenues based upon a fully implemented property-based tax system which is supported by an up-to-date and maintained property database.

In addition to this technical assessment of the process and its efficiency, the UK Government seeks to assess whether the projects it funds use the least costly resources available to achieve the desired impact. For this reason all IPP-related CEAs are undertaken in a consistent manner which will therefore facilitate comparison of the impacts for all projects within the Programme. This will in turn enable the UK Space Agency to demonstrate the extent to which space represents an efficient method for delivering developing world solutions, thereby making the case for future funding in this area.

IPP funding is classified as ODA (Official Development Assistance) and therefore this and other IPP projects can demonstrate that the funds have been spent in accordance with the OECD-DAC (Development Assistance Committee) requirements, as audited by the ICAI (Independent Commission for Aid Impact) in the UK.

As already indicated, an important element of the International Partnership Programme is that a project can potentially be rolled out to new customers following completion. The final part of the Dakar Change project has been the development of plans, a roadmap, to identify other locations where the same technology could potentially be implemented successfully. The roadmap builds on the work carried out during the project and explains how the technology, software and imagery will be marketed for urban applications in Senegal and elsewhere. It is also important to note that the roadmap is not only about technology and imagery, and its applications, but also about how technology can be used to build a culture and acknowledgement of the importance of data maintenance, which has significant application in multiple circumstances. The roadmap tasks, therefore, are concerned with explaining the importance of the technology developed in the project as the catalyst for property data maintenance and change monitoring service provision.

The IPP Dakar Change Project has served to crystallise the application of urban monitoring with the assistance of satellite imagery as a potential means of maintaining a database of properties as the basis for supporting property-based revenue generation. The role of the satellite based change monitoring is to improve the efficiency of data maintenance by focusing field data collection on changed parcels rather than a blanket approach. From this work there is now concrete information upon which to offer the concept to other cities and countries where revenue generation from property is already on the agenda.

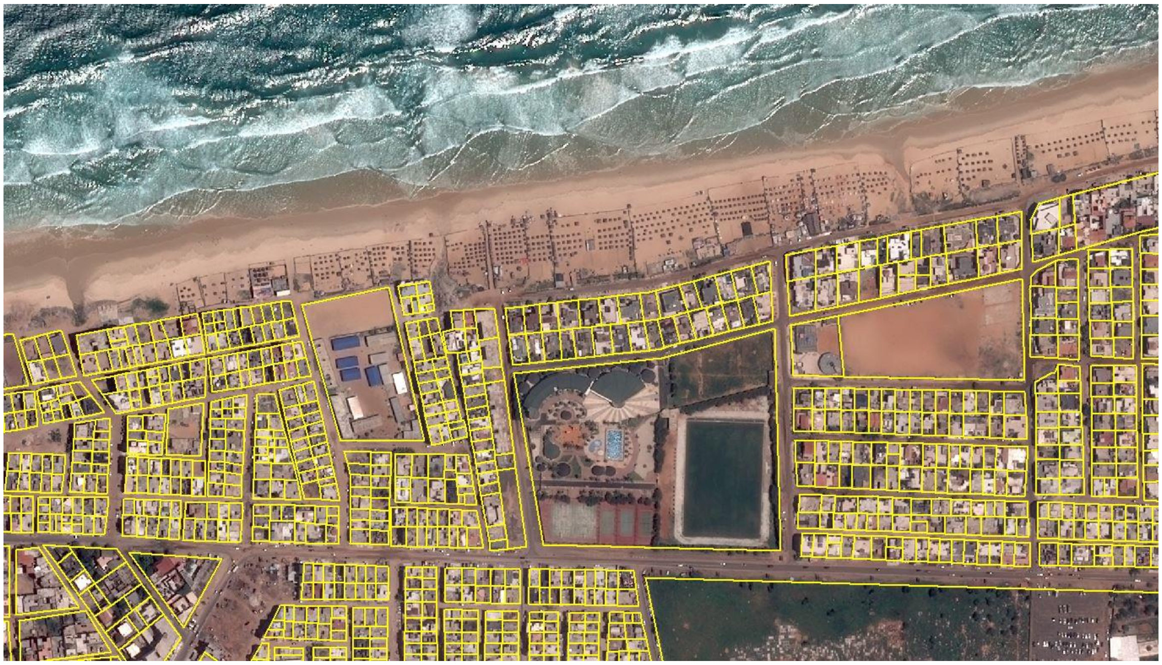

Figure 1 Pleiades imagery from January 2017 with interpreted parcel boundaries
(Source: Satellite Image Analysis for Operational Maintenance of a Property Database for Dakar City, Senegal, Milestone 10 Report, Airbus, 2019)

Figure 2 Evolution of buildings on three satellite images
(January 2017, September 2017 and April 2018)
(Source: Satellite Image Analysis for Operational Maintenance of a Property Database for Dakar City, Senegal, Milestone 8 Report, Airbus, 2018)

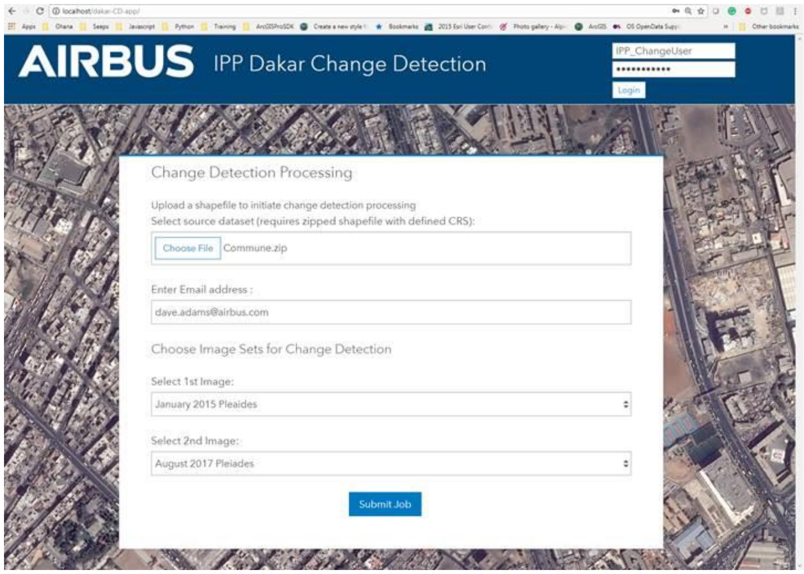

Figure 3 Change Detection Software Interface
(Source: Satellite Image Analysis for Operational Maintenance of a Property Database for Dakar City, Senegal, Milestone 8 Report, Airbus, 2018)

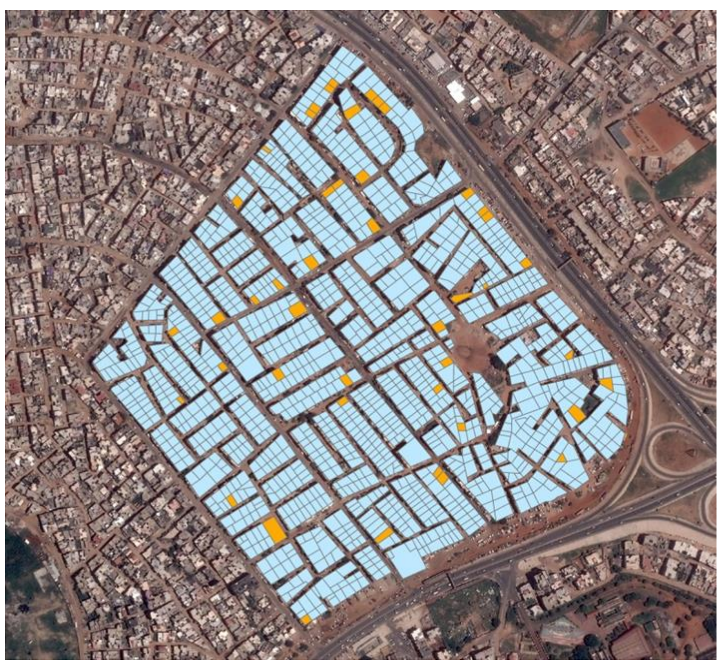

Figure 4 Change Detection in established area January to September 2017 (orange parcels: 3% change)
(Source: Satellite Image Analysis for Operational Maintenance of a Property Database for Dakar City, Senegal, Milestone 8 Report, Airbus, 2018)

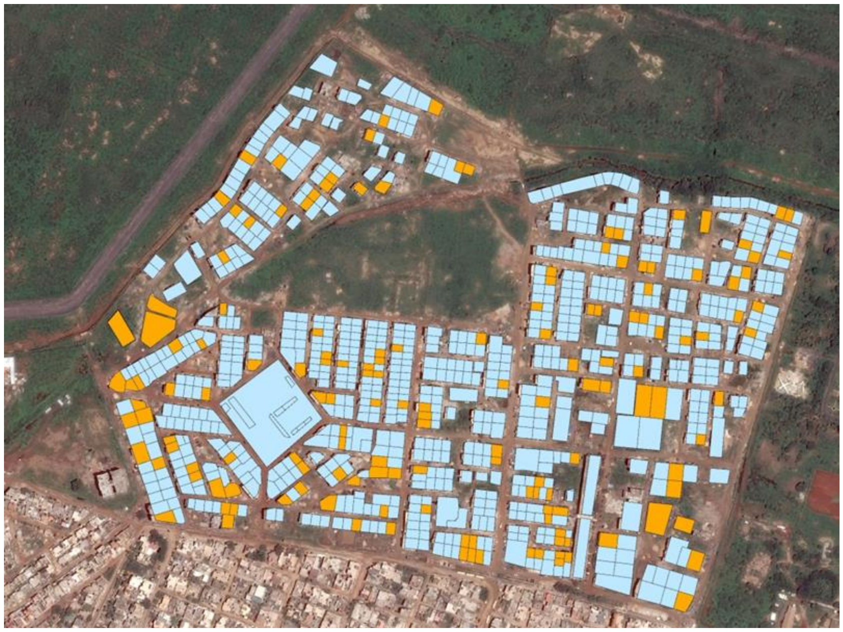

Figure 5 Change Detection in development area January to September 2017 (orange parcels: 17% change) (Source: Satellite Image Analysis for Operational Maintenance of a Property Database for Dakar City, Senegal, Milestone 8 Report, Airbus, 2018)

Scenario	Measure	Description	Nominal Costs (as in year of expenditure)	Real Costs (all in 2017 prices)	Present Value of Costs (in 2017 prices)
IPP Datellite Project Solution (2017-2023) Dakar Only	Present Value of TOTAL COSTS	ROM costs for 2017 - 2023	3,439,386	3,280,758	2,963,445
	Present Value of IMPACT	Increased revenue due to annual maintenance of property database			9,347,935
	COST-EFFECTIVENESS RATIO				**0.317**
IPP Datellite Project Solution (2017-2023) Forecast Cities	Present Value of TOTAL COSTS	ROM costs for 2017 - 2023	8,836,395	6,951,573	5,728,360
	Present Value of IMPACT	Increased revenue due to annual maintenance of property database			24,720,251
	COST-EFFECTIVENESS RATIO				**0.232**
Alternative 1 Field Only Method (2017-2023) Dakar Only	Present Value of TOTAL COSTS	ROM costs for 2017 - 2023	4,357,323	4,120,936	3,630,516
	Present Value of IMPACT	Increased revenue due to annual maintenance of property database			5,608,761
	COST-EFFECTIVENESS RATIO				**0.647**
Alternative 1 Field Only Method (2017-2023) Forecast Cities	Present Value of TOTAL COSTS	ROM costs for 2017 - 2023	17,008,975	13,394,043	11,148,517
	Present Value of IMPACT	Increased revenue due to annual maintenance of property database			14,832,150
	COST-EFFECTIVENESS RATIO				**0.752**
Alternative 3 Aerial Imagery (2017 - 2023) Dakar Only	Present Value of TOTAL COSTS	ROM costs for 2017-2023	4,428,406	4,193,902	3,760,180
	Present Value of IMPACT	Increased revenue due to annual maintenance of property database			9,347,935
	COST-EFFECTIVENESS RATIO				**0.402**
Alternative 3 Aerial Imagery (2017 - 2023) Forecast Cities	Present Value of TOTAL COSTS	ROM costs for 2017-2023	12,560,895	10,284,878	8,477,842
	Present Value of IMPACT	Increased revenue due to annual maintenance of property database			24,720,251
	COST-EFFECTIVENESS RATIO				**0.343**

Figure 6 Cost Effectiveness Ratios Calculated for Different Scenarios

(Source: Satellite Image Analysis for Operational Maintenance of a Property Database for Dakar City, Senegal, CEA Report, Airbus, 2018)