Africa Community Access Partnership

# The use of appropriate high-tech solutions for road network and condition analysis, with a focus on satellite imagery

## Technical Status report


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*AFCAP Project Reference Number. GEN2070A*

**2nd October 2017**

THE FUTURE OF TRANSPORT

DEFENCE AND SPACE

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| *Quality assurance and review table* | | | |
|---|---|---|---|
| Version | Author(s) | Reviewer(s) | Date |
| 1 | Robin Workman | | 30/08/2017 |
| 1.1 | Robin Workman | Les Sampson, J R Cook | 2/10/2017 |
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| AfCAP Database Details: The use of appropriate high-tech solutions for road network and condition analysis, with a focus on satellite imagery | | | |
|---|---|---|---|
| **Reference No:** | GEN2070A | **Location** | |
| **Source of Proposal** | | **Procurement Method** | |
| **Theme** | | **Sub-Theme** | |
| **Lead Implementation Organisation** | TRL Ltd | **Partner Organisation** | Airbus DS |
| **Total Approved Budget** | | **Total Used Budget** | |
| **Start Date** | 25/04/2016 | **End Date** | 31/12/2017 |
| **Report Due Date** | 12/08/2017 | **Date Received** | 30/08/2017 |

## Key words

Rural Roads, Satellite imagery, Road Condition, High-Tech Solutions

## AFRICA COMMUNITY ACCESS PARTNERSHIP (AfCAP)

***Safe and sustainable transport for rural communities***

AfCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa. The AfCAP partnership supports knowledge sharing between participating countries in order to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources. The programme follows on from the AFCAP1 programme that ran from 2008 to 2014. AfCAP is brought together with the Asia Community Access Partnership (AsCAP) under the Research for Community Access Partnership (ReCAP), managed by Cardno Emerging Markets (UK) Ltd.

**See www.research4cap.org**

## Acknowledgements

Airbus DS

## Acronyms, Units and Currencies

| | |
|---|---|
| AfCAP | African Community Access Partnership |
| ARMP | Annual Road Maintenance Plan |
| DEM | Digital Elevation Model |
| DFID | Department for International Development |
| DROMAS | District Road Management System |
| GIS | Geographical Information System |
| GNSS | Global Navigation Satellite System |
| GPS | Global Positioning System |
| IRI | International Roughness Index |
| LGA | Local Government Authority |
| OSM | Open Street Map |
| PO-RALG | President's Office – Regional Administration and Local Government |
| QGIS | Quantum Geographic Information System |
| RAMS | Road Asset Management System |
| RCMRD | Regional Centre for Mapping of Resources for Development |
| ReCAP | Research for Community Access Programme |
| RFB | Road Fund Board |
| SDI | Surface Distress Index |
| UAV | Unmanned Aerial Vehicle |
| UK | United Kingdom |

## Contents

## Executive Summary

This report assesses the current situation of the high-tech solutions project. The main research has been completed, but an extension is under way in Tanzania to test specific aspects of the methodology. So far certain conclusions have been drawn that confirm the technical feasibility of the system, and the Tanzania trials will test it in a roll-out scenario for a specific situation. A guideline has been completed and is available on the ReCAP website, which outlines potential high-tech solutions, and give specific guidance on the inventory and condition assessment methodology from satellite imagery. Guidance is also provided on how different technologies can work together.

## 1. Introduction

This Technical Status report is designed to assess the current situation of the GEN2070A high-tech solutions project, which is researching high-tech solutions for increasing knowledge of local road networks in Africa.

The project has carried out research into high-tech solutions and condition assessment from satellite imagery, and has produced a guideline on the use of high tech solutions for road network and condition analysis in Africa. This guideline includes a detailed methodology on how to use satellite imagery to assess road condition of rural roads, paved and unpaved.

The project has been granted an extension to test the satellite condition assessment methodology in Tanzania, which is in the process of re-assessing its rural road network and is interested in a system that can rapidly assess the network.

## 2 Background

The project has completed its original mandate, to identify high tech solutions for increasing knowledge of rural road networks and to develop a methodology for road condition assessment using satellite imagery. Research was carried out in four countries, Ghana, Kenya, Uganda and Zambia, and a guideline has been produced which sets out the applications and methodology for using such technologies.

The main research trials were to test the satellite condition assessment system in different environments and conditions and to determine how sustainable and appropriate it is in terms of providing the information that is required by each country. The results were consistent and the main outcomes were:

- The system is more accurate when fewer levels of condition are used, i.e. for 5-level conditions the accuracy is approximately 65%, and for 3-level conditions the accuracy was found to be approximately 80%.
- The system can be adjusted and calibrated effectively to suit the different conditions, environments and methods of condition assessment in each country.
- Digitisation of the roads was found to be an effective and accurate way of mapping the network, where no existing maps were present.
- Training of local engineers was effective, and regional remote sensing specialists were able to replicate the training effectively. Training materials have been developed.
- The system can rapidly assess large areas of road network. The main limitation on time is the number of people who can be trained and ensuring consistency between assessors.
- The system was competitive, financially, with traditional methods of condition assessment. Satellite imagery is expensive, but significant discounts can be negotiated and new

developments in the industry are moving towards more flexible and lower cost use of satellite imagery.

A logical next step for this system is to roll it out to assess a larger area of road network, or even a whole country network.

## 2.1 Tanzania extension

An opportunity arose in Tanzania to test the methodology and to assess how the satellite condition assessment system works with a Road Asset Management System (RAMS), as well as determining whether the system provides the information that is specifically useful to the Road Fund Board (RFB) in Tanzania. An extension of the project was therefore granted and the Tanzania trials are under way.

### *2.1.1 DROMAS 2 database*

A database is being developed to assist PO-RALG in Tanzania to manage their network. This database is called the District Road Management System version 2 (DROMAS 2) and is in the process of being populated. The database includes road network and mapping features, as well as providing information for the Annual Road Maintenance Plan (ARMP) and contract management tools. Network features include:

- Road name, code and class
- Road length and dimensions
- Pavement type and construction status
- Structures such as bridges, culverts, retaining walls and side drains
- Road furniture

Road condition is collected visually as a general condition, but specifically the International Roughness Index (IRI) and Surface Distress Index (SDI) are also collected, along with a speed rating and traffic information.

DROMAS 2 is an on-line facility, which works with other applications such as QGIS (a freely available GIS program that is also used by the satellite condition assessment system), Google Maps and SW-Maps. DROMAS 2 is still in the process of being developed, and faces some challenges ahead in terms of collecting the full inventory for roads and presenting it in an appropriate format for the RFB.

### *2.1.2 Requirements of the RFB*

At present the Road Fund Board requires more, and better quality, information on the Local Government Authority (LGA) network in order to equitably prioritise the funding of urban, district and feeder roads. The RFB believe that there is a need to check all aspects of the road network for completeness and accuracy, but more specifically the length of roads, their status and their condition should take priority. With this in mind the Road Fund Board is launching a tender for a comprehensive inventory and condition survey for all rural roads that will include a re-classification exercise for all roads in the country. There is potential for the high tech solution options to contribute towards that goal.

# 3 Technical status

This chapter summarises the technical status of the project to date.

## 3.1 High-tech solutions

Although there were limited practical trials with the ReCAP high tech solutions project, it is important to summarise the status of the technologies at this point in time. This is a very rapidly changing field, so the solutions assessed below can be subject to change and development within a short time of this report.

### *3.1.1 Range of options*

The range of options is essentially the same as shown in the 'Guideline on the use of high tech solutions for road network inventory and condition analysis in Africa', which is available on the ReCAP website: [http://www.research4cap.org/SitePages/Regional%20Projects.aspx](http://www.research4cap.org/SitePages/Regional%20Projects.aspx)

The main trials were undertaken on:

- DashCams: These were used to record the ground truthing surveys so that a technical audit could be undertaken. They were found to be very useful and there is scope to develop a low-cost product specifically for this use.
- Smartphone apps to measure International Roughness Index (IRI): The results from the RoadLab app used were good for paved roads and good condition unpaved roads, but accuracy declined significantly on fair and poor condition unpaved roads. As a low cost solution this is only appropriate within defined conditions.
- Smartphone app to report issues with the road through social media: A draft app was developed by the country counterpart in Ghana, but is yet to be trialled. Development is at present being undertaken by a counterpart engineer.

A number of other technologies are already established, or are being researched and developed by other organisations:

- Unmanned Aerial Vehicles (UAVs): There are a number of research studies using UAV imagery for assessing the condition of unpaved roads or bridge condition. The number of uses to which UAVs are being put is increasing rapidly. It would take more significant funds to carry out research in this area as it has become quite commercialised, so it is an appropriate strategy to wait and assess industry developments.
- Internet based solutions: A number of internet based solutions are also in development, with programmes such as 'FixMyStreet', 'OpenStreetMap', 'OpenRoads' and proprietary mapping sites such as Google Maps and Bing Maps. These are developing independently.
- GIS based solutions: There are many other GIS based resources that can help with road network knowledge, such as Digital Elevation Models (DEMs), drainage identification software and automated mapping. Most are well established so can be complementary to other high tech systems.
- Other satellite based solutions: Satellites can also provide imagery from Synthetic Aperture Radar (SAR), spectral reflectance, change detection algorithms and online streaming of high resolution imagery, as well as the opportunity to use archive imagery for back analysis.

Already established technologies were also mentioned with respect to how they can be used to enhance or supplement other solutions. These included:

- Aerial photography: traditionally from rotating wing or fixed wing aircraft, but increasingly from UAV platforms.
- LIDAR: Very accurate, but specific uses. Potential to develop alongside visual imagery to produce 3D visual images.
- Laser profiling: Established in developed countries, not cost effective for rural roads in LICs.

- Various methods of roughness measurement (using IRI): Most are designed for paved and strategic roads, but potential to develop a low-cost high-tech and reliable/accurate system for unpaved roads.
- Photogrammetry: Best potential for use with UAV imagery.
- Interferometry: Cost may prohibit use at the present time.
- GNSS: GPS is a very useful tool to complement other technologies, for example smartphones and DashCams can have integral GPS.

### *3.1.2 Complementarity of options*

The range of technologies is very wide, so it is important to select an appropriate solution for the task defined. The status of existing technologies and how they can be complementary to each other is shown in the 'Guideline on the use of high tech solutions for road network and condition analysis in Africa'. Table 2 on page 38 of the Guideline lists the main technologies that can be combined to increase knowledge of the road network, and how they can combine with each other to achieve the desired outcome. Due to the rapid advancement of many technologies this table should remain flexible, and subject to adjustment as new technologies are developed, and as new uses are found for old technologies.

### *3.1.3 Developing new technologies*

A number of new technologies have been identified which have the potential to be used for increasing knowledge of rural road networks. The technologies are either in the process of development, or are established and being utilised, but have not yet been applied in the rural roads sector. Potential solutions for the future that were not able to be trialled in this project included:

- Automated condition assessment from UAVs or satellite imagery
- Linked data/semantic web
- Data modelling/distributed computing
- Artificial intelligence/machine learning
- Internet of Things
- Big Data
- Thermal imaging, infrared satellites

## 3.2 Satellite imagery condition assessment methodology

The methodology developed to assess road condition from satellite imagery formed the main part of the practical trials undertaken by the main ReCAP project. A number of aspects were considered and have been included in the guideline, and their status is shown below:

### *3.2.1 Deciding whether to use the system*

The high-tech solutions assessment approach assessment is not appropriate for all situations, so the user should consider the options fully before deciding on which system to use. The user needs to be fully satisfied that the system will provide the outputs that they require, for a cost that is affordable and within the time it is required. They also need to check that they have the capacity to use the system.

The factors to be considered when selecting a system are:

- Cost: Whether this is the most cost effective solution or not. Costs are continually changing, so the cost effectiveness is subject to the latest prices.

- Detail: Whether the system satisfies the requirements of the local roads organisation in terms of the level of detail gained for road inventory and condition.
- Acquisition of imagery: Whether the weather will be suitable for image acquisition at particular times of year.
- Resolution: The resolution of the imagery is important to consider as there can be a trade-off between different aspects of resolution. Spatial resolutions are consistently improving with improved technology, so the technical feasibility of the system should continue to improve.
- Accuracy: The level of accuracy that can be achieved should also be considered, for example if a five level system is used the high-tech solution accuracy may not be sufficient for the local roads organisation.
- Time: This notes how soon the assessment needs to be completed. Satellite assessment is a rapid way of gaining a large amount of information.
- Resources: Define the resources necessary to carry out the assessments, as this is an important consideration.
- Record: Decide whether a permanent record is required, or not. Satellites provide a clear, dated and georeferenced record of the road.
- Licencing: Check the licencing agreement to ensure that the use to which the imagery is to be put is not contrary to the agreement.

### *3.2.2 Integrating with existing systems*

Some high-tech solutions have been recommended for use with the system, such as IRI measuring equipment or apps and DashCams, which are covered in the Guideline. However, there is also the possibility to use other technologies to enhance the implementation of the system. It is recognised that the only features that can be assessed are those that are visible on the satellite imagery, so bridges, culverts and other structures have limited visibility. In this case it may be possible to use other solutions, such as:

- Using UAVs to inspect under bridges or inside culverts. This is potentially a good supplement to the system as it is not possible to obtain such detail from the imagery. There are proprietary systems that can undertake such surveys.
- Using UAVs with photogrammetry techniques to provide detailed cloud maps of the road surface. This would only be feasible and cost effective for short sections where specific and detailed information is necessary. The technology is proven but at present would only have very limited use due to its cost.
- SAR imagery can be used to avoid issues of visibility and cloud cover. However, with the current cost of SAR it is unlikely to be cost effective unless a specific use could be found.
- DEMs can be used to identify drainage catchment areas and channels to provide an indication of the location of drainage structures not easily visible on the imagery. DEMs can be acquired free of charge and are a useful supplement to the system.

In general it is not sensible to mix the satellite assessment with ground-based visual surveys within the same area, other than for necessary bridge and culvert inspections. The satellite imagery is expensive and it should be utilised to the fullest extent, so carrying out on-the-ground surveys in areas where satellite imagery has been procured (other than the calibration surveys) defeats the object of using satellite imagery.

### 3.2.3 Local remote sensing partner

In each project partner country a local remote sensing partner was found. These partners were included in the training and assessment as they can provide a long term, local partner to the local roads organisation. These partners were identified and included in order to provide the specialist knowledge in remote sensing that is lacking in most roads organisations. They will be able to support the roads organisations until they have built their own capacity in remote sensing, image interpretation and GIS software. Given the lack of capacity for GIS in most road organisations in Africa, it is expected that local remote sensing partners will be needed for some time.

### 3.2.4 Correlation of results to ground truthing

The correlation of satellite manual assessments of road condition, as compared to the ground truthing baseline, was the principal method of assessing the accuracy of the satellite assessments. As mentioned above the assessment of roads with fewer condition levels (three) was found to be more accurate than assessments with more levels (five). The consistency of the results gives a level of confidence that suggests the system can be used on a larger sample.

### 3.2.5 Training

The training carried out so far on the project has been very successful. Initially detailed training materials were developed by Airbus DS, which proved to be very appropriate and needed very little adjustment through the course of the project. These consisted of a Powerpoint presentation and a Training Manual. Three of the countries (Ghana, Uganda and Zambia) were trained by the Airbus DS specialist and the TRL team leader, but the fourth country was trained by RCMRD, who are the regional remote sensing specialists based in Nairobi. This proved that training can be sourced and carried out using local suppliers, which is a positive finding in terms of the sustainability of the system. The present training model and materials are a good basis for replicating the system.

### 3.2.6 Development of assessment guidelines

The detailed methodology on how to use satellite imagery to assess the condition of paved and unpaved roads includes instructions in how to develop an assessment guide and reference document for satellite condition assessment. This document is the main guide that is used to assess the condition from the satellite imagery, in association with the training manual. It sets out examples of different road conditions and provides descriptions, as well as objective methods of measurement where possible, such as the variation in road width. A number of factors have been identified which can indicate road conditions, such as road width, edge straightness, surface shading and colour, texture and wheeltracking, so the assessment guide shows the user how to identify and interpret these to assess road condition.

### 3.2.7 Imagery interpretation and assessment

Local engineers and technicians were trained to interpret the satellite images and assess the road condition. Observations from the training and the subsequent assessment/analysis were that the training was effective and staff found it relatively easy to assess the images. However, it was noted that there were some inconsistencies if assessors tried to carry out the task too quickly or with insufficient care. Also it was predicted that the accuracy of the assessors would improve with practice, as they only had a relatively small sample to work with. This could be assessed more accurately if a larger sample were to be undertaken.

### 3.2.8 Potential uses

This system has some specific advantages, which makes it more appropriate for certain situations. The main advantages are:

- It can assess large areas rapidly. Potential delays could be acquisition of the imagery and logistics to undertake the ground truthing, but the assessment process can be undertaken quickly.
- It avoids resourcing constraints and inefficiencies, such as the logistics necessary to carry out traditional condition surveys. The fact that many countries fall behind with their scheduled condition surveys is testament to how difficult it is to arrange such surveys. This system offers a more efficient system with less administrative and logistical difficulties.
- It can be used for areas that are difficult to travel to, for either accessibility or conflict reasons. Potentially this is useful for conflict areas or areas affected by natural disasters.
- It provides a permanent record of the assessment, that is automatically georeferenced and can be audited.
- It provides accurate mapping and location references. In many cases mapping is inaccurate and out of date, this offers a system that is easy to update and that can use data from GPS enabled devices to assist with this process.

In this respect it is less beneficial when applied to situations where there are already up to date and accurate records of roads and their condition; it has more benefit in countries where the road inventory is less well developed and is harder to access.

### *3.2.9 Use with a database/management system*

An important aspect of the detailed methodology for road condition assessment from satellite imagery is the ability for it to link with a GIS based Road Asset Management System (RAMS) or database. As a standalone system using QGIS it is feasible, as proved during the research, but it's utility and user friendliness could be greatly enhanced by linking with a GIS based RAMS. The initial research in Nigeria under a separate project linked with a RAMS and was fond to be successful. This possibility will be explored during the Tanzania trial.

### *3.2.10 Providing relevant outputs*

It is also important that the outputs from the system are useful to the local roads authority. The Guideline sets out the factors to consider when selecting such a system, so the local roads organisation needs to consider these very carefully. The Tanzania trial is designed to specifically test the areas of data collection and knowledge generation that are important to the RFB.

### *3.2.11 Tailoring solutions to particular situations*

An important aspect of the system is that it is flexible enough to adapt to the very different environments and situations within Africa. The system is therefore established with the ability to adapt to the following situations:

- Different levels of condition assessment, typically three, four or five levels
- Different systems of condition assessment
- Different pavement surfaces
- Different maintenance regimes
- Different environmental conditions
- Different geological conditions

This makes the system more sustainable. So far the system has proved that it can adjust to the differences mentioned above.

### 3.2.12 Future options for development

As mentioned earlier the first step would be to test the system on a larger sample, possible even on a national network. There are many countries that have a lack of information of their rural road network or where conflict prevents a traditional condition assessment regime to be used. In such a situation the methodology proposed in this project could be appropriate and cost effective in providing knowledge of the rural road network.

There is also scope to research the possibility of automating the system, by developing algorithms that can automatically assess the road condition using some baseline information. A similar research is about to start in Tanzania using UAV imagery and machine learning. It is likely that lessons could be learned from this research and applied to any future attempts at automating the condition assessment process from satellite imagery.

# 4 Conclusions

A number of conclusions can be drawn from the project so far, they are summarised below:

- There are many potential high tech solutions that can be applied to the rural roads sector, either developed, in development or for the future.
- The condition assessment from satellite imagery was trialled using local resources with minimal input from the consultants. Despite some local barriers to implementation the results were positive and compared favourably to other recent research in Nigeria. The level of confidence is high for replicability in other countries.
- Local remote sensing partners were an important aspect of the project.
- DashCams and Smartphones were found to be useful technologies for the ground truthing.
- The training was effective and could be replicated by local remote sensing specialists.
- Mapping proved to be accurate and was also useful to the local roads organisations.
- The system was flexible enough to be able to adjust to the local environment and the current condition assessment regime.
- Assessment guides and reference documents were developed effectively from the satellite imagery.
- There is the potential to develop an automated system, in order to reduce subjectivity and decrease assessment time.
- Overall correlation between the ground truthing baseline and the satellite imagery assessment was consistent and high enough to be useful in most situations.
- Assessors are likely to become more accurate and faster as they gain more practice.
- Existing mapping resources are often out of date and inaccurate, even proprietary systems are not recent enough to use for satellite imagery condition assessment.
- The system would benefit from being incorporated into a GIS based RAMS or database system, for ease of manipulation and reporting.
- Satellite imagery condition assessment can be competitive financially, so long as discounts can be negotiated and road density is relatively high.
- Satellite imagery condition assessment is less environmentally damaging than traditional assessment methods.