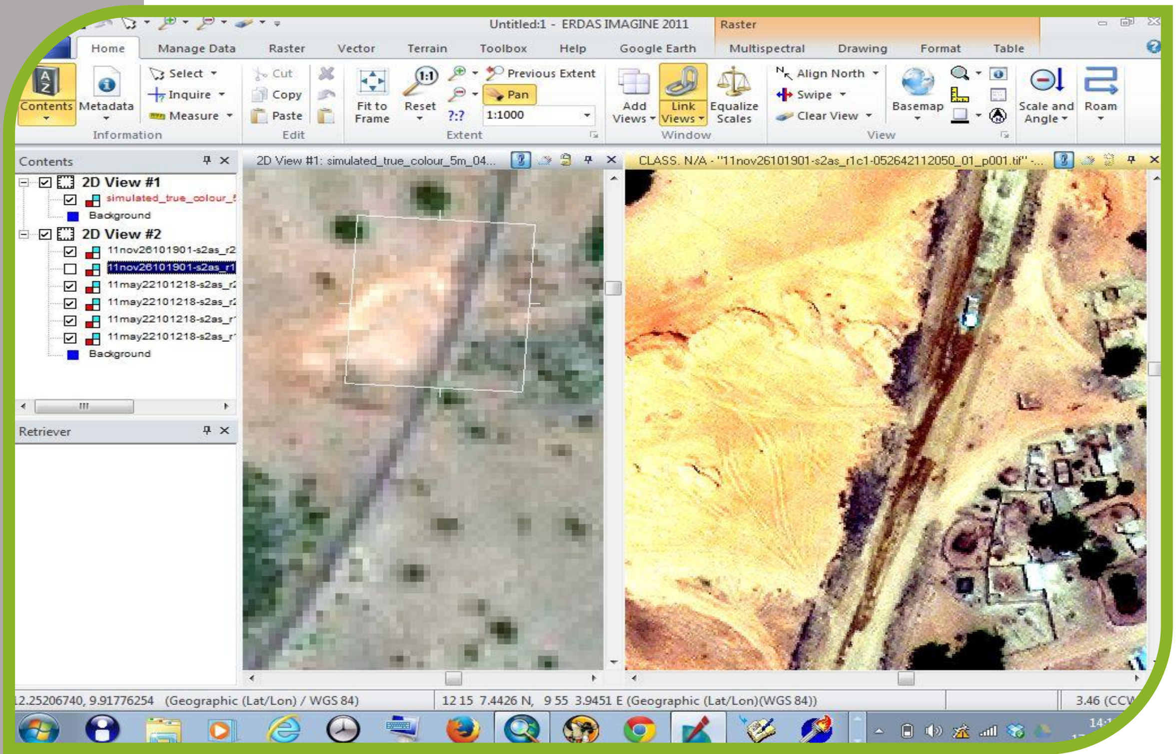
The use of appropriate high-tech solutions for road network and condition analysis, with a focus on satellite imagery

Peer Reviewed Desk Study Report



Robin Workman

Andrew Otto

Alex Irving

TRL Ltd.

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ReCAP Project Management Unit
Cardno Emerging Market (UK) Ltd
Oxford House, Oxford Road
Thame
OX9 2AH
United Kingdom

Shaping the Future

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Low Volume Sealed Roads, Satellite imagery, Road Condition, High-Tech Solutions, Network, Asset Management

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Acronyms

AfCAP	African Community Access Partnership
AfDB	African Development Bank
AU	African Union
CERSGIS	Centre for Remote Sensing and Geographic Information Services
CNN	Cable News Network
DIKW	Data Information Knowledge Wisdom
DoS	Department of Surveys
ESA	European Space Agency
GEM project	Economic Growth through Effective Road Asset Management
GIS	Geographical Information System
GPS	Global Positioning Satellite
GSMA	Groupe Speciale Mobile Association
HIC	High Income Country
ICIMOD	International Centre for Integrated Mountain Development
IMF	International Monetary Fund
IoT	Internet of Things
IQL	Information Quality Level
IRI	International Roughness Index
K	Kelvin
KCCA	Kampala Capital City Authority
LIC	Low Income Country
LIDAR	Light Detection and Ranging
LVR	Low Volume Road
MIC	Medium Income Country
NASA	National Aeronautics and Space Administration
OPERA	Open Platform for European Road Assessment
PMU	Programme Management Unit
QR	Quick Response
RAI	Rural Access Index
RAMS	Road Asset Management System
RCMRD	Regional Centre for Mapping of Resources for Development
ReCAP	Research for Community Access Programme
RFID	Radio Frequency Identifiers
SAR	Synthetic Aperture Radar
SMS	Short Message Service
SN	Structural Number
TIM	Transport Infrastructure Monitoring (project)
ToR	Terms of Reference
TV	Television
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
UN	United Nations
UNECA	United Nations Economic Commission for Africa
USA	United States Aid
USDOT	United States Department of Transport

Contents

Executive Summary

Many Low Income Countries (LICs) lack knowledge of their rural road network. In general their strategic networks are relatively well defined and there is usually mapping, inventory and condition data available, whereas rural networks generally lack such attention. The majority of roads on rural networks are unpaved, and where they are paved there tends to be higher levels of knowledge in terms of inventory, condition assessment and maintenance. There are many reasons for this lack of knowledge, from a lack of funding to a lack of accessibility to be able to collect data, to simple logistical issues. Whatever the reason, remote sensing and other high-tech solutions offer an alternative way to collect data and increase the knowledge of rural road networks.

The two main aspects of the project are:

- Potential high-tech solutions to increase the knowledge and use of rural road networks
- Development of a methodology for mapping and condition assessment using satellite imagery

High-tech solutions

This project investigates the potential uses of appropriate and cost-effective high-tech solutions in helping LICs to improve their knowledge of the location and condition of their rural road networks, whilst liaising with other AfCAP regional projects. This desk study includes a review of existing literature and previous research to inform the reader on the subjects to be researched in this project. Recommendations are made on which high-tech areas to pilot in phase 2 and which countries to partner with, including an indication of the resources they are willing to commit.

A number of high-tech solutions were investigated and discussed. The majority of these are well established in HICs and MICs, but have had limited exposure in LICs. Given the wide range of applications and the limited resources within this project to actually research these solutions, it was necessary to make some judgements on which could be the most relevant to Africa.

To this end a short-list of high-tech options has been produced (Table 10). The options were assessed on the basis of technical and financial feasibility and ranked accordingly. It is hoped that the top four or five options can be trialled, depending on the ability of partner countries or other donors to finance the research. We anticipate that the most beneficial solutions are likely to be the web portal and repository, UAVs, social media apps, mini-satellites to determine accessibility and spectral reflectance for assessing the condition of paved roads. However, the computer and web-based items also have potential but are less likely to be applicable within the scope of this project.

Satellite imagery assessment of condition

A draft methodology has been produced for mapping and condition assessment by satellite imagery, based partly on TRL's experience in Nigeria with the Transport Infrastructure Monitoring (TIM) project (R Workman, 2012), which carried out a limited trial to assess the feasibility of assessing road condition using satellite imagery. The imagery interpretation was carried out visually, as this was found to be the most appropriate way to achieve the results in the given environment. We intend to continue this methodology for the countries in question, given the local capacity, the lack of resources to procure advanced software and the principle that it will provide employment, in line with AFCAP principles. This is likely to be a more sustainable approach, although we will consider the possibility for using some automated techniques if appropriate.

This project also builds on previous work on asset management by the World Bank and the initial report produced by the AFCAP asset management project Economic Growth through Effective Road Asset Management (GEM). The World Bank work has been used to put the project into context.

Some modifications have been suggested to the criteria and rules for condition assessment, based on the practical results of the Nigeria project. We expect this methodology to be reviewed and adjusted as the project progresses, due to the fact that we are trialling the technology in a wider range of countries and environments.

The key focus of this aspect of the project is to develop the Nigeria project work in a real environment, by using the existing condition assessment processes for ground truthing in each country as carried out by local staff. Local staff will also be used to carry out the image interpretation, following appropriate training. In the Nigeria project the condition assessments were done by the project and the image interpretation was done by Airbus in the UK.

Partner country inclusion

All AfCAP countries were considered for inclusion in the project as partner countries. A country selection report was produced and the most appropriate countries were chosen based on a number of factors that were relevant to the mapping and condition assessment aspect of the project, this can be seen in Appendix 1. This included aspects such as climate, vegetation, geography and local capacity. The confirmed partner countries are Ghana, Kenya, Uganda and Zambia, with Malawi as a possible additional country. This will be confirmed when the initial country visits have been made and countries have committed to providing the necessary resources.

During our initial visits to the partner countries we will discuss resources and explore the possibility of bringing in additional resources from external sources to fund the high-tech solutions, with the assistance of the Programme Management Unit (PMU) of ReCAP. There are no dedicated resources for this aspect of the project as the solutions were not identified until the inception phase. The Terms of Reference (ToR) for this project recommend this approach to funding and a number of potential interested donors have been identified.

Capacity Building

Capacity building is a key aspect of this project, so our aim will be to provide a system that can be implemented locally and replicated across Africa, and possibly further afield. Our aim is to carry out as much training and capacity building as possible locally, using local resources. The system also needs to fit with the existing government systems and be sustainable in the way it is funded. We have identified local partners in most countries who are able to assist with the remote sensing and IT aspects of the project, whilst specialist training will be carried out by TRL and Airbus DS, but involving local trainers where possible.

Dissemination and Uptake

Dissemination and effective uptake is essential to the success of the research beyond the project period. To this end a web portal has been established on the AFCAP website, with the aim of sharing relevant information and keeping all interested parties informed of developments in the specific sector. The expected results will also be shared with relevant stakeholders through various mediums, wherever possible via the local partners, so we have identified regional conferences in Ghana and Zambia as appropriate platforms to share the progress and results of the research.

1 Background

1.1 Project Aim

The aim of the project is to investigate the potential uses of appropriate high -tech solutions in helping LICs to improve their knowledge of the location and condition of their rural road networks.

The project also has the mandate to identify any alternative uses for the captured data sets within the scope of AfCAP, with a particular focus on climate risk analysis and consequent options for climate resilience and transport services assessment. We have liaised with the other regional AfCAP projects on asset management and climate resilience and relevant recommendations are given in this report.

Ultimately this project is expected to lead to alternative, cost-effective methods to support asset management through enabling countries to gain a better understanding of their rural road networks and to make more informed decisions on the funding for maintenance and management of those networks. In addition to this the project is expected to develop a method for using cost -effective satellite imagery to assess the condition of roads, following on from previous research undertaken in Nigeria in 2013.

1.2 Project Objectives

The project objectives as stated in the ToR are:

- **Research** – The first objective is to provide a cost-effective and reliable high-tech solution for the capture of maintenance management data related to inventory and condition of a country's rural road network. This includes mapping of previously un-mapped networks and finding a way to assess their condition in new and innovative ways. The satellite imagery aspect of this project was based on the TIM project (R Workman, 2012), which carried out research as part of a project to test the technical feasibility of assessing road condition from satellite imagery. This research takes this concept further by testing the technical and economic feasibility of the process using existing conditions in each country, relying on existing systems, processes and resources to carry out ground truthing and local engineers and technicians to carry out the image interpretation.

- **Capacity Building and Technology Transfer** - Capacity building is an integral part of this project and its deliverables. The project is expected to enhance the capacity of relevant partner-country Road and Transport ministries, departments and agencies in the key areas covered by the project. It is important to agree on the most appropriate staff members to be trained, and to extend the training to the relevant departments so that there is a critical mass of staff members who are proficient in the technology. This will guard against loss of skills through staff transfers and turnover.

  Wherever possible we will use local institutions to carry out some of the training, essentially ensuring that all staff involved with the project have the necessary level of GIS and image interpretation training, which will provide a more cost effective and sustainable solution. Our initial investigations have determined that there are appropriate and experienced organisations in each partner country that could assume this role; these organisations vary from government departments to Universities and independent institutions. If there are costs associated with this approach we would expect the partner countries to provide the funding, which we believe will not be excessive.

  Airbus DS will provide the specialist training in assessing road condition through image interpretation. Our proposal allowed for two visits of the specialist trainer, assuming that it would be possible to train different countries together regionally. We will try to arrange this, so that they can learn from each other and share experiences, which will consolidate the uptake of knowledge. However, if this is not possible additional visits of the specialist trainer may be necessary. We will use regional conferences and events to disseminate the knowledge gained, with local partners making the presentations wherever possible.

- **Uptake and Embedment -** In line with the ReCAP guiding principles the project is expected to incorporate a process for keeping relevant agencies fully informed on project outcomes and how these outcomes can be cost-effectively utilised in normal practice. As discussed later, we are planning to establish an information centre which will involve all agencies involved in this type of research, and which will act as a data repository and a place where information can be shared. This is likely to be attached to the AFCAP website and maintained by the project consultants in the short term. In the longer term a more sustainable home will need to be found for this site.

1.3 Previous research

We have undertaken an extensive desk study which has uncovered a large amount of previous research into the use of remote sensing to establish knowledge on rural road networks, as well as research and practical experience in other high-tech areas of road knowledge and management that could be applied in the African context.

2 Introduction

This project is designed to look to the future for road management in Africa and explore different and innovative solutions to well established problems. This document is supported by an extensive literature review and exploration of the innovative technologies that are already being used in the roads sector across the world, and some that could also be applied to countries in Africa, but with some adjustments.

Before we explore the solutions, it is necessary to define the problems facing road management in many countries in Africa today. These include, but are not limited to, the following:

- Lack of knowledge of the low volume road network, in terms of road length, characteristics, road location (mapping), other road assets and road condition.
- Lack of knowledge of structures and drainage, including their vulnerabilities. This includes bridges, culverts and how vulnerable they are to extreme weather events, especially in the context of climate change. There is also some vulnerability to vehicle overloading and a lack of regular maintenance.
- Inappropriate design standards and specifications for roads and their constituent materials. Standards and specifications in Africa have largely been 'borrowed' from other countries and do not adequately take account of local conditions, materials and resources, meaning that roads are often over designed and local materials are not utilised to their full potential, making road construction and maintenance more expensive than it needs to be.
- Insufficient information upon which to base planning and maintenance decisions. As mentioned earlier, many countries lack the basic knowledge of their rural road networks to make objective and informed decisions on maintenance funding and new road construction.
- Insufficient resources to collect and process the necessary information outlined above. There is still a lack of focus on road maintenance in LICs, which has led to a lack of incentive to commit resources to collect road inventory and condition data. This was evident in the TIM project in Nigeria, where there was essentially no information available for the unpaved rural road network.
- Inappropriate management systems for rural infrastructure; where systems exist they are mainly focused on the strategic network and are not appropriate for rural roads. These systems are expensive and require constant upkeep, so are often seen as unnecessary for the rural network where very little maintenance is undertaken.

A lot of this information can be provided by remote sensing and other high-tech methods. For example, the satellite assessment aspect was borne out of the research undertaken in Nigeria to map and assess the condition of rural, unpaved roads (R Workman, 2012). The main principle of that research was to test the feasibility of using satellite imagery as a way to avoid on-the-ground surveys in an area that is heavily involved in conflict and where many areas are too dangerous or remote to visit safely and economically.

This project will explore the possibilities of introducing high-tech solutions for road management and maintenance in Africa, with the possibility in the future of introducing successful technologies into Asia and beyond. Much of the high-tech solutions already trialled or proposed are delivered through remote sensing, which can be defined as not requiring contact with the road surface. Although it is unlikely that remote sensing will be able to replace all traditional evaluation methods, it is possible to integrate them to some extent.

Remote sensing is a significant part of the high-tech solutions as it has the advantage of being able to assess large areas, usually in very little time. This is set against traditional methods which require presence on the ground with the risks that involves, as well as being expensive, labour intensive, time consuming and carbon intensive. As stated above, for the purposes of this project we will assume that remote sensing includes everything that does not require contact with the road itself. This means that the sensors could be vehicle mounted, aircraft mounted (fixed wing, helicopter), mounted on Unmanned Aerial Vehicles (UAVs), or located on satellites. The various options for remote sensing will be explored later.

One primary issue is that civil engineers do not necessarily have an academic or practical background in remote sensing, as well as the remote sensing community being largely unaware of the needs of transport related engineers. Judging by the amount of research that is now being published on the subject this is clearly starting to change, but the fundamental differences between the two disciplines remain and continue to be a barrier. A link is required between the two disciplines, to share research, information and needs. A paper published in the European Transport Research Review (E. Schnebele et.al 2015), provides a good overview of the various remote sensing methodologies for pavement management and assessment.

Remote sensing has also proved to be a useful tool to monitor natural and other disasters, and assist in humanitarian relief efforts following the disaster. The application of remote sensing is well established so we do not intend to revisit this, unless there are specific innovative applications that can significantly add to the existing technology.

2.1 Background to roads

This project is focused on Low Volume Roads (LVRs), both sealed and unsealed. The majority of such roads in Africa are unsealed, but we will also consider sealed roads. Roads are an important and valuable asset for all countries, but they are also an asset that deteriorates quickly through the action of traffic and environmental factors. The environment is becoming increasingly harsh as the realities of climate change become more evident.

Roads are designed to last for a specific period of time, given appropriate levels of maintenance. If maintenance is carried out regularly and to the specified standard, this life will be realised and could even be extended. However, if maintenance is neglected the road will quickly deteriorate and the asset will be lost or devalued. Not only is the asset devalued, but as the road condition worsens it becomes more expensive for vehicles to operate on that road, with consequent higher prices for passengers and goods. Accurate and up to date information on the road network helps engineers to make the best decisions for maintenance and to ultimately carry out more cost effective work, with the subsequent benefits to road users.

If remote sensing and other high-tech solutions can help in the evaluation of roads this could lead to significant savings in expenditure and increases in efficiency. In short, the country would benefit as a whole from a more efficient road network.

However, the application of such measures is likely to differ between countries. Those with good knowledge of the extent of their network and who carry out regular traditional inspections will have different uses to those who have little or no knowledge of their network and really just need a basic interpretation of length, location and condition. In addition, road construction types, materials and designs are very different, as discussed later in this report. Finding and managing the resources to carry out traditional road assessments has been challenging for LICs, so we aim to find an alternative that will enhance their ability to manage this situation and increase their knowledge of their roads.

The defects that are found on roads can be categorised into three main areas:

- **Structural Strength:** This can be measured using the Structural Number (SN) or the elastic moduli approach. This can be defined as the ability of the road to transfer the traffic load to the sub-grade on which the road is constructed. This is the least relevant for remote sensing applications as the assessment usually requires contact with the road surface.
- **Surface Defects:** These are the visible defects that can be seen on the surface of the road. They are related to the roughness of the road and are the most likely defects to be detectable by remote sensing. The defects will vary between unpaved and paved roads.
- **Skid resistance:** This can be defined as the surface friction that allows vehicles to maintain control when undertaking turning manoeuvres and is a function of the type of surface and its condition. Skid resistance is more relevant for surfaced roads and is possible, but not easy, to monitor from remote sensing.

The AFCAP GEM project has defined the defects that are likely to be found on low volume paved and unpaved roads. We agree with those definitions and will follow them when developing the criteria for satellite assessment.

2.2 Background to Remote Sensing

As mentioned earlier, remote sensing in the context of road evaluation can be defined as any data collection that does not require contact with the road. Remote sensing can consist of a variety of different technologies, from visual images (photographs) to radar and thermal images. The range of technologies can be summarised by wavelengths on the electromagnetic spectrum, with different wavelengths producing different information in different ways. It is also possible to combine two or more technologies, for example LIDAR and photography, to produce the required result, as TRL did in Uganda when mapping the roads of Kampala (R Workman, 2013).

Much remote sensing has its origins in military use, for example UAVs (drones) and satellites. The coverage varies greatly from satellite images that can cover hundreds of square kilometres in one image, to laser applications which can measure deviations in the road surface to the nearest millimetre. Although the spatial coverage of satellites is a great benefit, there are issues that come with this, such as cloud cover, spatial resolution and the frequency of visits. Some satellites stay in geostationary orbit and thus produce images of the same place constantly, which is useful for say weather tracking. Others are able to take images of different places across the globe.

Fixed wing and rotating wing aircraft have been used extensively for remote sensing, especially aerial photographs and LIDAR, but this is starting to be superseded by UAVs, or drones. UAVs have the advantage that they are cheaper as they are unmanned and therefore do not need to carry the payload of humans and their support systems, meaning that they can be manufactured to a much smaller scale. Coupled with the development of micro cameras and computer technology, this makes them cheaper and more flexible in terms of where they can fly and how they can be used.

Road vehicles are still the most common platforms for remote sensing and can house very sophisticated equipment that can measure multiple defects to great accuracies. Most remote sensing vehicles can capture data at normal traffic speed and have the advantage that they can collect that data under tree canopies, bridges, walkways etc, which would hamper data collection from satellites or aeroplanes. Typical vehicle mounted systems include lasers, cameras or videos, Ground Penetrating Radar (GPR), thermal scanning or acoustics.

2.3 Application to unpaved roads

Although unpaved roads are generally cheaper to construct, they require more frequent maintenance due to their vulnerability to environment and traffic. This means that their condition also needs to be monitored more closely. However, in terms of remote sensing, where a visual method of image interpretation is used, the defects found on unpaved roads are likely to be more obvious and hence more easily estimated than those on a paved road. For paved roads most visual assessments look for surface defects such as potholes, cracks, rutting and deformations. The latter three will not be visible from satellite imagery, and potholes will only be noticeable if they are large. On unpaved roads the wheel tracking and change in colour/shading is more visible and a good indicator of condition. Using visual imagery and pattern identification it is possible to identify defects such as rutting, potholes and corrugations on unpaved roads. The production of 3D models can also indicate loss of crown and material loss issues. This is discussed in more detail later.

2.4 Application to paved roads

Within the context of low volume roads in Africa, paved roads are almost exclusively bituminous and not concrete. Due to the more uniform nature of the road, automated methods of assessment are likely to be more feasible. In addition to visual imagery, other techniques have been used to identify defects, such as LIDAR, photogrammetry, spectral reflectance, infrared thermography and radar, as well as some new techniques such as the acoustic measurement of sounds from vehicle tyres (Ref. V. Saykin et al, 2012 and Y Zhang et. al, 2012).

Visual methods are the most common and can be used on any platform from vehicles to satellites. Detection of small failures such as cracks is harder to determine from lower resolution imagery as they can be disguised by changes in texture and lighting differences or shadows. Some methods have been tried that use a combination of systems, such as a camera and a laser range finder, which uses pairs of images from the same perspective, but with different lighting to determine crack depth (Ref Y Su et al, 2010). Also photogrammetry can offer 3D information which identifies cracks and potholes (M Ahmed, Hass C, 2010).

GPR and Infrared thermography can be used to detect voids, but the latter is also used to evaluate defects as it detects the stone in the surface when the asphalt ages. Hyperspectral imagery can be used to gather detailed information on chemical and mineral properties, which can be applied to asphalt. In this way the reflectivity of the asphalt can be measured, which can be an indicator of the road condition.

2.4.1 Alternative research

Overall there has been much more research on paved roads in terms of remote sensing, which is logical as they are more expensive to construct and predominate in high and medium income countries. We will not endeavour to repeat any of this research unless there is a new and innovative aspect that would bring clear benefits to LICs, especially those in Africa.

There are, however, some areas that have been suggested in the past, but have not yet been researched. These include the use of data from traffic cameras, where it is suggested that data can be collected during periods of low traffic when the road surface is more visible. This could be useful in countries such as Kenya, where there is an abundance of traffic cameras in Nairobi, although this is unlikely to be relevant for low volume rural roads.

The use of volunteered information, for example through social media, is also a possibility and is growing rapidly in Africa. Any data provided should be geo-referenced and current. This is essentially using people as sensors. It is already being used for traffic monitoring, as well as programs such as Street-Bump in Boston which predicts the presence of potholes. This area is so far unexplored in Africa, but is discussed in more detail later.

In addition pavement management systems are a good source of information. The data collected tends to be utilised separately, but there should be possibilities to fuse such data to increase the accuracy of the information and provide a more complete representation of the outputs available from such systems.

3 Potential High-Tech solutions

The ToR requires us to identify potential uses of appropriate high-tech solutions to help LICs improve their knowledge of the location and condition of their rural road network. We have carried out a review of the available literature, which covered a large number of documents and research papers across a range of relevant subjects. The main subjects of interest are shown below:

- Big Data
- Mobile Phones
- Social media and crowdsourcing
- UAVs
- Internet of Things
- Internet related solutions (linked-data, semantic web)
- Computer related solutions (data modelling, distributed computing)
- Machine learning and artificial intelligence
- LIDAR
- Aerial photography
- Alternative satellite applications

There is a certain amount of overlap in the above categories, for example satellite data can be considered as Big Data, UAVs can be used with LIDAR, etc. The subjects above will be explored further in the remainder of this section:

3.1 Big Data

3.1.1 Background

Big data is the term increasingly used for data sets that are so large or complex that traditional data applications do not have the capacity to analyse and manage them. There are several aspects of big data; it is not just the volume of data that defines it:

- Volume – By its definition, big data is big! Organisations receive data from a wide range of sources including transactions, sensors, communications, social media, etc. Storing this data can be an issue, although systems are being developed to manage this.
- Speed – Data can now be streamed at very high speeds, but this increases the need to deal with that data in a timely way, in some cases almost in real-time!

- Diversity – Data is produced in a wide variety of formats. In order to get the most from diverse data it is necessary to be able to combine data in different formats.
- Inconsistency – The supply of data can be variable, coming in peaks and troughs throughout the day, varying daily, weekly or seasonally and can even be triggered by certain events, which makes it challenging to manage. This is especially challenging if the data is unstructured.
- Complexity – Data comes from many different sources, providing a challenge to link it together and transform it across systems. There is a need to keep on top of this challenge to prevent losing control of the data coming in.

As well as analysis and management, other challenges of big data include capture, data cleaning, search, data sharing, data storage, data transfer, visualisation, querying, updating and ensuring that the data maintains its privacy. The term big data is often used to define how a data set is analysed or how the value is extracted from it. Big data can lead to very accurate results, which in turn could lead to more confident decision making. Logically better decisions can result in greater operational efficiency, cost reduction and reduced risk.

There are numerous applications that have already been identified for big data, but inevitably very many that are yet to be found. Data sets are growing rapidly, partly because they are increasingly gathered by numerous and cheap information-sensing mobile phones and tablets, remote sensing devices, software logs, cameras, microphones, radio frequency identification (RFID) readers and wireless networks, as well as many other devices. In addition many more organisations are making data available through open source outlets, with governments and aid agencies especially adopting open source policies. The world's technological per-capita capacity to store information has roughly doubled every 40 months since the 1980s; (CGD Report, 2014) It is claimed that as of 2012, 2.5 Exabytes (2.5×10^{18}) of data is created every day (M Wall, 2014 / IBM, 2013). The ownership of big data is also a question that has not been sufficiently answered.

3.1.2 Introduction

There is an increasing volume of research and projects that use big data, and our capacity to manage such data sets is improving all the time. Big data is a very broad term that overlaps with many of the other areas we are looking at, for example satellite data can be termed as big data, as can mobile phone data.

Many of the projects that use big data are linked to remote sensing, such as the Transport Infrastructure Management (TIM) project (ESA, 2015). This is a European Space Agency (ESA) project which measures ground movements using Global Navigation Satellite Systems (GNSS); it uses archive satellite data (big data) from the ESA to identify ground movements and is using the M25 as a pilot study. The main aim of the project is to develop a methodology for processing and harmonising data to meet a specific need of the client.

AfCAP itself has researched the use of GPS data in determining road condition in Mozambique (D Geilinger, L Herman, 2013). This uses traffic speed as an indicator of road condition with the objective of developing a practical, affordable, reliable and objective method of monitoring condition and level of service of the unpaved road network. This has the potential to use big data from mobile phones for the same purpose.

A similar exercise was undertaken in Nigeria where mobile phone data was used to determine journey times on the strategic road network. The data on thousands of journeys was analysed and was compared with data collected from the more traditional moving observer journey time method. The objective was to monitor the impact of a large transportation programme, based on the premise that if road condition improves, journey times will reduce.

The African Development Bank has established a big data portal on its website which will provide open access to big data: http://www.afdb.org/en/knowledge/statistics/open-data-for-africa/. Similarly the World Bank, UN Global Pulse, IMF, USAID, Development Gateway and AidData, amongst others, have all provided open access to data (A Bhushan, 2012).

The Centre for Global Development comments on the importance of open data in Africa for a number of reasons, including assisting in the fight against poverty and providing greater transparency (CGD Report, 2014).

Big data is being used in various ways in High Income Countries (HICs), including to predict driving conditions as a result of weather. Europe already has an initiative to use big data for the transport sector, called the Open Platform for European Road Assessment (OPERA). This is 'cloud based' and focuses on generating value through reuse of public and private road infrastructure information. A vast amount of data is being generated, but it is fragmented and needs to be harmonised. With road authorities facing restricted budgets, OPERA aims at improving methods for using data for optimal mobility and safety. The overall aim is for all European road authorities to make their road data available to the public, which will lead to the creation of big data companies and services and the development of new and improved products for the road sector (HO Nielsen, 2014).

3.1.3 Potential areas of development

The capacity of the world to process big data is growing (M Hilbert, P Lopez 2011). There is potential for African countries and organisations to learn from the examples noted above and to form links and partnerships with relevant bodies, with the aim of utilising big data for the benefit of roads in Africa. There are many areas where this could be exploited, but cross border issues provide probably the most important, including:

- Information on contractors, rating their performance, whether they are solvent, etc.
- Identification and harmonisation of different technologies
- Materials and how they can be used
- Standards and specifications: At present many African countries use different design and maintenance standards, often from varying sources and using different testing regimes. Big data would help to better inform countries on more appropriate standards and how they should be applied.
- Maps and cadastral data
- Optimising product performance and identifying new products that have not been successful
- Cross border transportation, making regional transport routes more efficient
- Harmonisation of rules and regulations such as axle weight monitoring

It may be possible to establish a link between local bodies such as the Regional Centre for Mapping of Resources for Development (RCMRD) and established HIC organisations to share big data processes and learn from their experience, as well as having direct access to useful data.

3.2 Mobile Phones

3.2.1 Background

Mobile phones were developed soon after the Second World War, following advances in radio communications during the war. In their early development they were large and heavy and used analog networks, whereas modern phones use digital networks. The first mobile phone networks were created in the late 1970s in Japan.

Early mobile phones were expensive, costing in the region of three thousand pounds. However, as the technology has advanced and become more widespread, and competition has developed in this multi-billion pound sector, prices have continued to fall. This has made mobile phone technology widely available in LICs and last month a smartphone was released in India for just £3, just one thousandth of the original price, not taking into account inflation over the intervening forty or so years.

3.2.2 Introduction

The capacity of mobile phones and the functions they can perform have increased exponentially, to the extent that they can almost replace a personal computer. Mobile phones today are not only phones, they have a wide range of other uses. The uses for a mobile phone in 2016 include:

- Telephone calls
- Texting / SMS
- Email (direct to servers or via the internet)
- Internet
- Watch/clock (many, especially younger, people primarily use their phones to tell the time)
- Camera (the first mobile phone that included a camera was produced in 2000 in Japan)
- Video (digital video recording)
- Audio recording
- Gaming
- Document viewer (including Microsoft applications, Adobe, etc.)
- Music player (either through the phone speaker or external speakers)
- Computer (uses 'apps' to perform functions)
- Calculator (almost all phones have advanced calculator functions)
- TV (can be streamed live to mobile phones)
- Wallet (for online banking or payments direct)
- Bar-code reader (barcodes and Quick Response or QR codes)
- Fingerprint scanner
- GPS tracker (defines the phone location by satellite)
- Accelerometer (tells the phone which way up to present the screen)
- Bluetooth connectivity (wireless connection to external devices)

However, making a call is now only the sixth most common use for a mobile phone, a study has found (Mail Online: 2014). Navigation apps such as Google Maps are popular, with one in six respondents admitting they would feel unable to travel around an unfamiliar city without one. Mobile phones started a rapid rise in LICs from the mid-1990s, but few people predicted the rise in Africa would be as spectacular as it has been (Figure 1). Now, with more than 400 million subscribers, its market is larger than North America's, as Africa took the lead in the global shift from fixed to mobile telephones.

Figure 1 – The extent of mobile phones in Africa

A UN article (UN [1], 2010) states that 'Rarely has anyone adopted mobile phones faster and with greater innovation'. Africans are coupling their already extensive use of cell phones with a more recent and massive interest in social media. In the process, Africans are leading what may be the next global trend: a major shift to mobile Internet use, with social media as its main drivers. Mobile internet and social media are the fastest-growing areas of the technology industry worldwide and it is predicted that mobile internet use will soon overtake fixed internet use.

An indication of the popularity and extent of mobile phones can be seen from the fact that out of the world's estimated 7 billion people, 6 billion have access to mobile phones, whereas only 4.5 billion people have access to a working toilet. (UN [2], 2013)

3.2.3 Application of mobile phones

Mobile phones are used for communication in roads authorities and agencies around the world, with the use of calls and SMS being the most obvious advantage. However, they have also been used innovatively to contribute to the knowledge and evaluation of rural roads. Some of the most effective ways have been:

- Mobile phone camera – with the increase in quality of mobile phone cameras and the ease with which the photographs can be transferred by email or by other means, has greatly facilitated monitoring of road maintenance, projects, etc. This can also include videos.
- Roughness measurement – Mobile phones include an accelerometer which helps to monitor which position the phone is in and maintain the screen in the correct position so that it is readable at all times. This accelerometer has been used innovatively to measure the roughness of a road, based on how much the phone moves whilst in transit within a vehicle. There are now several 'apps' on the market that utilise this feature.

  The Android app 'RoadLab' uses accelerometers, gyroscopes and GPS to autonomously measure and evaluate road roughness on IRI scale (International Roughness Index) before sending the information to cloud servers via cellular network or Wi-Fi. Algorithms used by the app take into account vehicle speed, suspension type and the phone's position in order to achieve precise measurements for roughness. The app starts making measurements automatically when the vehicle's speed reaches 30km/h or it can be controlled manually. The app also includes a feature for manual submission of dangerous road problems such as severe road bumps or debris, or road accidents. A user only has to take a picture of the issue and it will be sent with GPS coordinates to cloud servers managed by local road management agencies.

  Apart from the app there is also a web interface for road management agencies that receive and analyse the incoming data and make visualisations on the map. This innovative solution is one of the first to use consumer tech and crowdsourcing principles with a goal to improve road infrastructure around the world. This collaborative approach provides wider coverage of the network at frequent intervals and collects uniform data to support strategic and network level asset management decision making.

- Crowdsourcing – Mobile phones have also been used to identify areas of a road that require maintenance. This again uses the accelerometer but by identifying large movements that could represent a pothole or other defect. The information is automatically sent to a client's server who then analyse the data to identify defects in the road, based on the number of corresponding 'hits'.
- Other crowdsourcing uses related to transport are the monitoring of journey times using mobile phone data, as well as monitoring and reporting traffic density at certain times of the day. These uses clearly depend on being able to access the data from the mobile phone company, which may not be free of charge.

We plan on using the World Bank app 'RoadLab' to gain an estimation of roughness on the roads to be ground truthed, which is available free of cost. The function of producing a GPS track of the road which can be used for mapping purposes, as well as the photographs or videos which will be geo-referenced, are an important aspect for the road manager.

3.3 Social media and crowdsourcing

3.3.1 Background

Social media are computer based tools that allow people, companies and other organisations to create, share, or exchange information. There is a wide range of social media types, but there are some common features:

- They contain user-generated content such as text, digital photo or digital video posts
- Users create their own profiles for the website or application
- Social media facilitate the development of online social networks

Social media depend on mobile and internet based technology to create highly interactive platforms through which individuals and communities share, co-create, discuss, and modify user-generated content. They have introduced substantial and wide-ranging changes to communication between businesses, organisations, communities, and individuals.

Some of the most popular social media sites are:

- Facebook
- Linked-In
- Twitter
- Snapchat
- Instagram
- WhatsApp
- YouTube

Crowdsourcing is a modern term first used in 2006. It can be defined as the process of obtaining needed services, ideas, or content by soliciting contributions from a large group of people. This source is usually an online community, rather than employees or suppliers. This mode of sourcing is often used to divide work between participants.

3.3.2 Introduction

Studies suggest that when Africans go online (predominantly with their mobile phones) they spend much of their time on social media platforms (Facebook, Twitter, YouTube and so on). Sending and reading e-mails, reading news and posting research queries have become less important activities for Africans.

In recent years Facebook, the major social media platform worldwide and currently the most visited website in most of Africa, has seen massive growth on the continent. The number of African Facebook users stood at over 17 million in 2010, up from 10 million in 2009. CNN reports that in 2014 that figure stood at 100 million (over 80% by mobile phone) and in 2016 that figure has jumped to over 120 million (CNN, 2014).

An example of crowdsourcing is the Boston Streetbump (City of Boston, 2013) as mentioned earlier, where mobile phone users are asked to download an app that will record road condition through the accelerometer on a mobile phone, and transfer the results to a central repository. This data is then analysed and is used as the basis for road maintenance programmes.

3.3.3 Applications of social media or crowdsourcing

We plan on using social media to encourage people to report defects in the road, hazards or other issues. This would consist of linking with a popular social media product, such as Facebook, to make the reporting accessible to everyone and easy to do. Ideally the report would be in a standard format with check boxes and the ability to attach photographs. The location and photos should also be geo-referenced. There could then be a possibility to link with satellite imagery as a check of validity and urgency.

This is of course dependent on the rural communities having access to smartphones and network coverage. Our first task therefore would be to investigate the feasibility of the research from this perspective. We recognise that this level of access may only be possible in urban or peri-urban environments, although we assume that many rural towns will have adequate access.

It may be possible to persuade Facebook to produce the app for this pilot, otherwise we will seek alternative funding in association with the partner country.

3.4 Unmanned Aerial Vehicles (UAVs)

3.4.1 Background

Unmanned Aerial Vehicles (UAVs) have become very widespread in all aspects of life and have undergone a massive increase in popularity over the last 3 or 4 years. However, the history of drones can be traced back more than 100 years as a fixed wing military development during World War One. They get their nickname 'drone' from the worker bee.

The military has played a large part in the development of 'drones', which has pushed the technology forwards. The main advantage for the military is that they are unmanned, indeed it could be argued that modern commercial aircraft are essentially UAVs where the pilot on a normal long haul flight could be in full manual control of the plane for as little as 3 minutes. Commercial UAV companies are becoming established in large numbers across Europe and the US, as well as Asia and especially China. Recently there has been an exponential increase in capacity, on a similar scale to the computer industry.

The key aspects of drones are the gyros and the batteries, in terms of what they can do and how long they can do it for. They are managed by a gyro control system and when under remote control are generally limited to line of sight control with a range of 500m from pilot to vehicle. They have a built-in homing device if the line of sight is lost or the vehicle flies out of range. As most systems are developed in China the default 'home' is in China, so the operator must re-set the 'home' to prevent the vehicle from trying to return to China when contact is lost. The failure to re-set to home is one of the major causes of drone crashes.

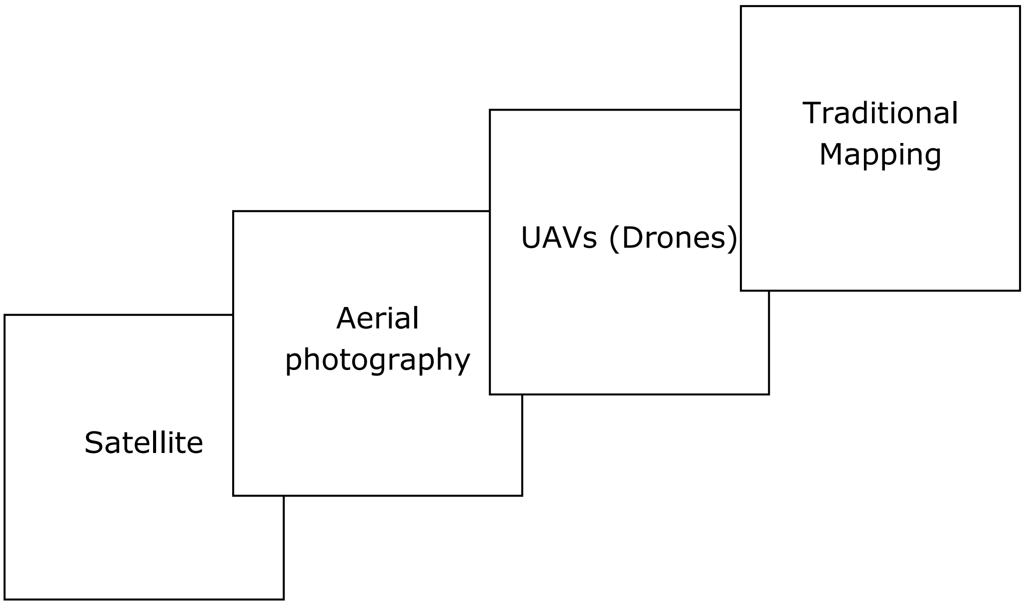
In a similar way to satellite imagery, UAVs are restricted by vegetation and weather. The vegetation issue is more negotiable as UAVs are able to fly below tree canopies, but weather is still very restricting. In UK other issues include range, with multicopters being limited to up to 30 minutes on one battery, although very lightweight solar drones can in theory fly without limit. Also licencing and restrictions on where they are able to fly are limiting because the procedures for flying near to or in populated areas can be quite onerous. Insurance against accident and injury is also necessary.

3.4.2 Introduction

There is certainly a market for UAVs in mapping and road evaluation, see Figure 2. Their versatility allows them to fill the gap between satellite imagery and aerial photography, and traditional mapping. There is also an element of cost effectiveness which enhances this role.

Multicopter devices, such as the one shown in Figure 3, are the most agile and popular for most uses, but their speed and range could limit their usefulness and cost effectiveness for road condition monitoring on a large scale.

Figure 2: The Drone Zone:



Also, in UK UAVs must be controlled by line of sight, which also limits their usefulness, although this may not be a problem in Africa. The typical cost of a commercial vehicle with camera equipment is between £12,000 and £45,000.

Figure 3 – Multicopter UAV

Source: Ocuair

The recently developed hybrids of fixed wing and multicopter have the potential to be more appropriate for road condition analysis. The Jouav hybrid pictured in Figure 4 is one example, which can take off vertically and will then fly as a fixed wing plane. It has an operating time of up to four hours at a potential cruising speed of 90km/hr. It can operate up to a ceiling of 4,000m as fixed wing, and its hovering ceiling is 1,500m.

In theory the range of some UAVs is unlimited when they can operate on solar power or be refuelled in flight, but at the moment their development is not at the stage where they can be used robustly for road condition assessment. The Airbus HAPS Zephyr is being used operationally and could potentially be used for road condition assessment, although at present the focus is mostly upon military and security applications (Airbus, 2016).

Figure 4: Hybrid UAV

Our literature review has uncovered many and varied uses of UAVs, from building inspections and mapping to disaster assessment and agricultural monitoring. However, there were relatively few instances of UAVs being used to monitor road condition and assets. The two main items we uncovered were:

- Monitoring the condition of unpaved roads with remote sensing and other technology, Final Report for US DOT DTPH56-06-BAA-0002, Principal Investigator: Dr. Chunsun Zhang, 2011.
- Characterization of Unpaved Road Condition Through the Use of Remote Sensing Project, Final Report for US DOT RITARS-11-H-MTU1, Colin Brooks, 2014.

From 2011 to 2014 the Michigan Technological University and United States Department of Transportation (USDOT) carried out a project entitled "Characterization of Unpaved Road Conditions Through the use of Remote Sensing". This project primarily considered using flown surveys and concluded on hexacopter UAVs (Figure 5) as the most appropriate, cost effective and practical system for assessing the condition of unpaved roads.

This project took three years to complete and was worth $2,483,814 (approximately £1,700,000). From our extensive search it appears to be the only detailed research undertaken using UAVs to assess the condition of unpaved roads. There were estimated to be more than 1.4 million miles of unpaved roads in the US in 2011 (MTU, 2013), so the scale of the asset warranted the research budget.

Figure 5 – Hexacopter using in MTU research

Source: Michigan Technological University, http://integratedglobaldimensions.com/unpaved/

In the United States LIDAR pods have been developed to be small enough for use by UAVs. This is further discussed in the section on LIDAR, but is clearly a new and innovative use of an existing technology.

In Africa defibrillators are being transported by drone to remote places where they are needed, where going by road would be much more onerous and take more time. Drones are also being used to deliver vaccines and other medicines to remote and inaccessible areas.

Apparently some multinational organisations are considering large scale transportation of goods within Africa, and even establishing a drone superhighway!

3.4.3 Applications of UAVs

We see the application of UAVs being mainly in the road condition assessment area. With mapping being possible by the use of medium resolution and cheap or freely available satellite imagery, their cost effective use in this area is likely to be minimal. However, their use with various mediums of evaluation, such as LIDAR, photography, etc. would be appropriate to research.

The main issue in this area will be the funding of UAVs to undertake the research. The cost of UAVs makes it unfeasible to procure them for the scale of research to be undertaken, so it makes more sense to hire them. However, unless they are available within country, there are also likely to be barriers to importing them and using them in an environment where perhaps they have not been used before. The World Bank has encountered such issues with their project in Mozambique (World Bank, 2015).

However, we believe that UAVs will be available to hire locally, which would overcome this issue. For example, they are available for hire in Malawi and the only regulation at the moment is that they are not allowed to fly above 500 feet. It is of course possible that the lack of local regulations for a new technology such as this will mean that there is greater flexibility and scope for using the UAVs.

The areas we would like to trial using UAVs are:

- Visual imagery, possibly using photogrammetry
- LIDAR

As mentioned before the cost of these technologies will be prohibitive, so unless additional funding is identified by the partner countries or other partners it will not be possible to include UAVs in the pilots.

3.5 Internet of Things (IoT)

3.5.1 Background

The internet of things (IoT) is the network of physical devices, vehicles, buildings and other items that are embedded with electronics, sensors, software and connectivity to the internet or other networks that enable these objects to collect and exchange data. More recently it has been defined as "A global infrastructure for the Information Society, enabling advanced services by interconnecting (physical and virtual) things based on, existing and evolving, interoperable information and communication technologies" by the International Telecommunication Union (ITU) (ITU, 2012). In 2013 the Global Standards Initiative on Internet of Things (IoT-GSI) defined the IoT as "the infrastructure of the information society." (IoT, 2013).

The IoT allows objects to be sensed or controlled remotely using existing network infrastructure. This creates opportunities for more direct integration of computer-based systems into the physical world. The potential rewards could be improved efficiency, accuracy and economic benefit. The IoT can also be augmented with sensors and actuators, which can produce the concepts of smart homes, intelligent transportation and smart cities. Each thing is identifiable uniquely through its embedded computing system, but is able to operate within the existing internet infrastructure. Experts estimate that the IoT will consist of almost 50 billion objects by 2020 (D Evans, 2011).

The term IoT was initiated in 1999 by Kevin Ashton, whilst working at Auto-ID Labs which use RFID (Radio Frequency Identification Device) technology. IoT is expected to offer extended connectivity of devices, services and systems that is beyond machine to machine communications. The interconnected nature of these objects or devices is expected to facilitate automation in nearly all fields.

"Things," in terms of the IoT, can refer to a wide variety of devices from vehicles with built-in sensors and operating devices that can assist in search and rescue operations, to heart monitoring implants and DNA analysis devices for environmental monitoring. 'Things' can be seen as an eclectic mix of hardware, software, data and services which collect useful data with the help of various existing technologies and then autonomously flow the data between other devices.

As well as the expansion of Internet-connected automation into a wide variety of new areas, IoT is also expected to generate large amounts of data from diverse locations, with the consequent necessity for quick aggregation of the data and an increase in the need to index, store, and process such data more effectively. IoT is one of the platforms of today's Smart City and Smart Energy Management Systems.

3.5.2 Introduction

There is a common discussion about whether the IoT is real. In terms of a practical use for the IoT, a number of things need to be in place for it to be a reality. Firstly a 'thing' needs to have a unique identity. This is at the core of computer functionality, in the same way that every website has to have a unique address so that the computer can work out what it is connecting with. Secondly the 'thing' has to have a means of communicating, in order for it to be connected to the internet. There is a wide range of different ways to connect. Thirdly, the thing that really defines the IoT is that a 'thing' has to have a sensor. This can be any number of sensors, from an RFID to a GPS sensor, but it will be able to tell you something about the 'thing'. Lastly there has to be a way to control the 'thing'. We are seeing more and more how devices are being controlled by smart phones, which is the most common way that IoT things are controlled.

An example of this use of the IoT could be a car. If this car had a unique identity, a sensor and connectivity then in theory you would be able to find out who is driving it and where they are going from anywhere in the world. It would also be possible to control certain aspects of that car, if the appropriate mechanisms were in place.

The future of the IoT seems to be boundless. Some of the key potential uses for IoT are shown below:

- Learning about things. At present we can learn about things through the internet, by reading and researching. As sensors become more widespread we will be able to learn about things directly, maybe using our smartphones to interrogate things for information. An example could be learning about a used car before we buy it, finding out its history, who owned it, how many miles it has done, what crashes it has had, what parts have failed, how it has been driven over a number of years, etc. At the moment we can get some of this information via the internet, but in the future it could be possible to find this out with a single push of the button.
- Monitoring things. At the moment we use sensors to monitor things. Using the IoT can combine a number of sensors and combine the data to provide more knowledge. A key potential area of use for monitoring is health. It could be possible that smartphones can be used to monitor our activity, our diet, our heart beats and a number of other things. This could then be combined to give us regular updates on our health and even warn us when an issue is expected.
- Searching for things. At the moment it is possible to buy GPS sensors that are attached to our possessions and we can then track their movements on our smartphones or computers.

If we can tap into the existing array of sensors already in place around the world, we could search and find almost anything, even aeroplanes at the bottom of the ocean.

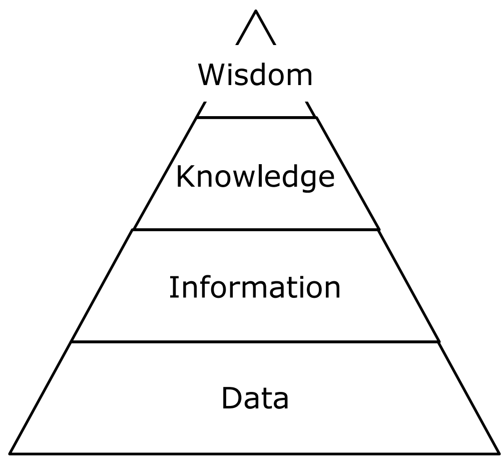
- Managing things. A lot is being made of smart homes and smart cities, where energy and resources are managed in a more efficient way. With more than half of the world's population now living in urban areas, and the majority of resources being consumed there, there is a lot of interest in making our energy use more efficient. In most African cities there is a serious problem with traffic; if we could use sensors and the internet to make traffic flows more efficient, this would have a great impact on resource usage.
- Controlling things. Smart meters are an example of how we can control things through the IoT. For example, the appliances in our house could be linked together and told to operate at the most efficient times for energy usage, whilst we are not there. In the context of roads we could control traffic lights in response to incidents on the road. If we had greater control of traffic systems and vehicles we could drastically reduce the number of road collisions per year, currently running at more than 1 million annually around the world.
- Playing with things. Finally there is also scope for games to interact with the sensors around us to create games where things and people in our present location become part of the game. This uses images from our smartphones or archive pictures from the local environment. This has already been initiated by one gaming company and is likely to take off in the near future.

The potential drawback to this of course is viruses and the various ways that things interconnecting could be corrupted and viruses passed on to any number of things. This is probably the biggest challenge to the IoT, but in the same way it creates an opportunity for software developers to create fixes.

The DIKW pyramid (Figure 6) is often referred to for an explanation of the hierarchical relationships between data, information, knowledge and wisdom. The ultimate goal of IoT is to learn from the data collected. Initially data is collected and analysed for its core principles. When the data is separated into its core principles, it allows questions to be asked of it, such as who, what, where? When these questions are asked patterns are formed which transform the information into knowledge. Knowledge is essentially an understanding of the data, but this knowledge is subjective to the end goal of the user. Once the data has become knowledge, wisdom can be gained through recognising relationships between the knowledge centres.

The wisdom can then be used to shape the future. People can review what worked in the past and make decisions on what to do in the future. New data that is gathered will be based on previous wisdom gained. This helps to move society forward and in theory avoid repeating mistakes of the past.

Figure 6 - The DIKW pyramid



The IoT has been described as the central nervous system of the planet. If it progresses as expected there could be six or seven connected devices for each person in the world by 2025. In terms of the roads sector, the applications are probably only limited by our imagination. There are already sensors in vehicles, in the road for traffic counters and traffic lights, in our smartphones which we always carry with us, and in several other things in and around the road. So the infrastructure is already partly there, the next step is to see how it could be used.

IoT is a relatively new concept for Africa, but it has already made an impact as the emergence of connected hardware takes off. One of the reasons for this is the extended use of mobile phones in Africa, and in particular smartphones. Every area of life has the opportunity to benefit from the innovations and efficiencies possible in a fully connected world. The IoT is already making its presence felt on the African continent by addressing a host of issues around security, water control, energy, health monitoring and medication, mining and traffic congestion. Africa has unique problems and an HIC solution may not be the best fit for the local environment. It is therefore essential to first identify and define the problem, before we devise a solution.

Many African countries have already taken advantage of IoT technologies; from utility service providers using connected meters to track usage and pre-empt surges in demand or faults, to allowing healthcare providers to track the health of outpatients. RFIDs are a good example: These very small identifiers can be inserted into an object and when scanned, will provide a unique identification. They have been used in clothes (to prevent theft from shops), in pets to identify strays and even attached to steel bars where they can be identified after they have been encased in concrete. RFIDs are superior to barcodes as they do not need to be visible to be scanned.

The flexibility that is present in Africa due to the lack of legislation in this area is actually allowing African countries to leapfrog in a number of areas that HICs would find difficult.

Initially IoT initiatives were primarily used in vehicle tracking. However, they quickly moved into mobile payments and even smart cities. Some examples are:

- South Africa has started to use smart meters to measure household utility usage in Johannesburg.
- The mining sector is using sensors to detect methane and rock movement.
- Fuel pipelines have been fitted with sensors to monitor leaks.
- Some research has also been carried out using sensors to monitor moisture in roads and the seasonal effect that rainfall has on road deterioration.
- The retail sector has also used RFID tags to track items in a retail environment.

Many other uses are identified in the article 'How the IoT is having an impact in Africa' (Guest Author, 2015). This article also claimed that by the end of 2014 the number of cellular machine-to-machine connections in the developing world totalled 128 million, or 52% of the global numbers, as estimated by the global industry body GSMA. They predict that this figure will rise to nearly 60%, or 575 million, by 2020. However, with relatively low internet availability and accessibility in some African countries, this can be a barrier to IoT adoption. With internet accessibility growing and connection speeds increasing there is a need to create more security and reliability around IoT data.

Mobile phone giant Ericsson has predicted that IoT is set to overtake mobile phones as the largest category of connected device by 2018 (IT News Africa, 2016).

3.5.3 Application of IoT

There is potential to use IoT in this project in the following areas:

- Vehicle monitoring, with relevance to transport movements, cross border movements, etc.

- Journey time surveys using mobile phone data or vehicle sensors, similar to that carried out in Nigeria. This would require mobile phone companies to release large amounts of data, which may be difficult to achieve
- Accelerometers in mobile phones. These have been used in various applications already to measure roughness as IRI and are likely to be included in the condition monitoring pilot.
- Road Safety. Monitoring and controlling vehicle movements, detecting faulty vehicles, monitoring driver behaviour including tiredness, and many other possibilities.
- Alleviating traffic congestion. This is happening to some extent in HICs, but has the potential to help alleviate the serious traffic congestion issues in many African cities.

3.6 Internet related solutions (linked-data, semantic web)

3.6.1 Background

Linked Data is about using the Web to connect related data that wasn't previously linked, or using the Web to lower the barriers to linking data currently linked using other methods. More specifically, Wikipedia defines Linked Data as "a term used to describe a recommended best practice for exposing, sharing, and connecting pieces of data, information and knowledge on the Semantic Web using URIs and RDF”. A Uniform Resource Identifier (URI) is a string of characters used to identify a resource. Such identification enables interaction with representations of the resource over a network, typically the World Wide Web, using specific protocols. The Resource Description Framework (RDF) is a family of World Wide Web consortium (W3C) specifications originally designed as a metadata data model. It has come to be used as a general method for conceptual description or modeling of information that is implemented in web resources, using a variety of syntax notations and data serialisation formats. It is also used in knowledge management applications.

Linked data is a method of publishing structured data so that it can be interlinked and become more useful through semantic queries. It builds upon standard Web technologies but rather than using them to serve web pages for human readers, it extends them to share information in a way that can be read automatically by computers. This enables data from different sources to be connected and queried.

The Semantic Web is an extension of the Web through standards by the World Wide Web Consortium (W3C). The standards promote common data formats and exchange protocols on the Web, most fundamentally the RDF. According to the W3C the Semantic Web provides a common framework that allows data to be shared and reused across application, enterprise, and community boundaries. The term was coined by Tim Berners-Lee for a web of data that can be processed by machines. While its critics have questioned its feasibility, proponents argue that applications in industry, biology and human sciences research have already proven the validity of the original concept.

3.6.2 Introduction

Essentially, the concept of linked data and the semantic web marks a change in thinking from publishing data in human readable HTML documents, to machine readable documents. This would mean that machines could do a little more of the thinking work for us. Today, much of the data available from the web is delivered in the form of web pages - HTML documents that are linked to each other through the use of hyperlinks. Humans or machines can read these documents, but apart from seeking keywords in a page, machines have difficulty extracting any meaning from these documents themselves.

The web contains a lot of information, but usually the raw data itself is not available from the web page directly. Only HTML documents which are constructed from data are available, assuming that a web site is generated from a database.

So the theory of the semantic web is to change the landscape of the internet with regard this problem in the following ways:

- Opening up data on the web to artificial intelligence processes, which essentially is aimed at getting the web to do a bit of our thinking for us.
- Encouraging companies, organisations and individuals to publish their data freely, in an open standard format. This is being done to some extent, but usually in different formats.
- Encouraging businesses to use data already available on the web.

In essence, it involves taking all the information published in HTML documents in different places, and allowing it all to be treated and researched as if it were one database. The benefits to the automated research of all the data the world has to offer on the internet in comparison to today's tools and software are tremendous.

3.6.3 Applications of internet related solutions

Generally the accessibility of web information in a single format would be good for all types of research and useful for road authorities around the world. The potential applications for using data in the roads sector are massive, but some that are immediately obvious include:

- Mapping. The World Bank is managing a project in the Philippines which is using various different sources of data to build up mapping. This method was used in the Nigeria project to build up the mapping, but the data was not readily available on the web and it proved to be quite an onerous process, so the semantic web could have helped in this instance.
- Road Safety. It is possible to combine maps of an area with road traffic collision records and see which routes are the safest or most dangerous. This can also be disaggregated to show specific modes of transport, for example bicycle collisions.

At present it is not clear at this stage how this can be utilised within the scope of this project, until the data that is required has been identified. However, there are certainly massive gains to be had in the future.

3.7 Computer related solutions (data modelling, distributed computing)

3.7.1 Background

Data modeling is a process used to define and analyse data requirements needed to support the business processes within the scope of corresponding information systems in organisations. Therefore, the process of data modeling involves professional data modelers working closely with business stakeholders, as well as potential users of the information system.

There are three different types of data models produced while progressing from requirements to the actual database to be used for the information system.

- Conceptual Data Model: The data requirements are initially recorded as a conceptual data model, which is essentially a set of technology independent specifications about the data and is used to discuss initial requirements with the business stakeholders.

- Logical Data Model: The conceptual model is then translated into a logical data model, which documents structures of the data that can be implemented in databases. Implementation of one conceptual data model may require multiple logical data models.
- Physical Data Model: The last step in data modeling is transforming the logical data model to a physical data model, which organises the data into tables, and accounts for access, performance and storage details. Data modeling defines not just data elements, but also their structures and the relationships between them.

Data modeling techniques and methodologies are used to model data in a standard, consistent, predictable manner in order to manage it as a resource. The use of data modeling standards is strongly recommended for all projects requiring a standard means of defining and analysing data within an organisation.

Distributed Computing is a field of computer science that studies distributed systems. A distributed system is a model in which components located on networked computers communicate and coordinate their actions by passing messages. The components interact with each other in order to achieve a common goal. Three significant characteristics of distributed systems are:

- concurrency of components,
- lack of a global clock, and
- independent failure of components.

Examples of distributed systems vary from Service-Oriented Architecture (SOA) based systems to massively multiplayer online games to peer-to-peer applications. A computer program that runs in a distributed system is called a distributed program, and distributed programming is the process of writing such programs. There are many alternatives for the message passing mechanism, including pure Hypertext Transfer Protocol (HTTP), Remote Procedure Call (RPC) like connectors and message queues.

3.7.2 Introduction

A distributed system consists of more than one self-directed computer that communicates through a network. All the computers connected in a network communicate with each other to attain a common goal by making use of their own local memory. On the other hand, different users of a computer possibly might have different requirements and the distributed systems will tackle the coordination of the shared resources by helping them communicate with other nodes to achieve their individual tasks. Examples of distributed computing are the World Wide Web, Facebook, Cloud based systems.

Some of the advantages of distributed computing are:

- Ease of access
- Software and cost sustainability
- Robustness, as there are no single points of failure
- Modular, scalable architecture
- Open source software, vendor independence

Distributed computing is also related to other concepts such as Grid Computing and the Cloud.

Whereas distributed computing refers to managing large numbers of computer systems to enhance memory and processing power, grid computing has additional characteristics; it looks to maximise the entire computational pool of resources of a company or companies to create a larger pool of computing resources. It offers an opportunity to access greater computing power at a fraction of the current cost of technology and provides a powerful aggregated computing facility useful for high performance scientific and business activities. Universities and research communities have already started using the grid for solving complex and difficult problems that were previously unsolvable.

Cloud computing can be defined as a system that enables individuals and businesses to choose how they will acquire or deliver IT services, with reduced emphasis on the constraints of traditional software and hardware licensing models. Cloud computing is a style of computing that is very scalable and flexible, and where capabilities are delivered as a service to the users using the Internet. The services could include infrastructure, platform, applications and storage space. The users only pay for the services and resources they actually use and they do not need to build infrastructure of their own.

Cloud computing usually refers to providing a service via the internet, such as off-site storage or computing resources, whereas distributed computing means splitting a large problem to have a group of computers work on it at the same time.

3.7.3 Applications of computer related solutions

The applications of these systems in general are unlimited. In relation to the roads sector and in particular to African roads, there will clearly be benefits in the future. Although the existing applications of these systems will benefit the project, such as cloud storage, its application to this particular research at this time is yet to be defined. As the project progresses we will continue to look for opportunities to utilise these systems.

3.8 Machine learning and artificial intelligence

3.8.1 Background

Machine learning is a subfield of computer science that provides computers with the ability to learn without being explicitly programmed. It has been around for a long time and initially evolved from the study of pattern recognition and computational learning theory in artificial intelligence. Machine learning explores the study and construction of algorithms that can learn from and make predictions on data.

Machine learning is closely related to (and often overlaps with) computational statistics, which also focuses in prediction-making through the use of computers. It has strong ties to mathematical optimisation, which delivers methods, theory and application domains to the field. Machine learning is sometimes linked with data mining, where the latter focuses more on exploratory data analysis and is often known as unsupervised learning.

Because of new computing technologies, machine learning today is not like machine learning of the past. It was born from pattern recognition and the theory that computers can learn without being programmed to perform specific tasks; researchers interested in artificial intelligence wanted to see if computers could learn from data. The iterative aspect of machine learning is important because as models are exposed to new data, they are able to independently adapt. They learn from previous computations to produce reliable, repeatable decisions and results. It is a science that is not new, but one that is gaining fresh momentum.

While many machine learning algorithms have been around for a long time, the ability to automatically apply complex mathematical calculations to big data – over and over, faster and faster – is a recent development. Some examples of machine learning applications are:

- The self-driving Google car.
- Online recommendation offers such as those from Amazon and Netflix.
- Knowing what customers are saying about you on Twitter, machine learning combined with linguistic rule creation.
- Fraud detection.

Artificial intelligence (AI) can be defined as intelligence exhibited by machines. The ultimate goal of AI would be to recreate the most complex machine in the universe, the human brain!

In computer science, an ideal "intelligent" machine is a flexible rational agent that perceives its environment and takes actions that maximise its chance of success at a particular goal. Normally, the term "artificial intelligence" is applied when a machine mimics cognitive functions that humans associate with other human minds, such as learning and problem solving.

3.8.2 Introduction

It could be argued that machine learning and AI are very similar and that the line between them is blurred. Recent arguments propose that machine learning is really the only type of AI we have achieved, as we haven't yet found a way for machines to really think for themselves. The recent move towards 'Deep Learning' is probably the closest we have come yet to true AI.

In theory, as machines become increasingly capable, facilities once thought to require intelligence are removed from the definition. For example, optical character recognition is no longer perceived as an example of artificial intelligence since it has become a routine technology. Capabilities currently classified as AI include successfully understanding human speech and competing at a high level in strategic game systems such as Chess, but this is defined as narrow AI. For example a computer can beat the human world champion as Chess, but ask it to play draughts, a much simpler game, and it wouldn't know where to start. So there is a long way to go before we reach full AI, but if it is reached at some point in the future it is often said that it could change the human race forever.

3.8.3 Application of machine learning and artificial intelligence

The applications of this to roads, and specifically to roads in Africa, is in some aspects quite straightforward. The most obvious use is to map roads from a satellite image, where one would hope that AI could work out the places where roads are obscured by trees or other objects and be able to continue to map the road when it becomes visible again. It would also be able to identify significant changes in a road's character or width or other aspect and still recognise it as the same road.

A further step for AI would be to assess the condition of a road from satellite imagery. This would require many more variables and the computer would need to learn from its experiences in order to be able to assess the condition accurately. Given the variety of options available from earth observation if AI is developed in this area, it should be possible to make it more accurate than human visual assessment.

3.9 LIDAR

3.9.1 Background

LIDAR is generally thought to be an acronym for Light Detection and Ranging, but there are also claims that it was created as a portmanteau of 'light radar'. LIDAR originated in the early 1960s, shortly after the invention of the laser, and combined laser-focused imaging with radar's ability to calculate distances by measuring the time for a signal to return. Its first applications came in meteorology, where the National Center for Atmospheric Research in the USA used it to measure clouds. The general public became aware of the accuracy and usefulness of LIDAR systems in 1971 during the Apollo 15 mission, when astronauts used a laser altimeter to map the surface of the moon.

A flown LIDAR instrument principally consists of a laser, a scanner, and inertial measurement unit and a specialised GPS receiver, plus of course the computer and software required to collect and analyse the data. Aeroplanes and helicopters are the most commonly used platforms for acquiring LIDAR data over broad areas. Two types of LIDAR are topographic and bathymetric. Topographic LIDAR typically uses a near-infrared laser to map the land, while bathymetric LIDAR uses water-penetrating green light to also measure seafloor and riverbed elevations.

When an airborne laser is pointed at a targeted area on the ground, the beam of light is reflected by the surface it encounters. A sensor records this reflected light to measure a range. When laser ranges are combined with position and orientation data generated from integrated GPS and Inertial Measurement Unit systems, scan angles, and calibration data, the result is a dense, detail-rich group of elevation points, called a "point cloud."

Each point in the point cloud has three-dimensional spatial coordinates (latitude, longitude, and height) that correspond to a particular point on the Earth's surface from which a laser pulse was reflected. The point clouds are used to generate other geospatial products, such as digital elevation models, canopy models, building models and contours.

Airborne LIDAR is not at present generally used for condition assessment, although TRL is carrying out research into vehicle-based LIDAR systems for condition assessment. We believe it is however possible with the rapid development of UAVs to use small LIDAR pods attached to a multi-rotor or fixed wing drone. If this could be used in conjunction with visual images a very good map could be produced with related condition measurements.

3.9.2 Introduction

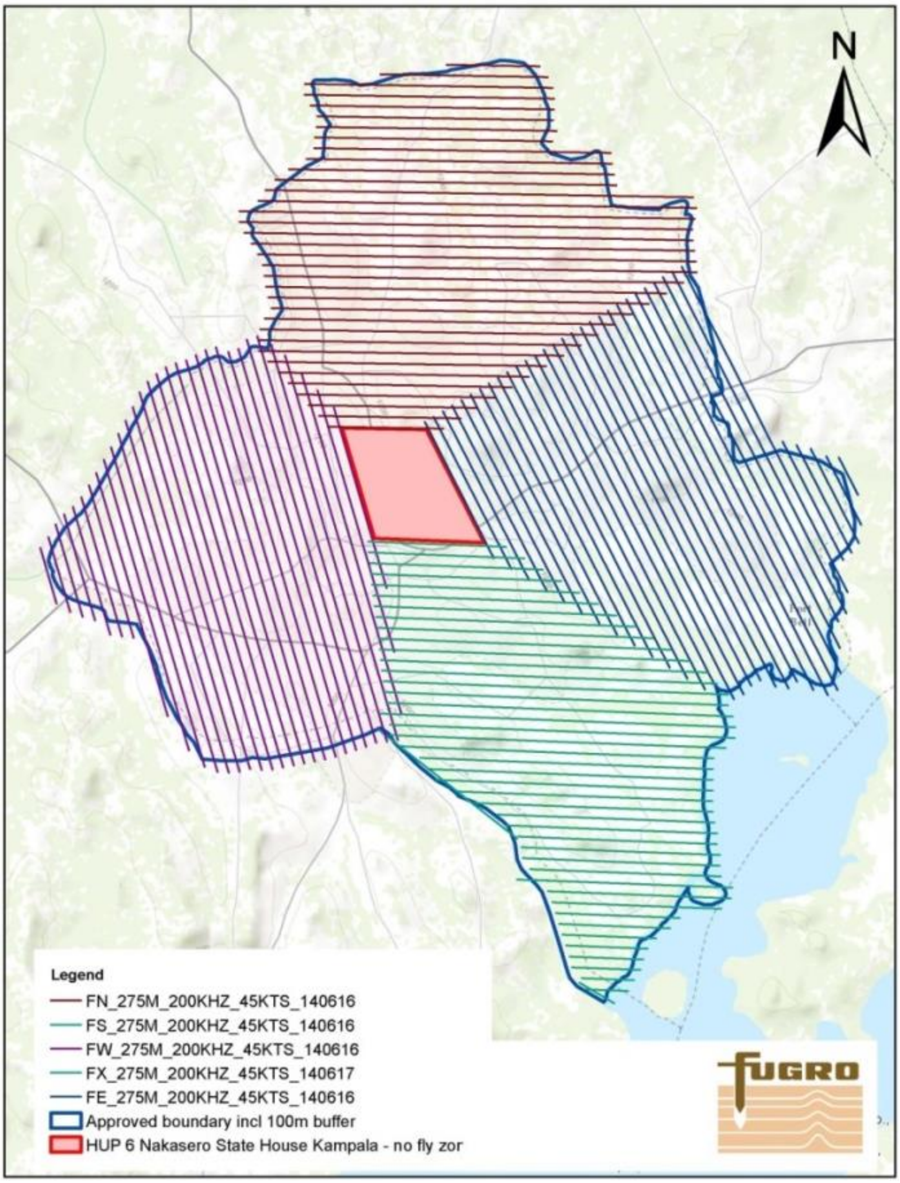
TRL carried out the mapping of Kampala in 2014 using flown LIDAR. This project included mapping and condition assessment exclusively for urban roads within Kampala, carried out for Kampala Capital City Authority (KCCA). Approximately 60% of these roads were unpaved, so a wide range of conditions was experienced.

The network was defined by flown LIDAR surveys and aerial photographs, using a helicopter, see Figure 7 below. The data and images were captured and analysed to provide geo-referenced centre-lines of all KCCA roads. The centre-lines were extracted by referencing to ground control points and analysing the LIDAR and aerial images in an office environment. The flown surveys were completed within two weeks, even with delays for weather and obtaining the necessary flight permits.

Figure 7 – Helicopter used for KCCA LIDAR surveys

The surveys were planned using a grid system, as can be seen in Figure 8. The grids were aligned around the no-fly zone in the centre, which had to be assessed using satellite imagery.

Figure 8 – Areas planned for the flown surveys



A series of ground surveys were planned to gather traffic levels and condition data on all roads. Condition data was collected using the Fugro ARAN 7000 equipment, which collects forward facing images, roughness and laser-measured profiles for surface condition and rutting. Traffic surveys were carried out at strategic points around the city, at sufficient frequency to provide a reliable estimate of traffic on all roads.

For urban roads LIDAR is an appropriate system as it gives a high level of detail to the road network and is usually carried out over a relatively small area. The main issue with conventional LIDAR is that a separate, ground based, system of condition assessment is necessary.

When used as a flown survey it can be quite expensive and it is best carried out in the dry season, as it is vulnerable to bad weather. In addition permissions are often necessary to carry out flown surveys over urban areas, plus some areas may be designated as no-fly zones. Also the data files are relatively large.

3.9.3 Application of LIDAR

The main benefits of using LIDAR are that it is a rapid and accurate way of establishing a road network. With the increase in UAV technology and the development of LIDAR into smaller and lighter units, it is now possible to use LIDAR with drones to carry out a similar type of survey to that undertaken in Kampala by TRL.

In terms of assessing road condition, we believe there is potential for LIDAR to be developed to assist in this area. The extreme development of LIDAR has seen very small units used to collect close-up data. This technology extracts the maximum performance out of the emitters and detectors used by employing components similar to those found in a TV remote control system to create a sensor that can measure distances out to 40 meters in a module that measures 51mm long X 30mm wide X 39mm tall (Dragon Innovation, 2016). At the other extreme commercial six or eight rotor units can use very accurate LIDAR units to create detailed maps of areas (Phoenix, 2015).

However, UAVs are very expensive with commercial units priced up to £45,000 each, although using locally established companies who have the equipment already may be an option. In any case, unless we can find partners to finance this research it will be beyond the scope of this project.

3.10 Aerial photography

3.10.1 Background

Aerial photography can be defined as the taking of photographs of the ground from an elevated position, where the camera is not supported by a ground-based structure. Platforms for aerial photography include:

- Fixed-wing aircraft
- Helicopters
- UAVs
- Balloons, Blimps and Dirigibles
- Rockets
- Kites
- Parachutes
- Birds / Pigeons

Aerial photography was first practiced by the French photographer and balloonist Gaspard-Felix Tournachon in 1858 over Paris. Aerial photography from kites was pioneered by British meteorologist E.D. Archibald in 1882. He used an explosive charge on a timer to take photographs from the air.

The use of aerial photography rapidly matured during the First World War, as reconnaissance aeroplanes were equipped with cameras to record enemy movements and defences. At the start of the conflict, the usefulness of aerial photography was not fully appreciated, with reconnaissance being accomplished with map sketching from the air. Germany adopted the first aerial camera in 1913 and the French began the war with several squadrons of Blériot observation aircraft equipped with cameras for reconnaissance. The French Army developed procedures for getting prints into the hands of field commanders in record time.

Commercial aerial photography came soon after, being used mainly for surveying and mapping purposes. Again, the Second World War saw rapid development of the technology for reconnaissance purposes, which ultimately played an important role in the war effort.

3.10.2 Introduction

Traditionally aerial photography has been by fixed wing aeroplanes as this is the cheapest, fastest and most reliable method. Much of the early remote sensing research relied on aerial photography, for example road alignment studies and various projects to map and predict landslides in vulnerable areas such as the Himalayas.

However, this has been superseded by the use of satellite imagery and more recently UAVs, with the recent increase in the technology behind these utility machines. However, it should be noted that UAVs are limited by the payload they can carry and hence the quality and resolution of the cameras that will capture the imagery. In addition they are very limited in how, where and when they can fly, which effectively increases their cost and ability to get imagery at the optimum time.

3.10.3 Application of aerial photography

In this project we mainly see the application of aerial photography being undertaken by UAVs, so our proposals in this area are included under section 3.4.

3.11 Alternative satellite applications

3.11.1 Background

About 6,600 satellites have been launched. The latest estimates are that 3,600 remain in orbit. Of those, about 1,000 are operational, whilst the rest have lived out their useful lives and are part of space debris. The main two types of satellite remote sensing that are applicable to this project are:

- Optical
- Synthetic Aperture Radar

Optical

The primary types of satellite data are visual images of the Earth's surface; these are simple to interpret and are comprehensible even to non-technical users. Both monochrome and colour images are available. For visual imagery the primary operational parameter is the resolution of the image which broadly represents the smallest object that can be distinguished. The main constraint with optical imagery is obscuration through cloud cover, which in some parts of the world makes optical imagery unreliable as a data source for routine operational services. However, as more satellites are launched, and the number of overflights increases, the likelihood of obtaining a clear sky image of the required area also increases. Figure 9 shows the two types of resolution used in the Nigeria research, 1.5m for mapping and 0.5m for condition assessment.

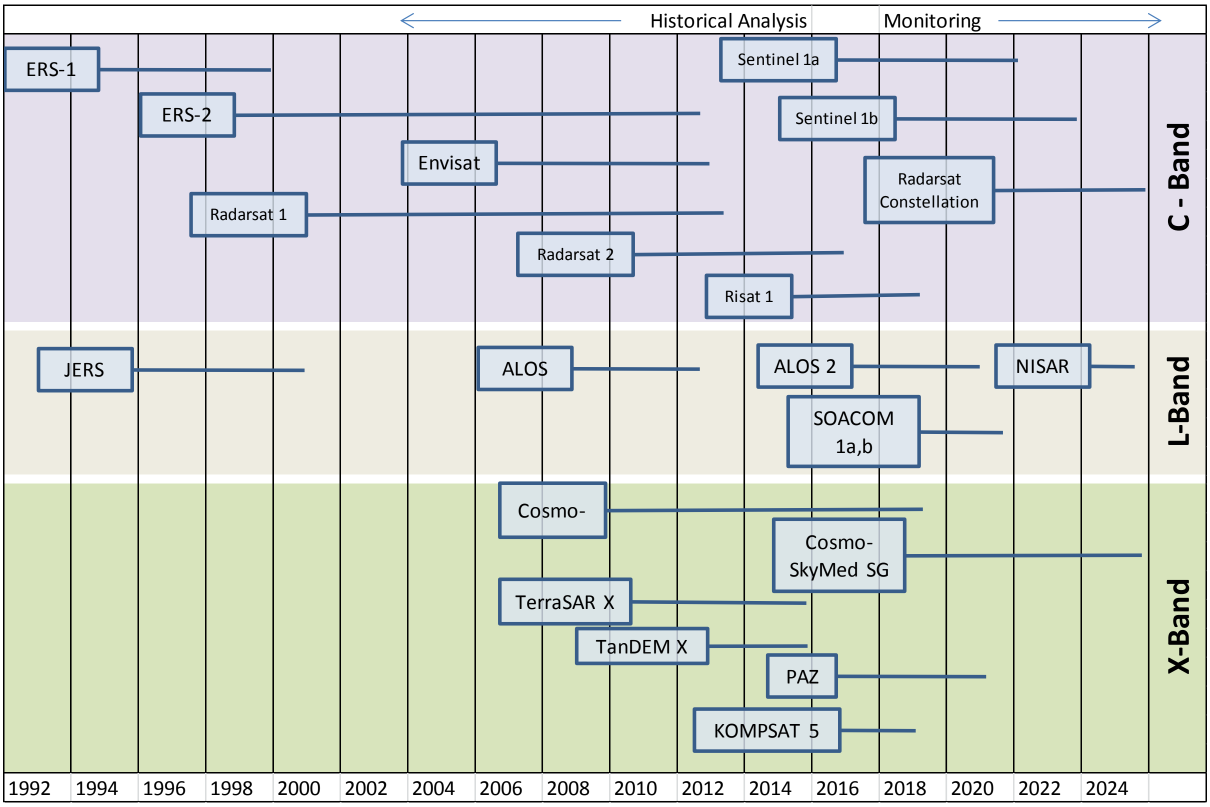
Figure 9 - Resolution of Satellite Imagery; Left 1.5m (Spot 6), Right 0.5m (Pleiades)

Synthetic Aperture Radar (SAR)

Satellites can use the Synthetic Aperture Radar (SAR) technique to provide a radar image of the surface. They orbit the Earth in a sun-synchronous low polar orbit and data acquisitions can be made at any time of day or night and are independent of cloud coverage, collecting both amplitude and phase data. This technique has the advantage of being free of cloud constraints, allowing surface imagery to be obtained in areas with persistent cloud cover.

Satellites with SAR have repeating paths which, using two phase datasets for the same location at different times, allows for interferometric SAR (InSAR) showing relative ground displacements between the two datasets along the direction of the radar beam. The SAR satellites operate at designated frequencies with L-band, C-band, and X-band being the predominate wavelengths. Figure 10 shows a chart of past, present, and projected SAR satellite missions (reproduced from https://www.unavco.org/instrumentation/geophysical/imaging/sar-satellites/sar-satellites.html).

Figure 10 – Chart of past, present and projected SAR missions



This imagery is however much more difficult to interpret as it is less lifelike, which is important when using visual interpretation of the imagery, as will be the methodology for this project. This requires more training and familiarisation than interpretation of visual imagery.

As radar is sensitive to the physical structure of the surface it is possible to determine the pavement characteristics, such as the roughness. The primary constraints on satellite radar data are its availability, with far fewer radar satellites operating than optical satellites, and its cost, especially for the very high resolution radar imagery.

Digital Elevation

Both optical and radar satellites can be used to create a digital elevation model with a variety of accuracies (and costs) depending on the technique used. The extent to which this can be used for road condition depends on the resolution at which the images are taken.

Orbit

The orbit of satellites is important to consider as it determines the quality and resolution of images that can be produced. Typically satellites in higher orbit will need larger cameras or sensors in order to reach the earth. Mini-satellites, such as those from Planet Labs, need much smaller cameras as they are much closer to the earth. The position of the satellite relative to the earth determines what can be seen and how long the satellite can remain in space. The orbits can be described as:

- Low Earth Orbit (LEO): Geocentric orbits ranging in altitude from 160km - 2,000 km (1,200 mi)
- Medium Earth Orbit (MEO): Geocentric orbits ranging in altitude from 2,000 km (1,200 mi) - 35,786 km (22,236 mi). Also known as an intermediate circular orbit
- Geosynchronous Orbit (GEO): Geocentric circular orbit with an altitude of 35,786 km (22,236 mi). The period of the orbit equals one sidereal day, coinciding with the rotation period of the Earth. The speed is approximately 3,000 metres per second (9,800 ft/s).
- High Earth Orbit (HEO): Geocentric orbits above the altitude of 35,786 km (22,236 mi).

3.11.2 Introduction

We are developing a methodology for assessing road condition from visual satellite imagery. There are however several other types of satellites and interpretation systems that could provide useful options for asset management of roads. They are:

- Navigation satellites: GNSS
- Mini satellites
- Spectral imaging
- Thermal imaging
- Photogrammetry
- Interferometry
- Drainage identification software
- Digital Elevation Modelling

Global Navigation Satellite System (GNSS)

There are many GNSS satellites in orbit and GNSS works on signals from several (three or more) satellites to locate the object at a specific point in earth. It can be accurate to sub-millimetre level, and to six decimal parts of a second, although this is only possible with the most advanced equipment. The first GNSS satellites were GPS 1993, and they can be used to monitor the location or height of objects from space. They can also track vehicles, monitor speeds and help to achieve accurate mapping.

An example of GNSS application is the GeoSHM of Bridges project (ESA, 2015). This European Space Agency (ESA) project measures the structural health of bridges by GNSS, using the Forth Road Bridge in Scotland as a pilot. This project measures bridge movement in three dimensions on a live basis using GNSS sensors on the bridge, and recorded unexpected movements of more than 3 metres laterally in the high winds of January 2015. This is used to identify unexpected stresses and deformations caused by load and extreme weather. TRL have attended review meetings for this project.

GNSS can also be used to monitor landslides and unstable areas. A sensor or sensors are established within the landslide and small movements are detected, which combined with rainfall and other events such as seismic movements can help to predict when a landslide will occur. GPS technology has also been used to measure changes in sea level with respect to predicting tsunamis, but we do not see the value of using this technology to monitor structures or ground movements on low volume roads at the present time.

Simple GPS tracking can be very useful for establishing the alignment of a road. This is used already in some countries, but the main barriers to carrying out this process are still present, namely resources, accessibility and conflict.

Mini satellites

A recent development in the space sector is the use of multiple mini-satellites, approximately 4kg in weight, which orbit the earth and provide images of everywhere on the earth, every day. This technology is being pioneered by Planet Labs, whose mission is essentially humanitarian, with other companies starting to follow a similar path. They use the commercial side of their product to fund the humanitarian side, which makes it very applicable to this project.

At present the resolution of the satellites is between 3m and 5m, adequate for network mapping and identification of blocked / damaged roads. So far this type of disaster response application and environmental monitoring has been the main humanitarian use of these satellites. We do not believe that condition assessment is possible at these resolutions. However, we will test the feasibility of these satellites to provide information on road condition, as well as considering alternative applications for mini-satellites within the context of this project.

In the aftermath of the magnitude 7.8 earthquake that hit Nepal on 25 April 2015, the International Centre for Integrated Mountain Development (ICIMOD) used satellite resources to support relief efforts. Immediately after the disaster, it formed a team of GIS and remote sensing experts to process and analyse the latest available satellite imagery (obtained through liaison with NASA, Digital-Globe, and national space organisations from India, China and Japan) to map pockets of settlements in affected districts and create profiles of affected villages to inform relief and recovery operations.

Landslides were a major obstacle to rescue and relief operations, with many roads damaged or blocked, cutting off quake-hit villages from aid and rescue workers. Some slopes were destabilised, leading to the risk of further landslides. Moraine dams of glacier lakes were weakened during the earthquake, which could have resulted in floods to communities downstream. ICIMOD and its partners monitored landslides, glacier lakes, and river courses by analysing the latest satellite images and communicating the latest findings to the Government of Nepal and relief agencies. ICIMOD set up a dedicated webpage to provide the latest maps, data, and information about the situation in Nepal (ICIMOD, 2015), which provided information products using remote sensing and GIS tools for rescue and relief activities including maps of settlements, terrain, safe landing spots, as well as potential hazard areas.

Although mini satellites were not used in this instance, possibly because their network was not fully established at that time, this would have been an ideal situation for them to be employed. They would be able to provide daily updates (subject to cloud cover) at approximately 3m resolution, which should be adequate to determine which roads are accessible and which are not. It should be noted however that an International Charter is in place which enables all satellite providers to immediately task their assets over identified crisis areas at no cost. Therefore regular updates of very high resolution imagery should be possible and the rescue organisations would not necessarily need to rely on the lower resolution mini satellites alone.

Spectral Reflectance

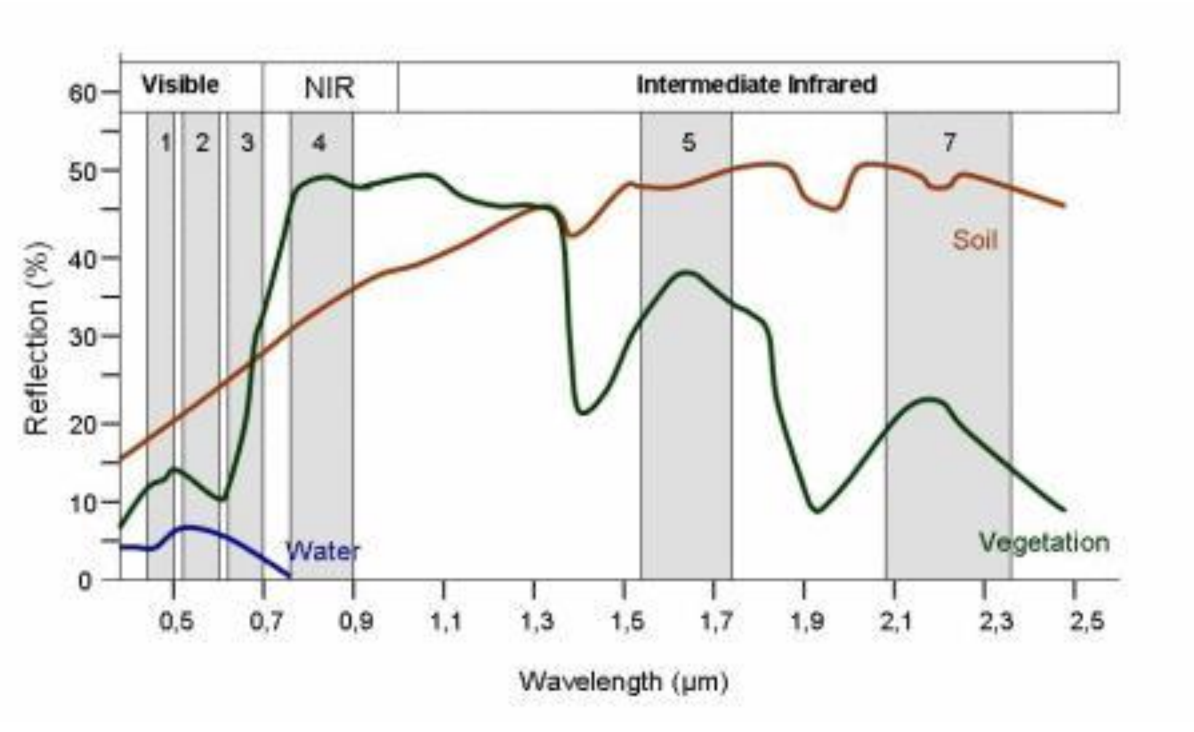
Spectral Reflectance is a remote sensing method that can help us to identify different earth features or materials by analysing their spectral reflectance patterns or spectral signatures. The signatures can be visualised in spectral reflectance curves as a function of wavelength.

The technology works by measuring reflected or emitted radiation from different bodies. Objects with different surface features reflect or absorb radiation from the sun in different ways, so the reflectance properties of an object will depend on the particular material and chemical state it is in at the time (moisture content), its surface roughness and geometric circumstances (angle of sunlight). The most important features are colour, structure and surface texture. The graph in Figure 11 shows the spectral reflectance for three different materials; vegetation, soil and water.

This technology has been used to determine the level and health of vegetation across the world. The spectral reflectance curve of healthy green vegetation has a minimum of reflectance in the visible portion of the electromagnetic spectrum, resulting from the pigments in plant leaves. Reflectance increases dramatically in the near infrared, so less healthy vegetation can also be detected because it has a significantly lower reflectance in the infrared.

However, the spectral reflectance of bare soil is much less variable, with the reflectance curve affected by moisture content, texture, surface roughness and the presence of other products such as iron oxide and organic matter. In contrast the water curve is characterised by high absorption at near infrared wavelengths and beyond. This makes it very easy to detect, locate and delineate with remote sensing data. Likewise contaminations in water such as algae and oil spills can be detected by a higher reflectance in the visible region than clear water. This system has been used effectively to identify road surface types.

Figure 11 – Spectral reflectance of different materials



Some research in assessing paved road conditions has been carried out using spectrometry (M Herold, D Roberts 2007) and (M Herold, D Roberts, 2008). The latter study integrates ground spectrometry, imaging spectrometry, and in situ pavement condition surveys for asphalt road assessment. Field spectra showed that asphalt aging and deterioration produce measurable changes in spectra as these surfaces undergo a transition from hydrocarbon dominated new roads to mineral dominated older roads. Several spectral measures derived from field and image spectra correlated well with pavement quality indicators. Spectral confusion between pavement material aging and asphalt mix erosion on the one hand, and structural road damages (e.g. cracking) on the other, poses some limits to remote sensing based mapping.

Recent advances in imaging spectrometry have the potential to map road quality over large areas. Imaging spectrometers are able to acquire a large number of spectral bands with narrow bandwidths. Such detailed spectral measurements allow for precise identification of the chemical and physical material properties as well as surface geometry of surfaces (RN Clark, 1999, D Roberts and M Herold, 2004). Early remote sensing studies in the 1970s dealt with the visual interpretation of physical surface distresses (e.g. cracks). The results showed that distresses are distinguishable but only in very large -scale aerial photographs. The potential of using imaging spectrometers to map pavement age and condition has been discussed in previous research (R Gomez, 2002, M Herold and D Roberts, 2005).

This potential was explored by the National Consortium on Remote Sensing in Transportation (NCRST) at UC Santa Barbara (M Herold et al. 2007), with the central objectives of this research including an improved understanding of the spectral representation of road aging and deterioration processes, optimal spatial/spectral remote sensor configurations to acquire such phenomena, and the assessment of capabilities and limitations of remote sensing technology compared to other road survey techniques.

We believe this is a valid potential area of research for this project. It would be relevant to the paved roads within the study areas, but will also inform higher volume roads where it could well prove to be more applicable. We intend to test this technique within the pilot areas using a broader spectral coverage, based on the previous research that has been carried out, as referred to above and in a research study carried out in Colorado (WJ Emery, 2012). We will identify locations for the research and determine the additional effort and resources that will be necessary to trial this technology, with the expectation that partner countries or other partners will be requested to provide the additional funding.

Thermal Imaging, Infrared satellites

Thermal imaging technology has been used remotely from aeroplanes to track the location of people on the ground, an example being illegal immigrants living in sheds. It is also used from drones to detect defects in building structures.

From satellites this technology has been used to monitor the activity of volcanoes, although the thermal resolution ranges from 0.2K accuracy for the highly precise AATSR satellites, down to 1.2K for less accurate equipment such as Landsat. Weather satellites can be used to determine the temperature of clouds or the earth’s surface. They have also been used to monitor forest fires. However this technology is very expensive and at the present time is probably not high enough resolution to be useful for assessing road condition.

Photogrammetry

Photogrammetry is the science of making measurements from photographs. It is used mainly for recovering the exact positions of surface points, as well as to recover the motion pathways of designated reference points located on any moving object, on its components and in the immediately adjacent environment. Photogrammetric analysis may be applied to one photograph, or may use high-speed photography and remote sensing to detect, measure and record complex 2-D and 3-D motion fields, which can deliver a similar affect to LIDAR with point clouds.

The applications of photogrammetry include satellite tracking of the relative positioning alterations in all Earth environments (e.g. tectonic motions etc.), topographic mapping, research into the movement of fish, birds or insect flight, or other relative motion processes. The quantitative results of photogrammetry are then used to guide and match the results of computational models of the natural systems. They help to invalidate or confirm new theories, to design novel vehicles or new methods for predicting or/and controlling the consequences of earthquakes, tsunamis, any other weather types, or to understand the flow of fluids next to solid structures and many other processes. In terms of roads it can be used to produce 3D images of the road surface.

Interferometry

This technology uses SAR, as explained above, to provide two images of the same place taken at different times, possibly on subsequent orbits. This process is very accurate and could identify for example the depth of ruts on an earthen road. This capability is constrained to the pixel size, e.g. Terrasar-X Spotlight 1.0m and Staring Spotlight 0.25m (Airbus [2], 2016). At present we do not see a cost effective use of this technology because SAR imagery is more expensive than visual imagery and there is no perceived demand for such accurate measurement of defects in earth or gravel roads, or even in paved roads that are low volume.

Drainage identification software

It is possible to use GIS software to identify drainage areas and routes from digital terrain models. This is based on use of the following datasets, or similar;

- SRTM 1 arc sec (https://lta.cr.usgs.gov/SRTM1Arc). The Shuttle Radar Topography Mission (SRTM) was flown aboard the space shuttle Endeavour from February 11-22, 2000. This was part of an international project to acquire radar data by NASA and the National Geospatial-Intelligence Agency (NGA), which was used to create the first near-global set of land elevations.
- ASTER GDEM (https://asterweb.jpl.nasa.gov/gdem.asp). The first version of the ASTER GDEM, released in June 2009, was generated using stereo-pair images collected by the ASTER instrument on board the Terra satellite. ASTER provides high-resolution images of the planet in 14 different bands of the electromagnetic spectrum, from visible to thermal infrared light. The resolution of images ranges between 15 and 90 meters. ASTER data are used to create detailed maps of surface temperature of land, emissivity, reflectance and elevation. ASTER GDEM coverage spans from 83 degrees north latitude to 83 degrees south, encompassing 99 percent of Earth's landmass.
- Daichi (ALOS)(aw3d.jp/en/). This satellite contained three sensors that were used for cartography and disaster monitoring of Asia and the Pacific.

This software uses the imagery above imagery and is able to pick out natural drainage channels and hence the location of drainage structures on a road. We plan to test this in one or two of the partner countries.

Digital elevation modelling

It is also possible to use specialist software to model the elevation of an area. If slope were to be an attribute for roads, for example identifying whether a road is flat, rolling or mountainous, this would be the appropriate software to determine that. Landslides can also be mapped in this way (A Hong et al, 2007). This software can be freely available, so if this attribute is required we will trial the software to see if it is appropriate for that use.

3.12 Summary of high-tech solutions

Table 1, below compares the various types of high-tech solutions discussed above and their suitability for use in asset management. The final column assesses whether the technology will be proposed for use in phase 2 as part of the pilot research. Those that are selected will be taken further and assessed in the recommendations section of this report. The final decision on the pilot research subjects will be made after the first meeting with partner countries.

Table 1 – Comparison of the potential of high-tech solutions for asset management

High-tech solution	Road identification	Structure/drainage identification	Unpaved road condition	Paved road condition	Structure/drainage condition	Roughness	Comments	Consider for pilot
Big Data	N/A	N/A	Possibly	Possibly	Possibly	Possibly	Potential untested	✓
Mobile Phones	N/A	N/A	Yes	Yes	N/A	Yes	Roughness apps available	✓
Social Media	N/A	N/A	Possibly	Possibly	Possibly	Possibly	Potential, but untested	✓
UAVs / drones	Yes	Yes	Yes	Yes	Yes	Possibly	Good potential but high cost	✓
Internet of Things	N/A	N/A	Possibly	Possibly	Possibly	Possibly	Potential, but untested	?
Internet solutions	Possibly	Possibly	Possibly	Possibly	Possibly	Possibly	Maybe beyond project scope	?
Computer solutions	Possibly	Possibly	Possibly	Possibly	Possibly	Possibly	Maybe beyond project scope	?
AI/machine learning	Yes	Yes	Possibly	Possibly	Possibly	Possibly	Maybe beyond project scope	?
LIDAR	Yes	Yes	Yes	Yes	N/A	Yes	Existing, maybe use with drones	?
Aerial photography	Yes	Yes	Yes	Yes	N/A	Yes	Old technology, well tested	x
GNSS satellite	Yes	Yes	Yes	Possibly	N/A	Possibly	Used to monitor large assets	x
Mini satellites	Yes	Yes	Possibly	Possibly	N/A	Possibly	Good potential for the future	✓
Spectral reflectance	Possibly	N/A	Possibly	Yes	N/A	N/A	Partially tested on paved roads	✓
Thermal imaging	N/A	N/A	Possibly	Possibly	N/A	N/A	Potential unknown	x
Photogrammetry	N/A	N/A	Yes	Possibly	N/A	Possibly	Good potential but limited	?
Interferometry	N/A	N/A	Yes	Possibly	N/A	Possibly	Good potential but limited	?
Drainage software	N/A	Yes	N/A	N/A	Possibly	N/A	Tested in limited situations	?
Digital elevation	Yes	Yes	Possibly	Possibly	N/A	Possibly	Potential but may be limited	?

4 Draft Methodology for Mapping and Condition Assessment

4.1 Mapping

4.1.1 Background

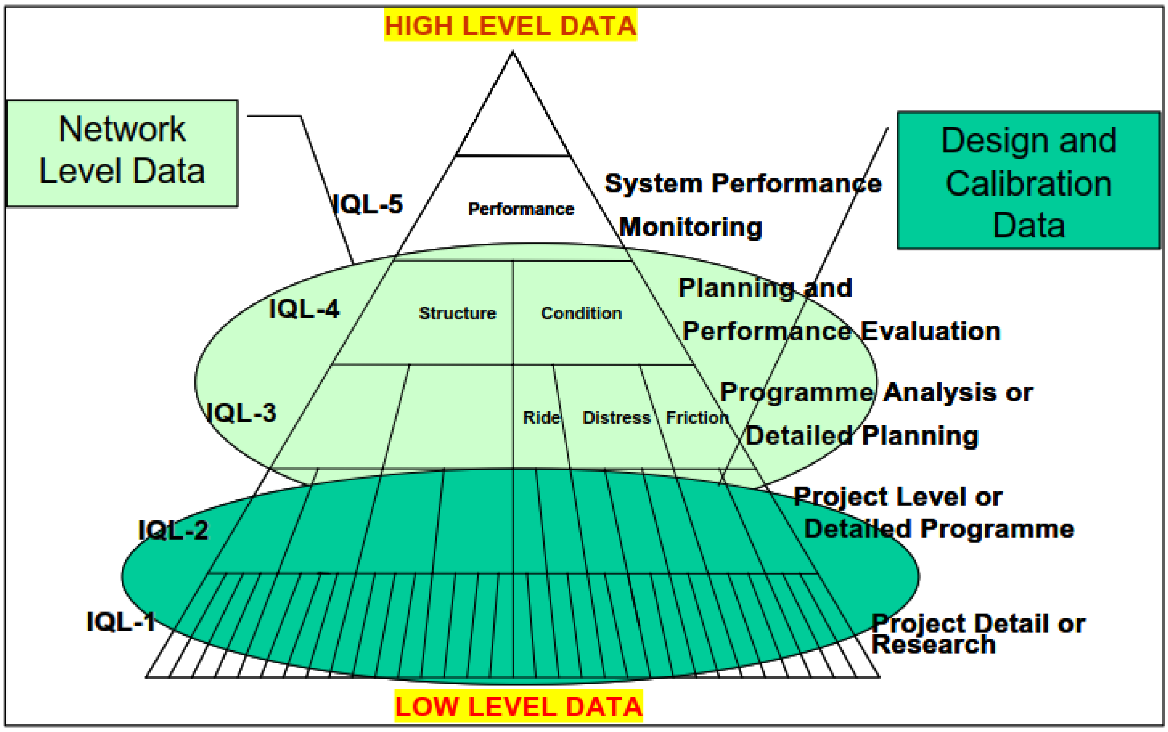
For countries with little or no knowledge of the length and condition of all or part of their rural road network, it is important that they are able to produce a basic map of the roads. This is the essential first step in gaining enough information to be able to plan and prioritise road management and maintenance.

It is important to put mapping and the information that is extracted from satellite imagery into context. For this reason we have used the Information Quality Levels (IQLs) which have been identified and defined by the World Bank for road management activities. The five levels of road management are summarised in (Bennet et al, 2007). They are as follows:

- IQL-1 has the highest detail of data, representing fundamental, research, laboratory, theoretical, or electronic data types, where numerous attributes (possibly 20 or more) may be measured or identified.
- IQL-2 level of detail is appropriate for engineering analyses for a project-level decision, using perhaps six to ten attributes.
- IQL-3 has only two or three attributes such as roughness, surface distress and texture, and is a simpler level of detail that might be used for a network-level survey or where simpler data collection methods are appropriate.
- IQL-4 is a summary or a key attribute which has use in planning, senior management reports, or in low effort data collection. This may be measured by class values (good, fair, poor) or by an index (e.g., 0-10).
- IQL-5 represents top level data such as key performance indicators, which typically might combine key attributes from several pieces of information, for example pavement quality with other structural adequacy, safety aspects, and traffic congestion—representing a higher order information, such as "road condition". Still higher levels can be defined as necessary. The Rural Access Index would typically fall into this category (P Roberts et. al., 2006), although it essentially measures accessibility based on household surveys and interrogation of various sources of mapping (including digital maps).

Figure 12 shows the different quality levels of data. The level of data collection envisaged for this project is between IQL3 and IQL5. For remote sensing the data will typically be collected where no contact with the road is necessary, so this could be data collected from a vehicle, aeroplane, satellite etc. This naturally limits the quality of data that can be collected, as most structural information on roads is collected in contact with the road.

Figure 12 – IQL chart



Source: World Bank (CR Bennett et al, 2007)

In order to carry out condition assessment of roads, by any means, it is necessary to have a reasonable quality georeferenced map. The asset manager will need to know the scope of his/her road network in order to prioritise work objectively, noting that 'road' includes the associated structures and earthworks. The details necessary for road network mapping are at the first level:

- Road identification, deciding what is a road and what isn't
- Road location referencing (georeferenced), start and end of each road, GPS track of the road. Most location referencing is now spatial, as opposed to linear, but sometimes a combination is used.
- Road lengths
- Road classification (main, feeder, rural)

These details would provide a basic network of road details that would give the asset manager an overall picture of the network in terms of road length per classification. However, in order to determine and prioritise the type and volume of maintenance that needs to be carried out on those roads, a second level of information is required:

- Road asset identification, such as drainage, structures,
- Road surface type
- Road sectioning, based on the information above
- Road condition

Only when this information is available can the asset manager effectively prioritise the work to be carried out on the network.

The mapping that was carried out in Nigeria used SPOT 6 imagery, which is 1.5 m resolution. This is categorised as Very High Resolution 2 (VHR2) by the ESA. Below are shown the range of categories for very high resolution, as stipulated by the ESA (ESA, 2016):

- VHR1 Very High Resolution 1 where resolution <=1m
- VHR2 Very High Resolution 2 where resolution >1m and <=4m
- HR1 High Resolution 1 where resolution >4m and <=10m
- HR2 High Resolution 1 where resolution >10m and <=30m
- MR1 Medium Resolution where resolution >30m and <=100m
- MR2 Medium Resolution where resolution >100m and <=300m
- LR Low Resolution where resolution >=300m

This chapter deals with the mapping of the road; the information that is largely contained in the first level of information above.

4.1.2 Mapping options

There are two options for mapping of low volume roads, automatic and manual (with a possibility of a combination of both). There has been some research in this area (Mokhtarzade, et al, 2008). It should be noted that low volume roads can be sealed (blacktop, concrete) or unsealed (earth, gravel) and the methodology for mapping either will vary.

- ***Automatic mapping***

The first option is automatic road detection, where roads are visible on low resolution images as lines, on high resolution as elongated areas. Using software algorithms to identify roads from satellite images has been an area of research for some time, with varying success. At different resolutions, different algorithms are used to identify roads, for example using line detection or width and curvature. The evidence presently available suggests that it is still not possible to automatically map roads without significant human intervention, whether that is to check the operation of the automatic mapping or to make the necessary adjustments where the automatic mapping has been less than accurate.

In a study using automatic extraction for urban and sub-urban roads (J Xiaoying and CH Davis, 2005), they state that the accuracy of the system they used to extract mapping details in terms of completeness is 70% to 86% and in terms of correctness is 70% to 92%. Bearing in mind that this is for urban roads in the United States of America, where the vast majority of urban areas are based on a grid structure, it still leaves a lot of work to be carried out manually to check and adjust the data.

Some automatic detection systems use the difference of the pixels on the road compared to the pixels off the road as way to distinguish roads. This is valid for surfaced roads, where the surface is different. However, in many cases earth or gravel roads essentially consist of the same materials, especially in desert and arid areas where there is little or no topsoil. This would make automatic detection by this method very difficult. However, in desert areas where there is desert varnish, car tracks can expose the unvarnished or brighter material, making the tracks highly visible from above.

In their paper 'Learning to Detect Roads in High-Resolution Aerial Images' the authors state that "Despite 30 years of work on automatic road detection, no automatic or semi-automatic road detection system is currently on the market and no published method has been shown to work reliably on large datasets of urban imagery" (V Mnih and G E. Hinton, 2010).

Most recently a paper was presented at the Living Planet Symposium in Prague in May 2016 (B Seppke et al, 2016), which reported on the use of 'superpixels' to reliably maps roads with a view to monitoring urbanisations. Superpixels allow flexible, highly adaptive segmentation approaches through their ability to merge as well as split and form new basic image entities. The paper presents a combined geometric and topological representation based on a special graph representation. The use of the special graph is represented by means of a case study where the extraction of partially occluded road networks in rural areas from open source (spectral) remote sensing images is achieved by tracking. Using publicly available Google maps information the system was able to provide mapping of approximately 90% of the network with more than 95% accuracy for roads that were completely visible. However, the real benefits seem to be in assessing partially occluded roads where the system achieved approximately 70% coverage with more than 80% accuracy, compared to a system developed by Shukla et al in 2002, that was limited to just 10% coverage. The suggestion is that this older system would lose the track of the road when an obstacle or significantly different feature is encountered, which is a drawback of many automated or semi-automated systems.

- ***Manual road detection:***

Secondly there is manual road detection: Some research has been carried out in this area to determine the capacity of trained and untrained analysts to identify roads from satellite images. Trained people did well, but it was found to be most effective if local knowledge was also included.

Some features on the road will require manual detection, such as bridges, culverts and other structures, due to the range of different types and sizes and the extent to which they are visible.

This was the main mode used for the Nigeria research study. The methodology employed was to collect all of the existing GIS information on roads in the study areas and combine them to make a consolidated map of the area. This was then checked by consulting with various local and State bodies, as well as the staff responsible for the roads. Where consolidated mapping does not exist in the partner countries, it would be possible to use a similar methodology to produce maps, associated with GPS tracking as part of the ground truthing, using hand held GPS equipment or GPS enabled cameras.

4.1.3 Identifying structures

From our previous research we found that it is necessary to use very high resolution imagery, as categorised by the ESA, (ESA, 2016) to identify structures, such as drains, bridges, culverts, retaining walls, etc. These assets can attract significant costs in terms of maintenance, so they should be captured if possible.

In terms of identifying their condition this will be more difficult by satellite, as it will not be possible to see inside the culvert or under the bridge, but the quantity and nature of structures can be defined. Many of the larger and more important structures such as bridges are inspected on a regular basis and may even be maintained under a different budget, so their condition can be ascertained from other data.

We intend to use a similar method for the identification of structures as was used in the Nigeria research. This will be carried out manually by taking two different approaches.

- The first approach will be to try and identify the structures themselves by locating headwalls of culverts, bridge decks or any feature that resembles a structure. On unpaved and paved roads the methodology will be slightly different due to the nature of the two different surfaces, for example:
    - Bridge decks are always paved, either asphalt or concrete. This different surface type will stand out on a gravel road, but not on a paved road (if the surface is the same as the road itself, which is usually the case). Therefore bridges will be more easily identified by the surface change on an unpaved road. However, there are usually very distinct features of a bridge that can be identified form satellite imagery, for example

the parapets appear as straight lines and the bridge itself is often slightly narrower than the road as there will be no shoulders or visible side drainage.

  - Culverts often assume the same or similar structure on both paved and unpaved roads. However the majority of this structure is beneath the road itself so we will reply on the visible parts such as headwalls, inlets and outlets to identify where the culvert is. Headwalls may be less pronounced or even absent on gravel roads, which will make them harder to see.

- The second approach to identifying structures will be to look for natural geographic or geomorphological features to identify where there should be a structure, then to look in more detail at the narrowed down locations.

- Examples of drainage features and natural features are:

  - Rivers, streams or natural catchment areas. These features will provide clues to the location of bridges and culverts, so if a stream can be seen flowing from one side of a road to the other, it is almost certain that there is a culvert of bridge to facilitate that flow below the road. In some cases the waterway may flow over the road, in which case a drift or causeway may be obvious. Other structures such as vented causeways should also be visible due to their size and nature. When the assessor becomes experienced they will be able to more easily identify such features of the road.

  - Roadside Slope Instability. Often landslides or slope instabilities are visible on satellite imagery, and in fact there have been several projects to identify landslides and potential landslides from satellite imagery. A landslide beside the road could indicate the presence of a retaining structure such as a toe wall or revetment wall. The structures themselves may be difficult to see if the vegetation has grown back.

We expect that this process will be refined during the ground truthing and data comparison stages.

4.1.4 Approach

Given that employment is a key factor in the development and capacity building of AFCAP countries, our recommendation is to carry out the mapping aspect of this project manually. Our approach will be to train local staff to carry out both the satellite image assessment and the verification. Verification can be achieved in a number of ways, which include checking against existing mapping in country, checking against freely available mapping such as Google Earth and checking with local roads authorities or agencies. The latter is most useful when considering the location and type of bridges, culverts and structures, which may not be clear on other sources of mapping.

4.1.5 Methodology

To manually extract mapping from a satellite image it is necessary to digitise the centre line of the road using GIS or CAD software. The georeferenced imagery is opened and viewed in the software, the analyst then digitises along the road centreline creating lines which can be attributed accordingly (e.g. road width, surface type). These lines form a (transport) network which can be saved as a vector file (e.g. an ESRI shapefile). This will also make the results more compatible with Road Asset Management System (RAMS) programmes. We will set parameters for defining different types of road. Our proposed criteria are shown, below, but they will differ for each country, plus they are flexible and may change as we collect and analyse the data. They are:

- Road width, note that the road width and use is likely to vary between paved and unpaved and will be dependent upon level of usage and environmental context. For example a 5m paved road could constitute a two-lane highway, but a 5m unpaved road could just be a village-village/town road where drivers have driven on the shoulders to avoid poor condition. The proposed widths below refer to the running surface as visible from the satellite imagery, but will be further refined as data is collected and compared to the ground truthing:

- < 2.5m = not expected to be a road, probably footpath or track
- 2.5m – 4.0m = village to farm road
- 5.0m – 8.0m = village to village road
- > 8.0m = feeder road, village to main road

- Road surface type:
  - Paved = asphalt, possibly concrete
  - Unpaved = gravel
  - Unpaved = earth

These categories will need to be verified by the local roads authority and by staff who are familiar with the road network in that particular area.

We intend to use sub 1.0m resolution imagery for this task as it can be used for both mapping and condition assessment. The decision on which satellite to use will depend on resolution, cost, availability (especially for archive imagery) and the conditions attached to use of the imagery. Some providers attach more restrictive conditions on use of the imagery than others, so this will be an important consideration in the decision on which imagery to use. We know that mapping can be carried out on lower resolution, but we can also down-sample the Pleiades or other imagery to appear as 1.5m or 2.5m resolution, to save procuring additional images at that resolution.

4.2 Condition Assessment

4.2.1 Background

The ToR requires a methodology for the assessment of road condition analysis using satellite imagery. We believe this will provide the main value added to this project as there has already been some research in this area and an effective methodology will enable the potential of this technology to be exploited in the most cost effective manner.

The vast majority of low volume roads are likely to be unpaved, so the main focus will be on this type of surface. We do, however, recognise that the trend in Africa is to seal low volume roads to reduce whole life costs, so we will also consider condition assessment on paved roads.

The Nigeria research carried out by TRL and Airbus DS considered automatic condition assessment, but concluded that it was not yet a viable option for unpaved roads and would be very unlikely to be practical on paved roads. For unpaved roads we therefore expect to use manual interpretation of condition, which will be more reliable, due to the large variety of features experienced on unpaved roads. In addition, manual assessment has the developmental benefit of providing skills and employment to many people, an important value added to the project.

The criteria for condition assessment in the Nigeria project were imposed due to the reliance on a partner project for ground truthing. Ideally the condition criteria would be developed based on the features visible on the satellite imagery and then linked to established road condition indicators.

Spectral reflectance can be used to detect concrete or asphalt surfaces by defining the spectral reflectance signature of a particular material, which would define whether the road is paved or unpaved. However, in terms of condition assessment its capacity is unproven.

Road condition will be assessed using two different systems:

- Visual surveys, including roughness measurements if possible (Ground Truthing)
- Visual assessment of satellite imagery using very high resolution imagery

The ground truthing will used to establish a baseline of the actual condition. This will then be compared to the satellite assessment to determine the correlation and demonstrate whether the method is viable and cost effective.

This methodology will be used to assess the roads in the selected areas, but it will remain flexible so that if the research uncovers an improvement to the methodology this can be incorporated. The methodology will provide part of the high-tech guidelines to be produced as a deliverable of this project.

4.2.2 Principle and Approach

The overarching principle we will use in this research is to carry out as many activities as possible using local resources and funding. In this way it tests the sustainability of the system and makes the replicability and uptake more likely. For example we intend to use local staff to carry out the ground truthing as well as the satellite imagery assessment, which will be done by assessing images visually. Whilst we realise there are certain techniques that can be used to enhance this, the main focus will be on visual assessment and other techniques will be incorporated if appropriate and sustainable. Both the ground truthing and the image interpretation will be undertaken in country, with training and support from the project team.

Our approach to developing the methodology will be to initially consider the scope of the technology available, under what conditions it can be employed and in which situations it would be most useful. For example, the previous research in Nigeria focused on areas where roads could not be accessed easily or safely due to conflict.

We will refer to the World Bank Information Quality Level (IQL) system as the guiding principle for quality of data, as shown in Figure 12. This has been referred to in order to provide context to the study as it is a general overview that is applicable across all LICs. In addition we will follow the lead of the AFCAP GEM project for the ground truthing system of assessment. In terms of the satellite imagery assessment criteria we will base this on the features and details visible on the imagery that will provide the best indicator of road condition. This will be linked to the ground truthing criteria, for example using the same rating system of Very Good to Very Poor, so that a direct comparison can be made.

Another principle is that the condition assessment by satellite should be simple. It is likely to be used at the planning level at IQL4 or 5 where structural details and in-depth information of the road is not necessary. This is likely to be most useful in countries where there is an overwhelming lack of information on the road network and will probably be particularly relevant for many countries in Africa, as was demonstrated in the previous research carried out in Nigeria.

The ToR stresses that the systems to be investigated must be cost-effective. So the cost of this system is important to assess, as compared to traditional methods of condition assessment. The pilot projects will provide the data necessary to compare the cost effectiveness of this high-tech approach with traditional assessment methods. This will include the cost of satellite imagery and what type of images can be used; for example we will explore the minimum resolution necessary to allow a proper condition assessment, as the required level of resolution is an important cost factor. The range of data available (and the age of the images) is also an important consideration; for example it may not be cost effective to task satellites to take images specifically. The cost of the satellite assessment will also include the ground truthing costs at the determined frequency.

4.2.3 Scope of Available Imagery

We have reviewed the satellite imagery available that could be used for road condition assessment. In comparison to the research in Nigeria, there are now higher resolutions than 0.5m available, but the cost is also higher. There are several options for Very High Resolution (VHR) optical imagery (a sample of which can be seen in Table 2), but only Pleiades 1-A & 1-B, Kompsat-3, WorldView (WV2), WorldView (WV3), GeoEye-1, Dubaisat 2 and DEIMOS 2 offer multispectral data in addition to panchromatic data. The panchromatic and multispectral option is preferred as it provides for improved ease of interpretation and greater scope for understanding the ground conditions compared to panchromatic imagery alone. We will consider the most appropriate imagery for the situation, given a range of factors as mentioned above in 4.1.5.

At this stage we do not know the exact locations of the roads to be assessed in each country, but we are confident that Pleaides imagery will be available either as archive or tasked images. Appropriate locations will be identified in each country which will provide a good sample of the network, at reasonable cost.

Given the previous research in Nigeria and the latest information available on satellite imagery, we intend to use Pleiades 0.5m resolution imagery (acquired at 0.7m, but resampled and offered as 0.5m) for road condition assessment. This was used in the Nigeria research project and proved to be appropriate. Pleiades is an appropriate provider because it has a good level of clarity that allows the assessor to identify the distinguishing features of a road that will show condition, such as colouring, shading, edges, wheeltracking and varying width. It is also reliable, has good coverage and can provide imagery at short notice.

The Pleiades constellation of 1A and 1B provide exceptional coverage and revisit capability, phased in 180º co-planar orbits, the twin satellites have daily revisits over most locations on Earth. The satellite pair has remarkable agility, due to their CMG (Control Moment Gyroscope) actuation capability, the satellites can pitch and roll forward, backward and sideways up to 45º very quickly. This agility enables them to capture a multitude of individual scenes, long strips, or broad contiguous areas of interest on a single pass. As regards accuracy, any very high resolution imagery can be improved by a large and well distributed number of ground control points. Pleiades can provide images with a positional accuracy of 3m CE90 without ground control points (GCP). With ground control points, which could be acquired by the initial ground truthing teams, accuracy could improve to 1m CE90.

However, where the Pleiades constellation does score well over the others is the radiometric resolution, where data is available at 12-bit, compared to 11-bit. Effectively this provides a greater range of reflectance values, for example 11-bit provides 2048 and 12-bit provides 4096. This greater range provides the analyst with a greater radiometric range to apply contrast enhancement techniques and thereby potentially provide greater discrimination of surface features. This could mean greater potential to discriminate differences in the appearance of unpaved roads.

Another factor in the cost effectiveness of satellite imagery is the conditions of the licence. All imagery will come with licencing restrictions which determine what the mage can be used for, who can use it and how many times, additional costs for additional users, and various other conditions. These will need to be taken into account when procuring the imagery in order to get a product that suits the purpose and is sustainable for the end user.

Table 2 – A sample of available very high resolution imagery

Type	Pleiades 1A & 1B	Kompsat-3	WV1	WV2	WV3	GeoEye-1	EROS B
Launched	1A 12/ 2011 1b 12/ 2012	05/ 2012	09/ 2007	10/ 2009	08/ 2014	09/ 2008	04/ 2006
Panchromatic band resolution (nadir/off-nadir)	0.7	0.7 / 0.82 @ 20º	0.50 / 0.59 @25º	0.46 Resampled to 0.5	0.31	0.41 Resampled to 0.5	0.7
Multispectral band resolution (nadir/off-nadir)	2.8	2.8 / 3.28 @ 20º	n/a	1.84 Resampled to 2.0	1.24 (7.5 SWIR) (30 CAVIS (corrects for Clouds, Aerosols, Vapors, Ice, Snow))	1.65	n/a
Spectral range (Nanometres)	470-840 (Pan) 440-540 (blue) 500-600 (green) 610-710 (red) 770-910 (NIR)	450-900 (Pan) 450-520 (blue) 520-600 (green) 630-690 (red) 760-900 (NIR)	n/a	450 – 800 (Pan) 400 – 450 (Coastal) 450 – 510 (blue) 510 – 580 (green) 585 – 625 (yellow) 630 – 690 (red) 705 – 745 (red edge) 770 – 895 (NIR 1) 860 – 1040 (NIR 2)	450 – 800 (Pan) 400 – 450 (Coastal) 450 – 510 (blue) 510 – 580 (green) 585 – 625 (yellow) 630 – 690 (red) 705 – 745 (red edge) 770 – 895 (NIR 1) 860 – 1040 (NIR 2) + 8 SWIR bands	450–800 (Pan) 450–510 (blue) 510–580 (green) 655–690 (red) 780–920 (near IR)	500-900 (Pan)
Revisit (days) Relative to degrees or GSD m off-nadir	1	1.4 @ <45º 4.1 @ <20º	1.7 days @ <=1m 4.6 days @ 0.59m@ 25º	1.1 days @ 1 m. 3.7 days @ 0.52m @ 20º	<1 day @1m 4.5 days @ 20º	<3	3 @ 30º 6 days @ 15º
Nominal Imaging swath width @ nadir (km)	20	16	17.6	16.4	13.1 10 (SWIR)	15.2	7
Dynamic range (bits/pixel)	12	14	11	11	11	11	10
Minimum Order Size (km2) - Archive	25	25	25	25	25	25	25
Minimum Order Size (km2) - Tasking	100	pending	100	100	100	100	50
Price/km2 (Standard 4 band Product if multispectral) -Archive	€10	$8	$14	$17.50	$19.50	$17.50	$6
Price/km2 (Standard 4 band Product if multispectral) - Tasking	€17 new prices pending	pending	$24	$27.50	$29	$27.50	$16

4.2.4 Criteria and Rules

Criteria and rules have been developed, to be used by the satellite assessment teams. These criteria and rules are at the moment flexible and may need to be adjusted as the project progresses and more is learned about the assessment process across the four different locations.

The criteria are:

Direct criteria (based specifically on what can be seen on the images)

- Road width: consistent, varied
- Edges of road: clear, faint, broken
- Drainage visible: culverts, bridges, side drains, as well as natural drainage such as fords.
- Surface: uniform, difference in shading/colour/texture; with good quality imagery at VHR 1 the interpreter should be able to identify between tarmac, gravel and earthen surfaces
- Variance of visible wheeltracking: straight, winding

Indirect criteria (may need additional information to supplement what can be seen on the images)

- Geology: If the area is arid and has little covering vegetation then identification of surface material will be easier. Underlying geology could also be determined by access to geological mapping or by specialist image interpretation.
- Motorability under different weather conditions, e.g. an earth road may only be capable of being used effectively in fair weather, whereas wet weather will result in degradation such that trafficability becomes severely affected or impossible.
- Construction, repair and /or maintenance of the structures on the road (e.g. under construction/fully functional/damaged/unknown)
- Overall condition.

The rules to be used are:

- Paved roads will be separated from unpaved roads and each will have separate assessment criteria.
- We assume that it will be difficult to determine between earth and gravel roads. This can be possible, but as is often the case it depends very much on context. In areas where the paler appearance of a graded gravel road (subject to dampness) is matched by the native soil type then separation between classes can be difficult. Often it is the overall smoother line and more defined edges that will assist in defining the difference between graded gravel and the less engineered earthen tracks.
- Bridges, culverts and other structures will be identified where possible. Where it is not possible to identify the condition of these assets (most cases) the condition will be assumed to be similar to the condition of the pavement surface. A nominal default condition of ‘fair’ or ‘unknown’ will be attributed to each, unless the condition is changed by the assessor. This will be confirmed on further liaison with the GEM project.

4.2.5 Unpaved Road condition categories

Initially our aim was to use three categories of condition assessment:

- Good
- Fair

- Poor

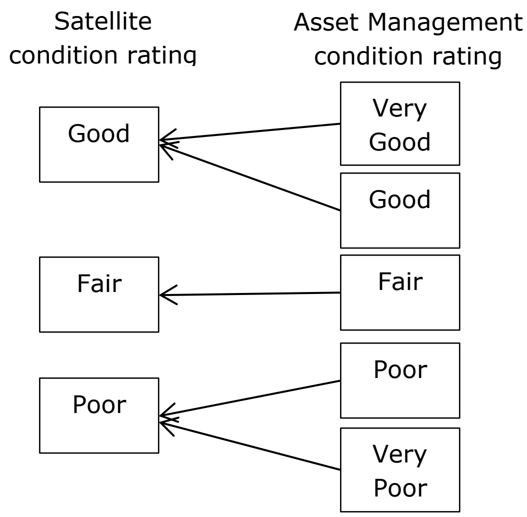
This is the simplest system and would mean that the assessors would only have to determine between these three levels when assessing the satellite images. Some research has argued that a three level assessment is adequate for the level of detail that can be seen on visual satellite imagery. However, given that the Nigeria study used five levels effectively and the strong likelihood that higher resolutions will become available in the near future, making more detail visible on the satellite images, we have decided to use five levels for this research (R Workman, 2014).

The GEM project is carrying out visual road condition assessments in four partner countries in Africa, two of which overlap with this project (Uganda and Zambia). This project is also using a five-level condition rating system because their methodology requires high level condition assessment for long-term monitoring and needs detailed assessments. This project is focused on providing information to fill a gap where countries have little or no quantitative information on their road networks and consequently do not have the information to make objective decisions on the maintenance of their roads. This would suggest that a less detailed condition assessment would be necessary. However, the more accurate the ground truthing is, the more accurate the comparison with the satellite imagery assessment will be.

We will endeavour to select the same areas for assessment as the GEM project, or at least overlap. The rationale for using the same system as the GEM project is that it is based on sound logic, is used elsewhere in Africa and is also based on the 'windshield surveys' that they have adapted for use.

We will, however, also consider the simpler assessment system of three levels. If the three level system is found to be feasible and more appropriate we will investigate whether the levels could be interpreted as shown in Figure 13 to correlate the five level system with the three level system. For example, it could be that Very Good and Good on the five level system could be assessed as Good on the three level system. This correlation will clearly require calibration using field trials, so this will be part of the process we adopt when dealing with individual countries.

Figure 13 – Matching condition levels



Given the descriptions of the five categories by the GEM project, we believe that the above assessment coordination will be possible if the criteria used to determine condition at the various levels is adhered to. The descriptions used for the five level criteria could be adjusted to be relevant for the three level criteria, and will reflect the intention of linking the two systems as shown in Figure 13 above.

We will also use the roughness measurements as a double check against the visual assessments, as was the case in the Nigeria research. Roughness becomes unreliable at the higher values, mainly due to variabilities in the construction and condition of the vehicles and the way the vehicles is driven. Roughness should not therefore be used as an absolute measurement to determine the road condition.

For the ground truthing we intend to collect roughness data using a mobile phone based app which uses the phone accelerometer to estimate roughness. There are various apps available, for example the World Bank 'Roadlab' app which provides a geo-referenced track, IRI and has the ability to link geo-referenced photographs. A similar app will be used by the GEM project. Most of these apps use a four level roughness categorisation, which has the levels of Good, Fair, Poor, Very Poor. This will again need to be calibrated to link with the ground truthing assessments.

A study by the World Bank in 1990 (Road Monitoring for Maintenance Management, Volume 1, manual for developing countries) produced visual roughness guidelines to allow engineers to estimate IRI from a visual inspection of the road from a vehicle, Table 3. This included descriptions of the pavement surface and estimated typical speeds. This guideline serves as a good overall indicator of roughness, but is somewhat subjective. One of the good points is that it does not depend so much on the type of vehicle, condition of the vehicle and how the vehicle is driven, as is the case with traditional roughness equipment such as bump integrators. In any case we are not recommending that it be used as an ultimate measure of roughness, but more as a guide to check the other methods of assessment.

Table 3 - World Bank Guideline on visual assessment of Roughness, compared to Asset Management Project criteria

Condition	World Bank description for roughness of unpaved roads	GEM Project criteria, observations and remarks	
Very Good IRI: 0,2,4	New or recently bladed surface of fine gravel, or soil with excellent longitudinal and transverse profile (usually only found in short lengths). Ride comfortable up to 80-100 km/h, aware of gentle undulations or swaying. Negligible depressions (e.g. < 5 mm/3 m) and no potholes.	No distress. Excellent surface condition and ride.	New construction or total Re-construction. Excellent drainage. Little or no maintenance needed.
Good IRI: 6,8,10	Ride comfortable up to 70-80 km/h but aware of sharp movements and some wheel bounce. Frequent shallow - moderate depressions or shallow potholes (e.g. 6-30 mm/3 m with frequency of 5-10 per 50 m). Moderate corrugations (e.g. 6-20 mm/0.7-1.5 m).	Dust under dry conditions. Moderate loose aggregate.	Recently regraded. Good camber and drainage throughout. Adequate gravel for traffic. Routine grading may be needed.
Fair IRI: 12,14	Ride comfortable at 50 km/h, or on specific sections 40-70 km/h. Frequent moderate transverse depressions (e.g. 14 20-40 mm/3-5 m at frequency 10-20 per 50 m) or occasional deep depressions or potholes (e.g. 40-80 mm/3 m with frequency less than 5 per 50 m). Strong corrugation (e.g. > 20 mm/0.7-1.5 m).	Good camber (75-150mm). Adequate drains on more than 50% of roadway. Gravel layer mostly adequate but additional work may be needed in some locations to correct corrugations.	Shows traffic effects. Re-grading (reworking) necessary. Side drain improvement and culvert maintenance required. Some areas may need additional gravel.
Poor IRI: 16,18	Ride comfortable at 30-40 km/h. Frequent deep transverse depressions and/or potholes (e.g. 40-80 mm/3-5 m at frequency 5-10 per 50 m); or occasional very deep depressions (e.g. 80 mm/ 18 1-5 m with frequency less than 5 per 50 m) with other shallow depressions. Not possible to avoid all the depressions but the worst.	Little or no roadway camber (< 75mm). Adequate side drains on less than 50% of roadway. Portions of the side drains may be filled, overgrown and/or show erosion. Some areas (25%) with little or no gravel.	Travel at slow speeds (less than 30km/hr) is required. Needs additional new gravel. Major side drain construction and culvert maintenance also required.
Very Poor IRI: 20,22,24	Ride comfortable at 20-30 km/h. Speeds higher than 40-50 km/h would cause extreme discomfort and possible damage to a car. On a good general profile; frequent depressions and/or potholes 5 (e.g. 40-80 mm/1-5 m at a frequency of 10-15 per 50 m) and occasional very deep depressions (e.g. 80 mm/0.6-2 m). On a poor general profile; 24 frequent moderate defects and depressions (e.g. poor earth surface).	No roadway camber or road is bowl shaped with extensive ponding. Little if any side drains. Filled or damaged culverts.	Travel is difficult and road may be closed at times. Needs complete rebuilding and/or new culverts.

The World Bank guideline provides different descriptions than the Condition Rating proposed by the AfCAP GEM project, but we believe that they represent very similar descriptions of the five condition ratings, as shown in Table 3. The World Bank criteria are based on visual assessment to provide an assessment of roughness, whereas the GEM project criteria are designed to provide a more inclusive assessment of the overall condition. We would therefore be happy for the GEM project descriptions to be used in the ground truthing process.

The World Bank data in Table 4 was used to determine the IRI values for the Nigeria Image Collection project, which provided the ground truthing for the Nigeria satellite assessment research. In the Image Collection project the IRI was measured using an Inertial Measurement Unit fixed to the chassis of the survey vehicle. For the range of roads found in rural Nigeria the IRI results suggested that the World Bank index needed to be extended to take into account higher roughnesses experienced in the field. Extended roughness values were therefore fixed for gravel roads and for earth roads.

Our experience in Africa suggests that the extended roughnesses are more appropriate for the type of roads conditions found in rural areas of the continent. The ranges of roughness we determined for the Nigeria study are shown in Table 4, for both earth and gravel roads. We have compared these to the World Bank index for roughness, also shown in Table 4. There is some difference in the figures shown, possible because the range of roughnesses in Nigeria is higher due to the fact that no maintenance has been carried out for several years and many of the roads encountered were in a very poor condition, necessitating a range that went above 30 IRI.

We have therefore estimated a combined range for IRI on gravel/earth roads as shown in Table 4, but these will need to be validated through field trials using available roughness measurements, such as the RoadLab software:

Table 4 - Proposed IRI values

	Nigeria Research			Combined & adjusted
Condition rating	IRI for earth roads	IRI for gravel roads	World Bank IRI for unpaved roads	Proposed IRI for gravel and earth roads
Very Good	< 10	< 8	< 5	**< 10**
Good	10-15	8-12	6-11	**6 - 15**
Fair	15-30	12-25	11-15	**10 - 25**
Poor	15-30	12-25	15-19	**15 - 35**
Very Poor	> 30	> 25	19-24	**> 30**

Gravel and earth roads have been combined in the unpaved category as it will be very difficult to determine whether a road is gravel or earth from satellite imagery.

In addition the World Bank study provided some typical speeds (Table 5) that could be reached at the different roughnesses provided. Previous research has been carried out in Mozambique to try and determine road condition from average speeds as collected from mobile phone of GPS data (D Geilinger, L Herman 2010).

Table 5 - Typical speeds at specific condition ratings

Condition rating (WB rating)	Typical Speeds achieved in km/h on an unpaved road
Very Good (Excellent)	80-100
Good (Good)	70-80
Fair (Fair)	40-70
Poor (Poor)	30-40
Very Poor (None)	<30

The descriptions in table 3 and the typical speeds in table 5 will be combined with the Nigeria research to provide an estimate of the roughness of the road, following the field trials. Speed will be captured using dash-cams and the video from the dash cams can be used to estimate the roughness using the visual condition assessment table.

The recommended combined values in Table 4 have been designed to have a wide overlap. This is because the IRI is not an exact measurement of roughness on gravel roads and depends on a number of factors which can ultimately reduce its accuracy. Roughness measurement by traditional means, and even by mobile phone app, is very much dependent on which line the driver takes on the road. When there are a lot of potholes the driver will tend to weave to avoid them, essentially taking the smoothest line possible and thus distorting the measurement of the actual roughness of the surface. Moreover, the vehicle and mobile phone are unlikely to be calibrated against an accurate IRI device, such as the MERLIN.

In order to gain an accurate roughness measurement the driver should drive straight in the normal driving line and not avoid potholes. In practice this is difficult to achieve, especially when the driver has responsibility for the vehicle and has spent his/her life avoiding potholes. Also the normal driving line may not be obvious, especially on poor condition unpaved roads where the road may have been widened by people driving on the shoulders or beyond to avoid the larger defects.

Therefore the IRI, where recorded, should be used as a guide to check the assessments against, rather than an absolute measurement of roughness.

Table 6 shows the criteria we propose to use for assessing road condition from satellite imagery on unpaved roads. These criteria have been developed based on what can be seen on satellite imagery to indicate the condition of the road. It may be necessary to adjust these slightly based on what we learn from the research across the different countries. The photographs will be replaced with more current ones, when the imagery has been procured and analysed.

Table 6 – Condition criteria for unpaved roads

Condition rating	Criteria for an Unpaved road	Example
Very Good	Edges of road straight and width of road is constant, even colour/texture to the surface, drainage visible at least every 500m, no wheeltracking or visible wheeltracking in straight lines	
Good	Edges of road can be straight with some wandering and width of road varies slightly, colour/texture of surface slightly uneven in places but overall reasonably similar, drainage visible at least every 1km and appears to be in good condition, visible wheeltracking meanders slightly	
Fair	Edges of road vary and width changes by up to 50%, some variation in colour/texture, drainage irregular but appears to be functional, visible wheeltracking across much of the road	
Poor	Edges of road very uneven and width varies up to 100%, variable colour/texture of surface, possibly shadows visible, any visible drainage appears to be damaged or not functional, visible wheeltracking across most of the road in uneven patterns	
Very Poor	Edges of road broken and irregular, width of road varies greatly (more than 100%), uneven colour, shading and texture so that overall appearance of road surface is very mottled, no drainage visible and visible wheeltracking extends across the full width of the road in weaving patterns.	

Note: The pictures above are taken form the Nigeria research, they will be updated for each country when we have relevant images of typical ground conditions.

4.2.6 Paved Road Condition categories

The World Bank maintenance manual also set out a scale for IRI on paved roads, as can be seen in table 7.

Table 7 - World Bank Guideline on visual assessment of Roughness

Condition	Description for paved roads
Very Good IRI: 0,2	V* > 120 km/h, Undulations hardly noticeable at 80 km/h. Visual inspection: No deformations or potholes. Depressions < 2 mm/3 m. Asphalt concrete or high quality surface treatment.
Good IRI: 4,5,6	V = 100-120 km/h. Aware of slight movements or gentle undulations at 80 km/h. Surface degraded by: depressions (5-15 mm/3 m), repairs and potholes (1-5 per 100 m). Surface not damaged, but undulations and corrugations exist.
Fair IRI: 7	V = 70-90 km/h Sharp movements and swaying. Depressions (10-20 mm) or frequent repairs, or occasional potholes; or surface not damaged, but strong undulations and corrugations exist.
Poor IRI: 9,10	V = 50-60 km/h Frequent and sudden movements and swaying. Serious faults; or frequent and deep depressions (20-35 mm at a frequency of 6-10 per 100 m); or frequent poor repairs and potholes (6-20 per 100 m)
Very Poor IRI: 11	V < 50 km/h. Frequent and deep depressions and potholes (> 40 mm; frequency 16-30 per 100 m).

We do not have any direct experience of IRI on paved roads in relation to satellite imagery assessment. However, table 8 shows two alternative values for IRI on paved roads, from the World Bank guideline on visual assessment of roughness and from HDM4 (R Archondo-Callao, 2008), At the lower and higher ends they are very similar, but the levels for Good and Fair especially are different. Again, we intend to assess these values against the situation on the ground, but we will propose a combined and adjusted version based on site trials. A suggested combination is shown below in Table 8.

Table 8 - Proposed IRI values

Condition rating	World Bank visual IRI for paved roads	HDM4 IRI for paved roads	Combined and adjusted: Proposed IRI for paved roads
Very Good	< 3.0	< 2.5	**< 2.5**
Good	4.0 – 6.0	2.5 - 3.5	**2.5 – 5.0**
Fair	7.0 – 8.0	3.5 – 6.0	**5.0 – 7.5**
Poor	9.0 – 10.0	6.0 – 10.0	**7.5 – 10.0**
Very Poor	> 11.0	> 10.0	**> 10.0**

Table 9 also shows the typical speeds that could be expected for different levels of IRI on a paved road.

Table 9 - Typical speeds at specific condition ratings

Condition rating (WB rating)	Typical Speeds achieved in km/h on a paved road
Very Good (Excellent)	>120
Good (Good)	100-120
Fair (Fair)	70-90
Poor (Poor)	50-60
Very Poor (None)	<50

There has also been some research into alternative modes of assessing paved road condition using high resolution satellite imagery. The paper 'Assessing paved road surface condition with high-resolution satellite imagery' (WJ Emery et al 2013) suggests that it is possible to use satellite imagery to discriminate between good, fair and poor paved road surface conditions by using satellite imagery brightness values, as a poor condition road will show a higher brightness than a good condition road. The pavement becomes brighter in panchromatic grey shade as it degrades and as a consequence the digital number increases and mean value increases. Also as pavement degrades the data range increases, the variance increases and the entropy parameter increases. This method would have to take into account variables such as sun angle/glint, different viewing angles, season and time of day the image is taken, all of which should be consistent in order to provide reliable results.

It is our intention to carry out ground truthing for all countries as far as possible during the dry season, with imagery procured at the same time, so that the appearance of the road is the same for both. This is an important aspect of control because, as mentioned earlier, the appearance of the road can vary between wet and dry seasons, plus the condition of particularly unpaved roads can change rapidly under extreme weather events. Most countries carry our condition surveys in this way, and where possible at the same time of year in order to be able to compare conditions on the same basis.

In Africa concrete is not used for rural low volume roads, so there is no need to consider the difference in appearance between these and bituminous roads. However, some countries have the options of using cobblestones, block paving or stone soling, although these are very rarely implemented. This is not the case in Asia, where concrete is used extensively for rural roads in some countries, such as the Philippines.

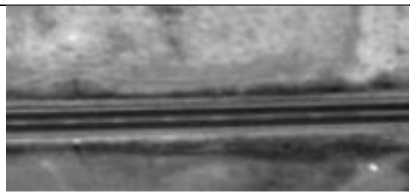
The results suggest that high-resolution WV2 satellite imagery can be used to assess road surface conditions to being in poor, fair or good condition, which was the prevailing classification of the local road authority and was linked to residual life and the time left until resurfacing was necessary. The researchers have identified a next step to carry out an exercise with CDOT to test if satellite data alone can be used to determine whether or not a road should be resurfaced. The paper 'Remote Sensing of Roads and Highways in Colorado' (W Emery and C Singh, 2013) came to similar conclusions.

There would be some value in replicating and extending this research to test the viability of using such high resolution brightness to determine condition. It is likely however that a full study would be beyond the resources of this project, so we intend to do a test in one country to determine whether there is scope for further research.

Unlike the unpaved road research in Nigeria, we have no direct experience of assessing paved roads for condition from satellite visual imagery. However, we have devised the following matrix using residual images from Nigeria of paved roads that were within the area of study. We will use this as a basis for paved road assessment and will adjust it as necessary during the research, based on our findings.

Table 10 shows the criteria we propose to use for assessing road condition from satellite imagery on paved roads. These criteria have been developed based on what can be seen on satellite imagery to indicate the condition of the road. It may be necessary to adjust these slightly based on what we learn from the research across the different countries. The photographs will be replaced with more current ones, when the imagery has been procured and analysed.

Table 10 – Condition criteria for paved roads

Condition rating	Criteria for a Paved road	Example
Very Good	Edges of road straight and width of road is constant, even and dark colour/texture to the surface, drainage visible at least every 300m, shoulders clearly visible and structures do not show any obvious damage	
Good	Edges of road straight with some slight variation and width of road is constant, colour/texture of surface slightly uneven in places but overall reasonably similar and still quite dark, drainage visible at least every 500m and appears to be in good condition	
Fair	Edges of road vary slightly with possible edge break visible, and width may change by up to 20%, some variation obvious in colour/texture and appears as medium shade, some small defects visible, drainage regular and appears to be functional	
Poor	Edges of road uneven and edge break may be visible, width varies up to 50%, variable colour/texture of surface and light in appearance with defects/large potholes visible, any visible drainage appears to be damaged or not functional, possible visible wheeltracking on shoulders	
Very Poor	Edges of road broken and irregular, width of road varies greatly (more than 50%), uneven colour, very light appearance, large areas of surfacing missing, no drainage visible and visible wheeltracking on areas with no pavement	

Note: The pictures above were taken from the Nigeria research and from other sources; they will be updated for each country when we have relevant images of typical ground conditions.

4.2.7 Ground truthing

The ground truthing will be carried out using local resources and staff, in a way that is robust and sustainable. We intend to use the GEM condition assessments where possible to provide an accurate baseline of the road condition. The same assessment criteria will be used, in terms of Very Good to Very Poor, but the assessment methodology will differ. The GEM project is carrying out detailed assessments at IQL 2 or 3. The assessments for this project are only required at IQL 4 or 5. Therefore, in order to establish the minimum level of ground truthing accuracy needed we intend to duplicate the GEM project system in one country using a similar, but simpler and more sustainable system.

If appropriate it may be recommended that videos or photographs be taken of the road, possibly using GPS enabled dash-cams or smartphones which will be useful for comparison with remotely taken imagery, if this is a cost-effective and sustainable option. This will have the advantage of providing a permanent baseline of the road condition and allowing independent auditing if necessary. The satellite assessment will be carried out using different local staff to the ground truthing, but they will have been through the same training in terms of condition assessment.

A traffic light system using shades of green for very good/good, yellow/amber for fair/poor and red for very poor, will be used, as per Figure 14. It is intended that the condition of each road will be mapped on the master maps using this colour coding system, for both ground truthing and for satellite assessment of road condition. This will facilitate analysis of the results by directly comparing the results from the ground truthing to the results from the satellite interpretation.

Figure 14 – Colour coding for conditions

Very Good	Good	Fair	Poor	Very Poor
Dark Green	Light Green	Yellow	Amber	Red

Frequency of ground truthing will be determined, i.e. what percentage of the entire network needs to be assessed to verify the condition assessment from satellite imagery? The reasons for the ground truthing in this research are to validate the satellite assessments, but it is expected that some amount of ground truthing will be necessary in each new location to:

- To verify and calibrate the parameters for the particular conditions of the area, in terms of geology, materials, etc.
- To verify and calibrate the environmental situation of the road, i.e. what time of year the road is assessed, dry season, wet season etc.
- To verify and calibrate for the surface type of the road, i.e. paved, gravel or earth.
- To check the accuracy of the system
- To audit the data that is produced

4.2.8 Defects on unsurfaced roads

The details of actual defects that are visible on high resolution satellite imagery are limited. However, in order to obtain a high quality baseline from the ground truthing it will be necessary to identify a wider range of defects.

In terms of the defects that can be found on unsurfaced roads we agree with the assessment made by the GEM project. The main parameters to be measured are:

- Cross-fall/profile: This reflects the ability of the road to drain water from the surface. When water is allowed to settle on an unpaved road it softens the surface and leads to damage.
- Erosion and scour: Where materials are washed from the surface of the road.
- Drainage: Damage or deterioration of drainage can lead to serious damage to the road surface itself.
- Material loss: Materials can be lost through water, dust and the action of vehicles, decreasing the life of the road. This may not be obvious form a single visual inspection, but could be monitored over time.
- Passability: The ability of the road to stay open to traffic throughout the year. Environmental effects can reduce passability, combined with poor design and maintenance. This may not be obvious from a single visual inspection, but could be determined by consulting with local communities and road maintenance authorities.
- Potholes: Potholes usually develop as a consequence of the ingress of water into the surface. They are not always obvious on unsurfaced roads because the surface material will be the same as the material in the pothole. Larger degraded areas are often referred to as spot patching.
- Rutting: This is the loss of materials in the wheeltracks and is often possible to see on satellite imagery. Rutting occurs parallel to the direction of travel and can be a good indicator of condition.
- Stoniness: This indicates oversize material in the pavement surface and indicates that poor materials are present.
- Dustiness: This can be as a result of an excess of fine material and a lack of plasticity in the surface materials. Dust is produced by the action of vehicles and can contribute towards significant material loss from the pavement structure.
- Corrugations: These are parallel crests that form perpendicular to the direction of travel on some types of unsurfaced roads, most commonly those where higher speeds are evident. They are caused by the action of vehicles and are determined by the material type, resulting in high IRI and an uncomfortable ride.

Roughness can also be used as an indicator of the condition of unpaved roads. All of the above parameters can be estimated from a visual survey, given accurate and easily interpretable guidelines. We will therefore utilise the GEM project visual condition assessment where possible and replicate it in the countries where we do not overlap.

4.2.9 Defects on Paved roads

The GEM project identified a number of defects that would be indicators of condition on paved roads. They are:

- Roughness: This indicates the relative degree of comfort experienced by the road user and can be a good indicator of condition on paved roads. It can be measured or estimated.
- Cracking: This can indicate structural distress in the pavement, with the type of cracking indicating the type of structural failure. Cracking can be recorded from a visual survey.

- Skid resistance: The skid resistance indicates the ability of vehicle tyres to resist sliding on the surface of the road when turning or braking. This can be measured using specialist equipment.
- Deflection: These measurements are used to measure the structural condition of the pavement. This can be an involved and expensive process and is not possible from a visual condition survey.
- Rutting: This is the longitudinal deformation that occurs in the wheeltracks of flexible pavements. It can be an indicator of different types of structural failure and can be measured or estimated in a visual survey.

These defects will undoubtedly provide an accurate indication of the road condition in terms of the five different categories. However, there are a number of indicators included here that require physical tests or measurements on the pavement itself. Given our principle of making the satellite assessment system and ground truthing simple and cost-effective we recommend that a visual survey is carried out to estimate the condition of the paved roads, with roughness measured or estimated as a double check.

The visual survey could include the following indicators:

- Cracking
- Bleeding (excess bitumen on the surface of the road)
- Deformation/Rutting
- Potholes/Patching
- Shoulder/Drainage/Structures condition

These categories can be aligned with the World Bank guide descriptions of roughness assessment in table 9.

4.3 Assessment and analysis of data

4.3.1 Mapping and condition assessment

Staff trained in image interpretation will need standard GIS software on their computers, i.e. QGIS, ArcGIS etc. They will also need standard MS Office and Windows applications. The data produced from this research will be collected as picture files, most likely in the jpg or tiff format. Pleaides imagery comes as 0.5m resolution, which is appropriate for both condition assessment and mapping. If mapping were to be carried out alone then SPOT 6 imagery could be used at 1.5m resolution, as it was in the Nigeria research. In order to replicate this situation we can down-sample Pleaides imagery to 1.5m in order to carry out the mapping to replicate a realistic situation. This would save procuring additional imagery from the Provisional Sum budget.

For condition assessment we will experiment with different resolutions to see which is the least we can determine condition from. The lower resolution imagery is cheaper so it is important in terms of cost effectiveness to find out what is the lowest possible resolution where condition assessment is feasible. To carry out this test we will down-sample the very high resolution imagery to 1.5m (equivalent to SPOT 6 satellite imagery) and 2.5m (equivalent to SPOT 5 satellite imagery). We will start by assessing whether condition assessment is possible from the 2.5m resolution in order to test the lower limit, then work our way up to the 1.5m and 0.5m imagery. This will be carried out on a small representative sample in one country and will provide a robustness to our research.

We will show the road condition on the imagery in the same way as we did in Nigeria, by using a traffic light system with a scale from Green as Very Good at one extreme, to Red as Very Poor at the other extreme, as shown in section 4.2.6. In order to do this the imagery will need to be converted into shape files and given the necessary attributes. In Nigeria the condition from the ground truthing was shown on the map as coloured dots (offset slightly to avoid overlap), whereas the condition from the satellite assessment was shown as a coloured line, as can be seen in Figure 15. In this way the image assessor can compare the two conditions directly and work out the correlation. The ultimate destination for the files will be a RAMS, most of which have many other uses for the data.

Figure 15 – Ground truthing compared to satellite assessment

Our results for comparisons will be geo-coordinated, for example they will only show correlation where the same condition is found on the same section of road. The correlation figure will not be created by comparing the overall volume of road that falls into each category, which would be misleading. We intend to manage the correlation by showing the conditions for ground truthing and satellite assessment on the same map and measuring the correlations manually. This exercise will only be carried out for this research, so there is no value in developing an expensive software application to determine the correlation when it can easily be carried out manually by the locally trained staff. If the research is successful and the methodology is adopted then there will be some value in the future for developing such software where the ground truthing could be used to calibrate the system for use in a new country.

In addition to the structured assessment for condition described above, we will experiment with different ways to analyse the surface and find out what other features or aspects we can determine.

In Ghana we will consider carrying out the assessment using SAR, in order to trial the technology in an environment where there is heavy cloud for most of the year. Before we commit to procuring SAR images we will assess the potential for determining road condition visually from such imagery, as well as assessing the potential cost, which is likely to be significantly higher than optical imagery. Cost effectiveness and overall cost are an important aspect of this study.

There may still be some issues with tree cover; long wavelength SAR can effectively see through tree cover, but the quality of the imagery you would then obtain from the earth's surface would be significantly less detailed and would be almost impossible to use for road condition. We therefore intend to use the shorter wavelength SAR to show condition through clouds and will assess how much tree cover interferes with the result.

SAR is much more difficult to interpret as it is less lifelike than visual imagery, it is black and white and very 'grainy' and depends on the angle the data was collected at. Features that are likely to be well visible on SAR are ditches, camber and texture of the road. The SAR data is acquired at approximately 1.0m resolution. The training course for Ghana therefore will be more oriented towards SAR imagery in order to give the trainees the necessary skills in SAR interpretation. For comparison purposes we will also procure a low cloud content/cloud free very high resolution image (acquired either in the wet or dry season, or both) for the same area.

As we are looking at low volume roads we do not expect to see many vehicles on the road. There is existing software that can identify and exclude vehicles from the image, but it is unlikely this will be necessary on the roads we intend to target as traffic volumes are so low, typically much less than 300 vehicles per day for rural roads and down to as low as 15 vehicles per day. Also this software can be expensive and requires the development of, or access to, a library of training sets, although it is dropping in price. An alternative would be the use of machine learning, although this is likely to be beyond the scope of this research. The exclusion of vehicles would be a consideration for high volume roads.

We have a mandate to identify cost effective solutions. It will therefore be important to assess the cost of carrying out mapping, condition assessment by satellite and the other pilots and compare them to traditional practices. This costing will need to take account of all the relevant costs, such as satellite imagery, specialist software, hardware, training and other support. In addition to the costs of the solutions we will comment on their environmental impact, compared to traditional means.

5 Potential partners

The Terms of Reference states that inputs from partner countries should be identified during the inception phase, based on the proposed research pilots. It is also stated that the service provider should identify potential partners for specialist high tech input, including remote sensing data, at the inception stage.

If additional funds are required over and above the provisional sum of £20,000, then this should be borne by partner countries or other donors. In the clarifications provided during bidding it was noted that the AFCAP PMU would provide assistance to identify additional funding sources, against agreed selection criteria that will need to be developed by the service provider.

Our partners on this project, Airbus DS, will supply the satellite imagery for the mapping and condition assessment.

5.1 External partners

We expect to have good coordination with other donors and potential partners on this project. Many of these organisations are providing their data free of charge through open source, including most recently USAID and the Gates Foundation. This is a trend that is improving the accessibility of satellite and other data around the world. Satellite organisations such as the European Space Agency (ESA) with Sentinel 2 and Planet Labs are making their information freely available, especially for humanitarian purposes.

The following contacts have been explored with a view to future partnership and collaboration on this project:

5.1.1 RCMRD

The Regional Centre for Mapping of Resources for Development (RCMRD) is a regional institution based in Nairobi, Kenya, which has 20 member countries from Eastern and Southern Africa, which include our partner countries of Kenya, Uganda and Zambia.

It is an independent body that was set up in 1975 by the United Nations Economic Commission for Africa (UNECA) and the original African Union (AU). Today it relies on income from member states (40%) and from the projects it undertakes commercially (60%). It has very good links to government in the 20 member countries, mainly with Land Ministries, as well as with Universities and other institutions, plus with commercial entities.

This organisation specialises in capacity building and training and is set up to do this either at their headquarters in Nairobi, or in their member countries. RCMRD can provide access to various levels of satellite imagery, much of which is freely available, especially if it is archive data. However, the high resolution data that is required for condition assessment is likely to attract a fee.

5.1.2 World Bank

The World Bank is carrying out research in this area and has already undertaken a number of initiatives:

- A road mapping project in the Philippines which uses various sources of remote sensing data to produce maps and basic road condition.
- A road mapping project in Mozambique using a mobile phone app. developed by the World Bank themselves.
- The bank also owns two UAVs which are planned to be used in Mozambique to monitor road condition. At present they are waiting for permission to operate the UAVs.
- We understand that there is research or experimentation being undertaken in Malawi with a World Bank project for the Department of Surveys (DoS). The project is modernising the DoS and includes data collection using mobile phone apps and UAVs. It is also understood that the DoS is in the process of procuring high resolution satellite imagery to cover the whole country. This imagery is expected to be 2016 or 2015, so will certainly be useful for mapping and possibly also for condition assessment.

TRL has already undertaken a video conference with the World Bank and the relevant projects in order to discover in more detail what each is doing and with a view to future cooperation. The researcher from Mozambique has also visited TRL offices to provide specific information on the Mozambique study.

5.1.3 Google, Facebook, Amazon and other internet companies

It is possible that Google and other multinationals will be interested in supporting this research. Facebook recently tested a solar drone that flies at 90,000 feet with the aim of supplying internet to remote areas of Africa (D Lee, 2013). Google are supporting anti-poaching initiatives in Africa by using drones, night vision goggles and Google Earth. Not only do the drones monitor elephant's movements, they can also be used to scare them away from areas where poachers are present (C. Spillane, 2013). Amazon are planning cargo deliveries by drone, whilst other companies are exploring this possibility within Africa (C. Mungai, 2015). The images provided by Google Earth can be very useful for estimating and checking mapping, but it is unlikely that the resolution or date will be appropriate for condition assessment. The images would, however, be useful for establishing an initial basic map that could then be checked and adjusted using higher resolution imagery. In any case, all of these companies have shown an interest in high-tech solutions for different problems in Africa, which makes them potential partners.

5.1.4 Drones for Development

This is a company based in the Netherlands who specialise in using drones for development purposes. Their aim is to improve the supply chain for small medical goods, thereby improving health care and saving lives of people in remote and hard to reach areas. They focus on setting up self-sustainable service organisations for the transportation of small medical goods, in alignment with relevant government rules and regulations, together with local hospitals and local entrepreneurs (J Ledgard and S MacMillan, 2015).

5.2 Links with other AFCAP projects

5.2.1 Asset management

We are optimistic that this project will link with the AFCAP GEM project in Uganda and Zambia. Both of these countries have committed to these projects and we are hopeful that the areas of investigation will be suitable for both projects. At present the tentative areas for research are:

- Zambia - Chongwe District
- Uganda - Kamuli District

These are however subject to further negotiation and change.

For the satellites project we had identified a savanna landscape as being appropriate for these two countries as it represents AFCAP countries in general. The tentative areas above do fulfil this criteria.

The specific synergies that we envisage for this project are mainly in terms of the ground truthing. We have aligned our ground truthing criteria and scale with that proposed by the GEM project and we expect that the condition assessment made by the engineers on that project will be appropriate for comparison to the satellite imagery. In those countries where the GEM project is not active we will use the same methodology for condition assessment.

5.2.2 Climate resilience

Our selected country in West Africa is Ghana, which overlaps with the AFCAP climate resilience project. Ghana is our example of a tropical country with densely forested areas. We intend to use Ghana as a test for radar satellite data to see if the road condition can be determined through forest canopies and clouds, which means selecting a tropical, forested area, most likely in the south west of the country. This area will be selected on our first visit to Ghana.

We will liaise with the climate resilience project to identify any potential uses for the satellite imagery, which would be useful for that project. This could include identifying catchments and areas at risk of flooding, or damage to drainage structures.

5.2.3 Data for transport services

Satellite data and Big Data have the potential to be used for monitoring or evaluation of transport services. Most of the links already established are related to traffic and urban movement, but there is also potential for transport services on low volume roads to benefit.

6 Capacity Building and Technology Transfer

Capacity building and training are a core aspect of this project. However, before we can carry out effective capacity building we need to consider some issues:

- This is a new technology for Africa so it is important to select appropriate people to be trained. The staff carrying out ground truthing should have an engineering qualification and some experience in condition assessment. Staff interpreting the satellite imagery could have a working knowledge of roads and familiarity with Windows-based computers from their work or studies, but they do not need to be experts in remote sensing as appropriate training will be provided. The staff also need to have a certain level of education, e.g. ideally equivalent to UK ‘A’ levels. Knowledge of Maths and Physics at equivalent to UK GCSE level should be seen as essential. This is to understand the basics of satellite imagery and for development of GIS skills. For satellite image interpretation a basic knowledge of GIS would be useful, but not necessary. It is not necessary for the staff selected for the imagery assessment to be familiar with the area, in fact it is probably best that they are not familiar so that they have to reply entirely on what they see on the image. This was the case with the Nigeria research.

- It is also important that the people selected are interested in the subject and motivated to carry out the research. We will advise on the skills and experience necessary to select dedicated counterpart staff who can champion the recommended solutions and facilitate their successful trial.
- It is important to train enough people to counter the effects of transfer and staff turnover, assuming that this is not expected to be excessive.
- We will propose high-tech solutions that are sustainable and can be incorporated into the local road authority's existing processes and procedures. In order for sustainability to be achievable it is essential that the local stakeholders take ownership of the process, so we will seek to ensure this is understood and implemented accordingly. We will avoid wholesale institutional change as it is disruptive and risks the effective uptake of new technology, but we will recommend small changes where necessary. Sustainable and appropriate training is key to successful technology transfer.

The project will be judged on its ability to provide high-tech solutions that countries can continue to apply cost effectively using their own resources. To support this process the TRL team is committed to sharing not only the results of research, but the processes and methods that were used in producing the results, which is a critical factor in making this project sustainable. An important part of capacity building is the dissemination of research results. This needs to be done through the appropriate channels and to as wide an audience as possible. We agree with the modes of dissemination proposed in the ToR and believe that the target audience it identifies is appropriate for the receipt of research outputs. The dissemination of research through papers at regional conferences in Africa has proven to be successful, but we will also look at expanding it to other relevant events within and outside the region.

In terms of capacity building for the future, most of the basic skills needed to use remote sensing are available in LICs through local suppliers. For example standard GIS technology, advanced computer applications etc. can be sourced locally and from the internet. In addition the engineering skills necessary to identify roads and assess their condition, both on the ground and via satellite imagery, can be gained through standard University courses or by carrying out an applied Masters course. Our strategy in the long term would be to use existing local resources as much as possible for capacity building in-country. A good example of this is the Kenya Institute of Highways and Building Technology (KIHBT) training centre at Kisii in Kenya, which specialises in training for labour-based roads and RCMRD, who specialise in remote sensing technology and training.

For phase 2 our strategy will be to carry out training separately in each country. Initially we had expected to be able to do this regionally by holding a training event in two of the countries, with the other two visiting, and priced our bid accordingly for two visits of the IT advisor. However, since making contact with the countries it has become clear that it is most appropriate to carry out training in each country using the conditions and technologies that exist there. Although the environment is likely to be similar, the technologies and materials do vary quite significantly across borders. In addition the countries are struggling to find local resources to fund the cooperation, and may not be able to afford to fly five or six trainees to a different country to be trained.

In order to maximise our trainer's time in country we recommend that the local training suppliers carry out some general training in GIS, image interpretation and analysis before the TRL training course. In order for us to pitch our training course at the appropriate level we will request the local trainers to carry out a student assessment at the end of the course and provide us with feedback. We would then carry out specialist training for 3 or 4 days in each country to teach staff how to identify roads and how to assess road condition from satellite imagery, specifically related to the local conditions. Ideally this training would include a field trip of not more than one day. In Zambia and Uganda we expect the assessment sites from the GEM project to be manageable within one day, but in Ghana and Kenya they will probably not. We therefore recommend using additional archive imagery to act as a practical training site close to the capital city, in a location where it can be visited within one day.

We will support the local suppliers to develop training for ground truthing and satellite image interpretation and we would invite the local suppliers to attend our specialist training in order to build capacity for the future. Ideally they would be able to develop their own training courses for mapping and road condition assessment, using a combination of the basic training they carry out, fused with the specialist training that TRL will deliver.

Given the situation outlined above if reginal training is not possible we will endeavour to maximise the specialist training using the two visits of the specialist Airbus trainer, as scheduled in our proposal. This could necessitate involving trainers from specialist organisations such as RCMRD and CERSGIS in the training in other countries, then using them to carry out the training in their home country. This would be more cost effective than proposing an additional two visits of the Airbus trainer to Africa. This could be arranged in the following way:

- RCMRD trainer attends training in Uganda. Then on return to Kenya is able to train the Kenyan engineers in the necessary skills.
- CERSGIS trainer attends the training in Zambia. Then on return to Ghana is able to train the Kenyan engineers in the necessary skills.

If the partner countries are unable to provide funding for this, we will seek additional funding from the project, or permission to use the provisional sum to fund this activity if there are sufficient funds after procurement of satellite imagery.

We also intend to trial distance learning in parallel to the main training. There are a number of freely available videos that provide a good basic training in GIS and satellite image interpretation which should be accessible from Africa. In addition we can also trial training by video conferencing, WebEx, Skype or a similar medium. This technology clearly depends on a good and fast internet connection. Although internet connections in Africa are improving both in speed and reliability, it is possible that distance learning by internet may not be feasible in all countries, all of the time.

Although it may not be necessary to have any background information in roads to be able to assess the imagery, we will aim to recommend counterpart staff with a working knowledge of rural road construction and maintenance, with good computer literacy. If they have some experience in GIS, mapping or remote sensing this will be an advantage, but it is not essential. The ground truthing will be carried out by different staff than those doing the satellite imagery assessment and we would expect the ground truthing staff to have a good knowledge of roads and some experience in condition assessment. For the training we aim to include field trips where the image interpreters will be able to have first-hand knowledge of the area they are to assess, the visual connection between what is present on the ground and what is visible on a satellite/aerial image can help some interpreters.

In accordance with the gender policies of ReCAP we will strongly encourage the partner countries to select female counterparts wherever possible. We believe that this type of work will be suited to female engineers, technicians and support staff.

During our initial visits we will investigate:

- The resource availability within potential partner countries to carry out road condition assessment via satellite imagery, in terms of staff, training, satellite imagery and software/hardware. It is essential to identify the software that is available in country and likely to be used, as this will be a factor in determining how the training courses are set up. For GIS work it is possible to use freeware such as QGIS, but if for example a country has already established ArcGIS then the training will be adjusted to take account of this.

- The skills existing in country to carry out this type of assessment, and consequently the capacity building liability for each country. Although only a basic working knowledge of roads and computers is necessary to carry out these tasks, gaining an idea of the existing capacity will help us to pitch the training at an appropriate level.
- The practical application of the technology and the chances of it being embedded as best practice in each country. This will involve gaining a more overall impression of the capacity of the local roads authority take up the technology and incorporate it within their standard practices. We will be making recommendations in the final report for sustainability and uptake of the technology.

This information will help us to make appropriate decisions when agreeing counterpart staff for the project, developing training courses and implementing capacity building measures.

7 Uptake and Embedment

Following a video conference with TRL, Airbus DS, the World Bank, Satellite Applications Catapult, AFCAP PMU and regional World Bank projects on 21st June 2016, it was proposed that a repository for remote sensing data and other high-tech information relevant to rural roads should be established. AFCAP volunteered to look into hosting this repository/information centre as the most appropriate body. Since this meeting the project has liaised with AFCAP and plans are in place to develop a web portal where experiences can be shared, information can be uploaded and discussions can take place.

Our initial investigations have indicated that there is a significant possibility of duplication of resources, due to the lack of a common platform where stakeholders can share their interests. For example we learned that UAVs were being used, or planned to be used in at least two countries. This was not common knowledge and could have led to the project carrying out expensive pilots with UAVs in a country that already has the capacity. Similarly we learned that the World Bank has a mobile phone app that measures roughness, which we had considered trialling with a different supplier, as were the AFCAP GEM project. We have now been able to inform them of this detail, but this is a good example of where a portal or shared platform would have avoided the issues in the first instance.

In addition to this proposal, there is a vast amount of data available through open source, with many of the funding agencies and some commercial suppliers providing satellite imagery and other data free of cost. In fact it is a principle of many of the donors to encourage open source data wherever possible. With the rapid expansion of remote sensing and earth observation it is likely that prices will become more competitive in the long term.

Dissemination and effective uptake is essential to make this project a success. The expected results will be shared with relevant stakeholders through various mediums, wherever possible through the local partners. There are two relevant conferences planned during the period of the project, the first in Ghana in October 2016 and the next in Zambia in May 2017. We have made a proposal to hold a workshop at the Ghana conference to discuss the issues around high-tech solutions and to gain feedback from the various stakeholders. We hope to be able to present the results of our research at the Zambia conference, which coincides with the completion of the project. We would expect local partners to present the results, which will also help towards capacity building.

The credibility of the research will depend on the research results being understandable, reliable and implementable. TRL is ideally placed to help the participating countries establish partnerships and links with any interested research organisations, road agencies/authorities, donors and other relevant agencies around the world. We will help to establish these links early on so that stakeholders can be kept fully informed of progress, but the dissemination process itself will happen in the third phase. The guideline to be produced will be a key aspect in achieving the project objectives, as it will provide the tools to allow countries to take up these high-tech solutions.

8 Country Participation

A separate country selection report is contained in Appendix 1. The countries selected for participation, subject to final confirmation of commitment to providing resources, are:

- Ghana
- Kenya
- Uganda
- Zambia

It is also possible that Malawi can be involved, pending further discussions. Since the country selection report was produced we have learned that the Malawi government is in the process of procuring high resolution satellite imagery for the whole country. If this proves to be current enough it could be used for condition assessment on a pilot area. Malawi could be included in a regional training course to carry out ground truthing and image interpretation, based on the same principles as the other partner countries.

We will also explore the possibility of carrying out some relative trials in South Sudan to test whether condition assessment can be achieved without visiting an area at all.

9 Conclusions

From our investigations in the desk study so far we can conclude that:

- There are a number of high-tech solutions that warrant further investigation and they have been proposed as pilots in the next phase. We will decide which countries they are to be trialled in when we have completed the initial country visits, which will determine who is interested to trial them and whether they have the necessary resources. They are detailed in the text above and will be proposed for pilot studies in section 10, below. Some high-tech solutions are very promising, but will be beyond the scope of this project due to scale and cost. Others that are ambitious, but still costly, have been put forward as potential solutions and will need additional funding to be feasible.
- A draft methodology for the satellite assessment mapping and condition evaluation has been developed. This methodology must remain flexible and we expect it to be adjusted based on what we find in the field. The first meeting we have with the partner countries will include a discussion on the methodology and ways in which it can be improved.
- There are appropriate local training providers in most countries, such as RCMRD, CERSGIS and Makerere University, who should be able to provide the necessary training and capacity building, with some support and guidance from TRL. RCMRD are established in Nairobi, Kenya, and have 20 members, which include Kenya, Uganda, Zambia and Malawi. CERSGIS are also established as a training centre for remote sensing in Ghana. Makerere University and the Zambian NRSC should also be able to provide general training appropriate to this project.

- Most identified partner countries have committed to providing some resources for ground truthing and satellite assessment. Due to the late notice they have not been able to include the cost in their annual budgets, but are trying to make provision by adjusting existing budgets. In this respect the local resource provision must be considered as a risk to the successful completion of the project. When the other high-tech solutions have been agreed the countries will need to make further budgetary provision or find alternative funding options if they are interested to undertake them as pilots.

10 Recommendations for pilot studies

The potential solutions that we recommend for pilot studies are as follows:

10.1 High-tech solutions

- Social media to report specific road defects, such as landslides, washouts, road blockages. We investigate the presence of such apps in the areas we are working and how feasible it would be to introduce this technology. If it is found to be feasible we will then contact the major social media platforms to explore the possibility of producing an app that make it easy to report such data through their platforms.
- Using UAVs to assess road condition. If significant funding is provided this could be done using LIDAR, but otherwise visual images will be used, possibly with photogrammetry or by visual inspection in the same way as the satellite condition assessment is carried out. Even the visual assessment will take additional funding, so we will explore the possibility of liaising with the World Bank projects in Malawi and Mozambique to monitor those pilots.
- Liaison with mobile phone companies to explore the possibility of using mobile phone data to monitor journey times and journey speeds, as a function of road condition.
- Using archived satellite big data to explore what can be learned by monitoring road condition over a number of years.
- Liaison with the AFCAP climate resilience project to see what climate related information can be extracted from the satellite imagery and how it could be useful to monitor climate change.
- Using mini-satellites to monitor accessibility following natural disasters. As mini satellites are able to produce images of most of the earth every day, they are an ideal tool to monitor changes or events on a daily basis. A recent example of where they would be useful is the earthquake in Nepal in 2015, where there were accessibility issues to remote areas. As Nepal is a mountainous area, many of the roads to remote areas were rendered impassable and helicopters were in short supply, meaning that their use had to be prioritised. This type of regular imagery would have been useful to determine which areas were still accessible by road and which were not.
- Big Data portals exist in Africa, mainly with the African Development Bank. We propose to liaise with the bank to recommend a dedicated roads portal which can point the user to big data relevant to roads.
- Following the video conference with the World Bank and partners, it was agreed that ReCAP and TRL would look into establishing a repository for remote sensing and high-tech solutions in the road sector for Africa. This will be a useful platform for people to share experiences, reports and discuss new developments in the industry.

- It is proposed that we test the feasibility of using spectral reflectance or brightness to monitor the condition of paved roads, using very high resolution imagery. This has been trialled in the USA and has potential to be developed further.

10.1.1 Matrix for high-tech solutions

Below in Table 11 is shown a matrix showing the potential research pilots for high-tech solutions. The first column summarises the subject for the potential pilot, with the next two columns showing what additional resources are required over and above that provided for in the ToR, from both the partner country/other donors and from the TRL team.

Table 11 – Matrix for high-tech solutions

#	High-tech solution	Resources required from country/ donor	Resources required from TRL team	Feasibility rating, tech (50) + cost (50)			Comments
				Tech (50)	Cost (50)	Total (100)	
1	Web portal and repository for relevant information	Yes: additional design of AFCAP portal	No: depends if data storage required	45	30	75	Feasible if based in ReCAP, costs should be minimal
2	UAVs, either with imagery or LIDAR	Yes: assume hire of UAV and equipment	Yes: additional assessment of imagery	45	15	60	Proven technology but high costs and other issues
3	Social Media, using apps to report maintenance issues	Yes: resources to promote app and monitor	Yes: from app design specialist	40	35	75	Depends on involvement of social media companies
4	Mini satellites for accessibility monitoring following disaster events	No: so long as imagery free of charge	No: depends on the research details	40	30	70	Proven technology, imagery low cost
5	Spectral reflectance for paved roads	Yes: additional assessment and analysis	Yes: possibly additional training	35	40	75	Technically feasible, cost depends on imagery
6	Big data portals focused for roads	No: unless website re-design	No: depends on the liaison details	35	25	60	Depends on collaboration, costs unknown
7	Climate resilience, information sharing	No: depends on the research details	No: depends on the research details	30	25	55	To be defined with AfCAP project, low cost
8	Mobile phone data for transport monitoring	No: unless mobile Cos. charge for data	Yes: to define solution and analyse data	25	25	50	Depends on permission to use records and cost
9	Archived satellite imagery for comparative back analysis	Yes: to interpret imagery	Yes: to monitor and analyse information	25	25	50	Depends on benefits for LVRs and cost
10	Internet related solutions (linked-data, semantic web)	Yes	Yes, to oversee and manage	30	20	50	Probably beyond scope of project
11	Computer related solutions (data modelling, distributed computing)	Yes	Yes, to oversee and manage	30	20	50	Probably beyond scope of project
12	Machine learning and artificial intelligence	Yes	Yes, to oversee and manage	30	20	50	Probably beyond scope of project

The columns under the heading 'Feasibility rating' show the potential feasibility in terms of technical and financial feasibility. Technical feasibility includes how proven the technology is, not just generally but in the environment in which it is proposed, for example for road authorities in Africa. The cost again is an estimate of how expensive the technology is likely to be given the environment in which it is expected to be used.

Technical and Cost have both been allocated a maximum of 50 points, with the total being shown out of 100. This is mainly a subjective assessment, unless the technology has been proven before which will give it a high mark. If the feasibility is unknown for either technical or cost it will be awarded 25 points. If a potential technology to be piloted shows a low score for cost it indicates that the real costs are likely to be high.

The technologies have been ordered based on their technical score. This is because we will try to secure appropriate funding for all of the proposed pilots, and the ones with the highest technical score are the most likely to provide positive results.

The technologies to be piloted will be agreed in consultation with the AFCAP PMU and the partner countries. Where significant additional funding is required it will also require the agreement of whichever donor is willing to provide the additional funds. We expect that there is capacity to pilot four or five of the technologies in phase 2, depending on the scale of the research. A detailed programme will be produced following the initial meetings with the partner countries.

10.2 Satellite imagery mapping and condition assessment

- We plan to use the mapping methodology as outlined in section 4. This is similar to the mapping methodology that we used in Nigeria, which is a semi-automated system. It will be based on medium resolution imagery, but we will also explore the possibility of using existing open source mapping, such as Google, etc. We will refine this system as the project proceeds, based on lessons learned, to confirm the most appropriate system for African countries.
- For the condition assessment we plan to use the new methodology as outlined in section 4.2. This will be undertaken manually using local engineers, technicians and others. The methodology will be treated as a live document and will be adjusted and revised as the project proceeds and as we learn from the data that is produced.

10.3 General

The guideline that is produced at the end of the project is expected to be oriented for the various features present in each country, which means providing specific assessment conditions on a country basis. This is because the technology, materials and conditions found in each country are likely to be slightly different, both in terminology and in practical application. However, our aim will be to provide a guideline that is considered as a flexible document that can be adjusted for use in any country.

10.4 Funding

10.4.1 High-tech solutions

We expect that partner countries or other donors will be asked to fund the small number of additional pilots that have been identified in section 10.1. We will not be able to provide firm estimates of the cost until we have liaised with the partner countries and determined the in-country costs of such research. However, an approximate outline has been provided below:

- Social media app: Two weeks of a programmer to develop this app. The provider would most likely be a specialist software developer who is familiar with the type of apps required, possibly even the social media provider themselves.
- UAVs: Hire of a locally based UAV, plus camera or LIDAR pod, for one week to take images of a sample number of roads. Additional training and analysis by the IT expert.
- Exploration of mobile phone data availability: No initial cost unless an application for its use is identified.
- Monitoring of condition over several years: Cost of satellite imagery over several years, additional local time to interpret and analyse the images, pus supervision.
- Mini satellites to monitor accessibility, or possibly a combination of available datasets, although there would be some effort required to combine different data sets if this approach were used: Imagery should be freely available if used from Planet Labs. Will require additional country input to interpret and analyse images, plus additional supervisory time from the team.
- Develop a repository for remote sensing and high-tech solutions in the road sector for Africa: If this is managed through the ReCAP website then there should be no cost to the project.
- Test spectral reflectance or brightness to monitor the condition of paved roads, using very high resolution imagery. This should be manageable using the imagery procured for condition assessment, but will require additional inputs from the IT advisor to develop a system for trialling this.

10.4.2 Mapping and condition assessment

The mapping and condition assessment cost is within the existing scope of the project and will be covered by the provisional sums. We anticipate that the Provisional Sums for satellite imagery will be approximately:

- 5 x Pleaides tasked images of separate areas – visual assessment and training (min. order 100km^2)
- 1 x SAR image – visual assessment for Ghana (min. order 1 scene)
- 2 x recent archive imagery - for training purposes(min. order 25km^2)

Table 12: Imagery estimate

Satellite	Mode	sq. km	Price / sq. km	Price (€)
Pleaides	Tasked	100	17	1,700
Pleaides	Tasked	100	17	1,700
Pleaides	Tasked	100	17	1,700
Pleaides	Tasked	100	17	1,700
Pleaides	Tasked	100	17	1,700
Pleaides	Archive	25	10	250
Pleaides	Archive	25	10	250
TerraSAR-X	Tasked	1 Scene	n/a	6,950
			Total (€)	15,950
Indicative Exchange Rate (€/£)		0.8	Total (£)	12,760

We have estimated based on the minimum order size for each type of imagery (Table 12). The area of imagery required will depend on the distribution of the roads within each pilot area, so it is likely that some areas will require more than the minimum, but this cannot be determined until the pilot areas are fixed. In any case we expect that the total sum for imagery will be within the provisional sum limit of £20,000.

We recommend that the remaining Provisional Sum be used for the procurement of small scale technical equipment that may not be available in Africa or can be procured at more reasonable prices outside of Africa. This would include equipment such as GPS enabled Dash-Cams for monitoring the ground truthing, hand-help GPS (if necessary) and smartphones able to run the World Bank road roughness app 'RoadLab'.

We recommend that additional funding be provided for our revised training methodology, as mentioned in section 6. This would involve two extra flights for the IT advisor and an additional six days input and allowances.

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Appendix 1

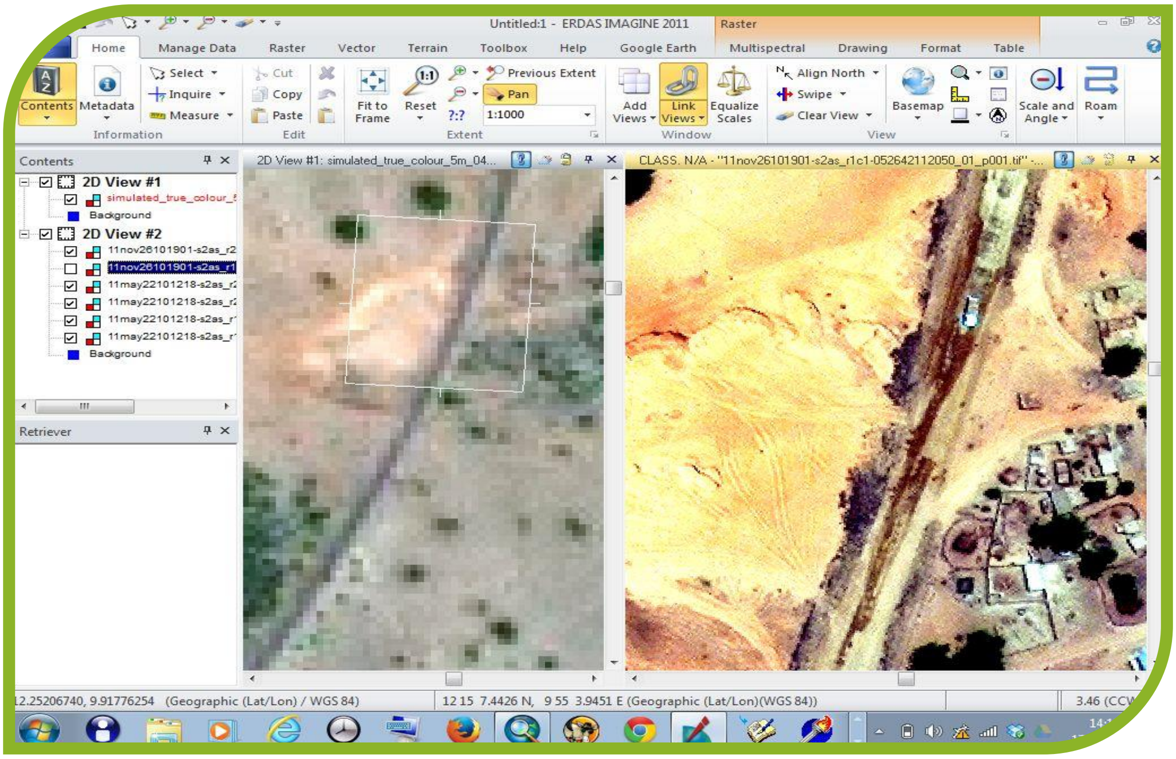
Country Selection Report

AfCAP
Africa Community Access Partnership

UKaid
from the British people

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

DRAFT Country Selection Report



Robin Workman
Andrew Otto
Alex Irving

TRL Ltd.

AFCAP Project Reference Number. GEN2070A

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ReCAP Project Management Unit
Cardno Emerging Market (UK) Ltd
Oxford House, Oxford Road
Thame
OX9 2AH
United Kingdom

Cardno
Shaping the Future

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RESEARCH FOR COMMUNITY ACCESS PARTNERSHIP (ReCAP)

Safe and sustainable transport for rural communities

ReCAP is a research programme, funded by UK Aid, with the aim of promoting safe and sustainable transport for rural communities in Africa and Asia. ReCAP comprises the Africa Community Access Partnership (AfCAP) and the Asia Community Access Partnership (AsCAP). These partnerships support 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 ReCAP programme is managed by Cardno Emerging Markets (UK) Ltd.

See www.research4cap.org

Acknowledgements

Airbus DS

Acronyms

AFCAP	- African Community Access Programme
AGRHYMET	- Agrometeorology, HYdrology, Meteorology
ARC	- AGRHYMET Regional Center
CERSGIS	- Centre for Remote Sensing and Geographic Information Services
GIS	- Geographical Information System
RCMRD	**- Regional Centre for Mapping of Resources for Development**
RRSU	- Regional Remote Sensing Unit
SADC	- Southern African Development Community
UN	- United Nations

Table of Contents

1 Introduction

The selection of partner countries for the project is based on the criteria set out in the ToR, as well as a number of other important factors that were derived from our experience of similar research in Nigeria and in other countries in Africa.

The initial indicator of countries was to determine who was interested to participate and could possibly provide counterpart resources and funding. A questionnaire was distributed at the AFCAP steering committee in Zambia from 17-20 May 2016, and the subject was discussed. The AFCAP Infrastructure Research Manager provided feedback that all countries were interested to participate, but that the following countries were the most likely candidates:

- Ghana
- Kenya
- Malawi
- Sierra Leone
- Tanzania
- Uganda
- Zambia

The Terms of Reference recommended a regional split of countries, with three countries from Southern and Eastern Africa and one from West Africa. The countries above therefore form our initial shortlist for selection, with a choice to be made between Ghana and Sierra Leone for West Africa and between Kenya and Tanzania for East Africa. Also we were asked to see if it is possible to combine Zambia and Malawi for Southern Africa, with Uganda as a standalone selection. We were also asked to consider whether South Sudan could be involved in some way, possibly near the Uganda border, as the conflict there is unlikely to allow any in-country work.

2 Categories and assessment

The countries interested can then be further categorised by the following subjects:

2.1 Vegetation cover:

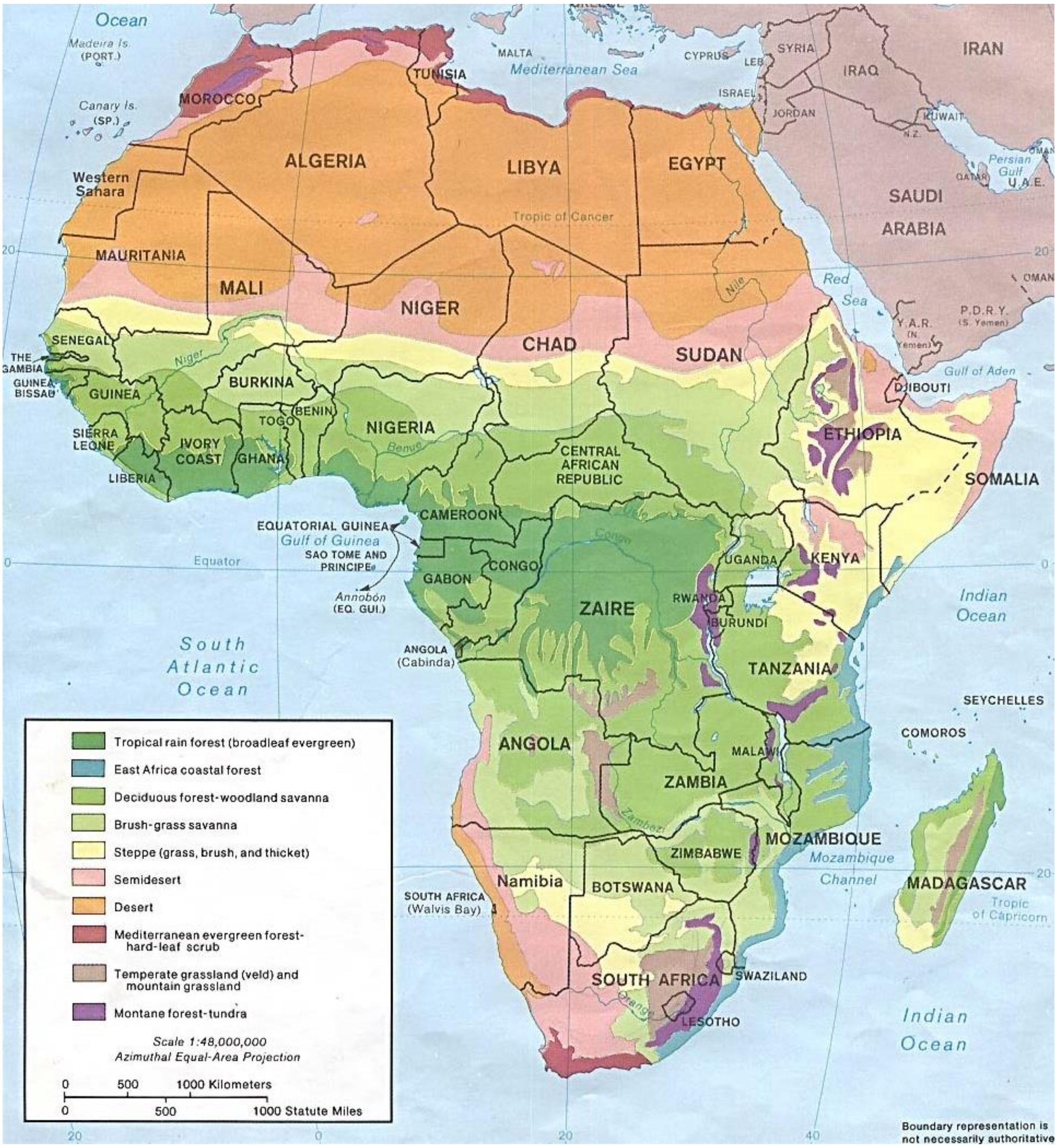
This is important as it determines what detail on the road is visible on normal medium and high resolution satellite visual images. This is the main factor for the specified research into network establishment and condition assessment by satellite. The ToR mentions that countries should be selected on the following basis:

- Two countries with arid areas – sparse vegetation
- One country with a well vegetated area
- One country with a tropical forested area

On researching the shortlisted countries, it has become clear that from these only Kenya has a truly arid area; the desert or semi-desert areas in the north of the country. One possible exception is Zambia, which has some semi-desert near their border with Namibia, but there are very few roads in this area. The map in Figure 1 shows the different vegetated areas in Africa.

The majority of land in the shortlisted countries is savanna, with medium or lightly vegetated areas and limited tree cover, usually deciduous forest. An initial internet map search has confirmed that roads in these areas should be easily visible on satellite imagery.

Figure 1: Vegetation of Africa.



Source: University of Texas https://www.lib.utexas.edu/maps/africa/africa_veg_86.jpg

This type of terrain is much more predominant in the AFCAP countries than arid or desert areas, so it is proposed that only one arid area is included, with two savanna type landscapes and one tropically forested area. From that perspective the countries can be grouped into the following categories, as seen in Table 1:

Table 1: Vegetation categories

Vegetation	Description	Country
Arid	Desert/semi-desert	Kenya
Savanna	Light vegetation	Tanzania, Zambia, Malawi
Savanna	Medium vegetation	Uganda
Tropical	Dense forest	Ghana, Sierra Leone

It is therefore proposed that only one arid area is selected, with one each from the light and medium vegetated savanna, plus the tropical forest area.

2.2 Climate:

The shortlisted countries are ranked for climate as shown in Table 2 below:

Table 2: Climate in shortlisted countries

Country	Climate	Other factors
Ghana	Tropical	More tropical in south with tropical forest, some drier areas in north
Sierra Leone	Tropical	More tropical in west with mangrove swamps/forest, drier in the east
Zambia	Sub-tropical	Tempered by altitude in some areas
Malawi	Sub-tropical	Tempered by altitude in some areas
Uganda	Tropical	Tempered by altitude in some areas, small areas of tropical forest
Kenya	Tropical	Arid in north, desert or semi-desert areas, some temperate areas due to altitude
Tanzania	Tropical	Some temperate areas due to altitude

It should be noted that the vegetation can vary greatly within a particular country, due to factors such as altitude. For example some countries in a tropical zone with much of the land mass above 1,500m may have a predominantly sub-tropical climate.

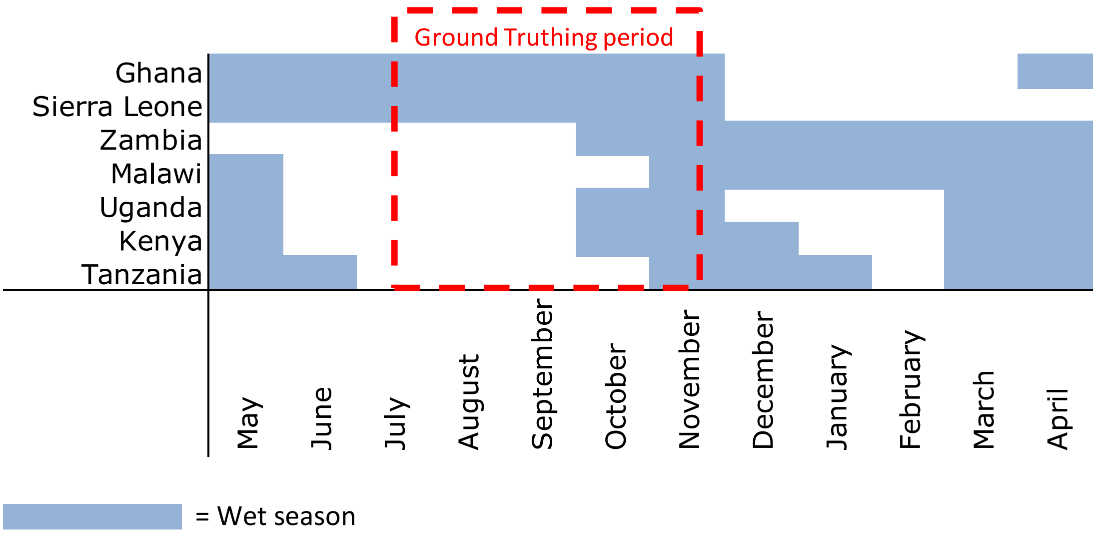
The ToR Mentions, as above, the vegetation of countries, which is closely linked to the climatic regions. This also has a bearing on the satellite imagery because weather conditions will determine the quality and accessibility of satellite imagery. Normal visual imagery will not be useful if the cloud cover is too dense, so good weather is essential. This will also have a bearing on the time of year that the research can be carried out. The most difficult areas to research will be the tropical ones, as the wet seasons are longer and cloud cover is more dense, in addition to the tree canopy possibly obscuring much of the road. It may be necessary to consider alternative types of imagery for this assessment, such as radar or thermal images.

Seasons:

In addition it is important to consider the wet and dry seasons in each country. This project only lasts for 12 months, and according to the initial programme provided there is a window of approximately 4 months in which to collect the ground truthing data on the roads. It is important that the roads are assessed in a similar condition, in order to facilitate comparisons between countries. It is recommended that road data is collected in the dry season, which will facilitate clearer satellite imagery and make it easier to carry out the ground truthing. The chart in Figure 2 shows the recognised wet seasons for each country, depicted as the bars in blue. The period planned for ground truthing and satellite image collection is shown as outlined in red.

This indicates that it would be appropriate to carry out the pilot studies in Tanzania, Kenya, Uganda, Malawi and Zambia during their dry seasons. In Sierra Leone and Ghana they would probably have to be carried out towards the end of the wet seasons. As these countries are selected for their tropical environments, this would be a reasonable test of the feasibility of the process in the tropics, as much of the year is wet. The window of testing would need to be carefully selected.

Figure 2: Wet seasons in shortlisted countries



2.3 Geography:

It is also desirable to have a range of geography within the areas selected for research. All of the countries on the shortlist are predominantly flat, although some have mountainous areas, most notably Kenya, Tanzania and Uganda. However, an initial scan of the mountainous areas in these countries reveals that they are almost all national parks and as such have very small populations and very few roads. Table 3 shows the altitude ranges in the shortlisted countries:

Table 3: Geography of selected countries

Country	Geography	Altitude, in metres above sea level
Ghana	Flat	0 - 885
Sierra Leone	Mainly Flat, some hilly areas	0 – 1,948
Zambia	Mainly Flat, some hilly areas	329 - 2,329
Malawi	Mainly Flat, some hilly areas	37 - 3,002
Uganda	Mainly Flat, some mountainous areas	620 - 5,111
Kenya	Flat, with Rift valley and mountains	0 - 5,199
Tanzania	Flat, with Rift valley and mountains	0 - 5,892

Based on this information we can conclude that it is neither feasible nor beneficial to include mountainous areas in the study. This could well be different in a different scenario, for example in the Himalayas in Asia, where there are large populations living in mountainous areas and dense road networks. Our proposal therefore is to concentrate on flat or rolling areas in the partner countries, as this represents the vast majority of the geography present in AFCAP countries, with the exception of Ethiopia.

2.4 Remote Sensing Centres:

An additional factor is the presence of a remote sensing centre within the country. Our initial investigations indicate that some countries have such a centre, whereas others do not. Table 4 shows the presence of remote sensing centres in the shortlisted countries:

Table 4: Remote Sensing centres

Country	Remote Sensing Centre	Affiliation
Ghana	Centre for Remote Sensing and Geographic Information Services (CERSGIS) AGRHYMET	University of Ghana Inter-govt.
Sierra Leone	AGRHYMET	Inter-govt.
Zambia	National Remote Sensing Centre (NRSC) RCMRD and RRSU (SADC)	Government Inter-govt.
Malawi	RCMRD and RRSU (SADC)	Inter-govt.
South Sudan	Geographical Information System Unit (GISU) RCMRD	Government Inter-govt.
Uganda	RCMRD only (although has a meteorological centre)	Inter-govt.
Kenya	Department of Resource Surveys and Remote Sensing (DRSRS) RCMRD	Government Inter-govt.
Tanzania	RCMRD only	Inter-govt.

There exists a regional remote sensing organisation for eastern and southern Africa, called the **Regional Centre for Mapping of Resources for Development** (RCMRD). This is based in Nairobi and covers all of the shortlisted countries, except for Ghana. This was established by the UN and is now managed by the African Union. Its functional programmes have moved away from a service technology framework (e.g. Remote Sensing, Geodesy, Cartography etc.) to problem solving applications in natural resource and environmental management, so the RCMRD now provides services on a demand driven basis.

Other relevant regional organisations that involve remote sensing, but not as their key activity, are:

- Southern African Development Community (SADC) Regional Remote Sensing Unit (RRSU) in Gaborone, Botswana. This centre is more focused on meteorological aspects of food security and disaster management, but is also involved in strengthening national and regional capabilities in the area of Remote Sensing, Agrometeorology and GIS.
- AGRHYMET (Agrometeorology, HYdrology, Meteorology) Regional Center (ARC) in Niamey, Niger. This centre mainly uses remote sensing data and maps to address natural resource management and food security issues. The centre deals mainly with food security, water resource management, desertification control and climate change impacts.

These regional centres are potentially useful partners for this project and we will explore their operations and interest to cooperate in more detail as the project progresses.

Table 4 shows that the countries with specific remote sensing centres are:

- Ghana
- Zambia
- South Sudan
- Kenya

We believe that a remote sensing centre with a country will better enable that partner country to participate actively in the project.

2.5 Conflict:

The only country of those on the shortlist that has an active conflict is South Sudan. The principle of the original research carried out by TRL in Nigeria was to test this methodology in a conflict environment, and it is stated in our proposal that we intended to include this as a criteria, if possible. However, it seems that the current status of the conflict, as well as the very limited resources available to the government, would make it difficult to carry out ground truthing at the present time.

As a compromise, however, it may be possible to link up with the pilot study in Uganda, which borders with South Sudan. If an area in Uganda that was similar in climate, vegetation and geography to South Sudan could be selected, the satellite imagery could be procured and assessed by the team in Uganda, using the same process as for the ground truthed area in Uganda. It would be an opportunity for Uganda to take on the role of mentor and trainer to its neighbour, which would test the replicability of the system in the local environment.

2.6 Synergies with AFCAP Asset Management project:

There are a number of synergies that have been identified with the AFCAP Asset Management project. If our choices of partner country are accepted, it is likely that we will overlap in both Uganda and Zambia.

The Asset Management project has the mandate to assess condition of low volume roads in both countries. They intend to use windshield visual surveys in association with roughness surveys using mobile phone accelerometers. This is in line with the ground truthing requirements for satellite ground truthing and there are likely to be areas where overlap would be beneficial to both projects. For example if the condition assessment from the Asset Management project can be used as ground truthing for the satellites project, this would save resources. The potential issues with this would be:

- The categories of assessment are designed for different purposes. The Asset Management project intends to use a five-level system of Very Good / Good / Fair / Poor / Very Poor, whereas the satellites project was intending to use a three-level system of Good / Fair / Poor. The lower number of categories for the satellites project is due to the detail that is likely to be identified from the satellite images. We will however investigate how the two systems can be amalgamated or integrated. It may also be necessary to do both assessments in parallel to check the parameters set.
- The Asset Management project will be collecting condition data in more detail than is required for the satellites project. The principle of the ground truthing for the satellites project is that is serves as a baseline check for the satellite image assessment, and only needs to be as detailed as the satellite assessment. So for example on paved roads it is unlikely to be necessary to collect detailed information on cracking, as this will not be visible from the satellite images. When carrying out the ground truthing, faults like cracking will be considered as one of the contributing factors towards an overall good/fair/poor rating.
- Our aim on the satellites project is to use as few resources as possible for the ground truthing, in order to make the methodology as sustainable as possible. It is our understanding that the Asset Management project will be carrying out much more detailed condition assessments.

At present the Asset Management project has not selected the specific areas it intends to monitor, but we will liaise with them with the intention of finding an area that is appropriate for both projects. Our methodology will take the issues above into account and will provide a basis for carrying out ground truthing in the selected countries. Wherever possible the most effective use of resources will be employed.

2.7 Synergies with AFCAP Climate Resilience project:

There are also a number of synergies that have been identified with the AFCAP Climate Resilience project. If our choices of partner country are accepted it is likely that we would overlap in Ghana.

The potential synergies could include:

- Using satellite imagery to identify changes in the nature and extent of extreme weather events.
- Using archive satellite imagery to identify changes in how roads and structures are coping with climate change.

– Using satellites to measure catchment areas and identify potential areas at risk from climate change.

– Using satellite imagery to provide any other useful information to the climate change project

We will continue to liaise with the Climate Resilience project to refine the synergies that can be benefited from within these two projects.

3 Conclusions

Having assessed all the member AFCAP countries for suitability as partner countries for this research, the following conclusions can be made. Table 5 shows a summary of the findings. All countries were interested in participating in this regional project, but following the steering committee meeting seven countries were prioritised. Those that were not prioritised initially have been greyed out.

Table 5: Summary of partner country categories

	Interested to participate? Y=Yes N=No	Remote sensing centre G = Govt. P=Private N=None	Funding/ resources avail. Y=Yes M=Maybe N=No ?=No info.	Estimated Uptake Potential H=High M=Medium L=Low	Location in Africa S, W, E	Geography M=Mountainous R=Rolling F=Flat	Climate T=Tropical S=Semi-trop A=Arid	Vegetation D=Dense M=Medium L=Low	Active Conflict area	Overlap with Asset Mgmt. Proj.	Overlap with Climate Proj.
DRC	N	N	?	M/L	S	F/R	T	D	Y		
Ethiopia	N	N	?	M/L	E	F/R/M	S/A	M/L			Y
Ghana	Y	P	?	H	W	F	T	D			Y
Kenya	Y	G	?	M/H	E	F/R/M	T/S/A	M/L			
Malawi	Y	N	?	M	S	F/R	S	M/L			
Mozambique	N	G	?	M/H	S	F/R	S	M			Y
Sierra Leone	N	N	?	M/L	W	F/R	T	D		Y	
South Sudan	Y	G	N	L	E	F/R	T/S	M	Y		
Tanzania	Y	N	?	M	E	F/R/M	T/S	M			
Uganda	Y	P	Y	H	E	F/R/M	T/S	M		Y	
Zambia	Y	G	M	H	S	F/R	S	M/L		Y	

From the research above we can conclude a number of factors in selecting appropriate countries to partner this project:

- Regionally the potential partner countries were divided into three regions, West, East and Southern. The ToR suggests one country from the West and three from the East/Southern regions. This broad classification was found to be appropriate and would allow the other criteria to be fulfilled.
- In terms of vegetation it would be appropriate to select one arid area, two savanna areas and one tropical area.
- Climate is closely linked to vegetation. Due to the high variation in climate across some countries a generic selection cannot be made in terms of selecting tropical and sub-tropical countries.
- Seasons are important to consider, as the weather will determine when clear satellite images can be achieved. Imagery from the dry season is more likely to be appropriate for mapping and condition assessment.
- Geography is a factor that should be considered, although it was found that mountainous areas tend to have a lack of population and hence roads. Flat and rolling areas will be more appropriate for selection.

- This technology has been proven to have potential for use in conflict affected areas. It may not be possible to carry out a standard ground truthing in South Sudan (the only interested country with an active conflict), but it could be possible to use neighbouring countries as proxy partners.
- There are a number of potential synergies with other AFCAP regional projects, such as the Asset Management project and the Climate Resilience project. These synergies should be explored in more detail, in association with the other projects, and exploited where possible.

It should also be noted that we have assumed the appropriate satellite imagery will be available at reliable levels throughout all of the AFCAP countries, both the lower resolution and the higher resolution. The main factors in acquiring recent imagery will be climatological, which determines when the image can be taken and how clear it is.

4 Recommendations

From the assessment above, it is recommended that the following countries are included as partner countries in the Satellites project:

- **Ghana:**

  Ghana and Sierra Leone are the only tropical countries with highly vegetated areas and high rainfall, and are similar geographically. They also satisfy the requirement to include a country from West Africa. Ghana overlaps with the AFCAP Climate Resilience project and Sierra Leone overlaps with the Asset Management project. It is understood that there is an independent remote sensing centre in Ghana at the University of Ghana.

  In terms of vegetation, climate and geography the two countries are similar, and either would make a good partner. However, as there are already two countries that overlap with the Asset Management project, it would be preferable to include one that overlaps with the Climate Resilience project, i.e. Ghana. Ghana also has an independent remote sensing centre in country, which could be an important asset in undertaking this project. We therefore recommend Ghana as a partner from West Africa in this project.

- **Uganda:**

  Uganda has a moderately vegetated savanna type landscape that is typical of many AFCAP countries. It has a typical tropical/sub-tropical climate and there is an independent remote sensing centre at Makerere University. Uganda is also an AFCAP Asset Management project partner, so some synergies will be expected here.

  The other candidate for the moderately vegetated category is South Sudan, which also registered interest. However, from initial feedback it seems that their ability to commit resources in terms of staff and funding, are limited. It is also very doubtful whether the ongoing conflict will allow sufficient access to carry out ground truthing. However, during further communications we will explore the possibility of South Sudan linking with Uganda to provide some experience of road assessment by satellite.

- **Zambia:**
  Zambia has a lightly vegetated savanna type landscape, which again is found in many AFCAP countries. It has a typical sub-tropical climate and a remote sensing centre that is part of government. Although Zambia is interested, commitment of resources is not clear for the present year. In this respect Zambia is a good candidate, but we will explore the resourcing issue in future communications.

  Malawi was also a potential candidate for this role of a lightly vegetated savanna landscape, as it is very similar to Zambia, its neighbour. With the current information Zambia is a better potential partner as it has a remote sensing centre, it overlaps with the AFCAP Asset Management project and there has been some previous project experience of network assessment by remote sensing.

When communications with the countries commence we propose to explore the possibility of involving Malawi in this role either as a joint partner with Zambia, or in place of Zambia, depending on their ability to commit resources.

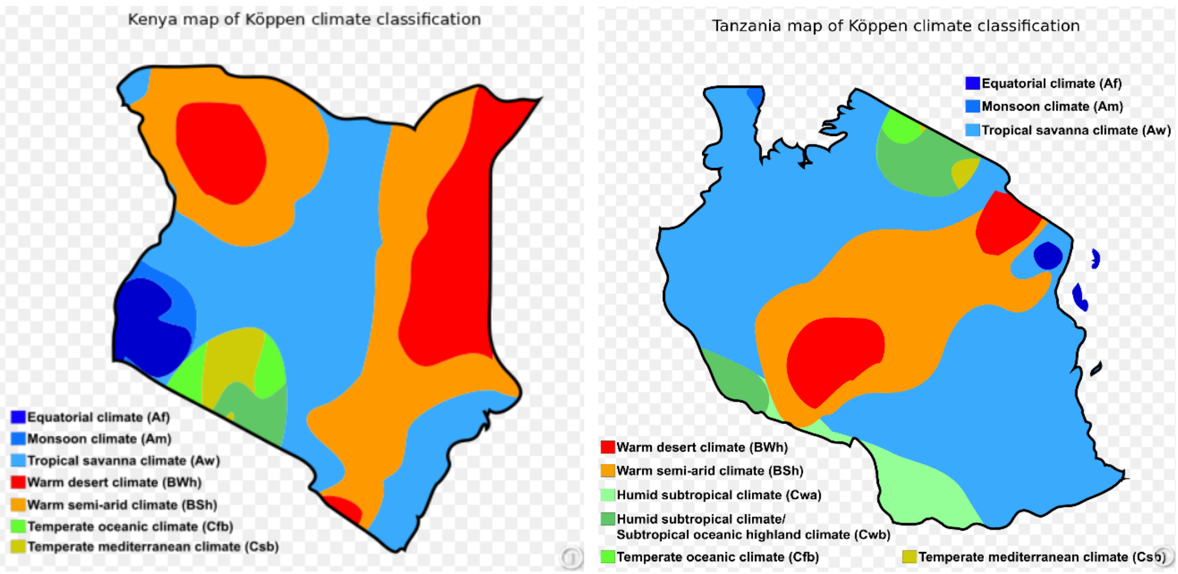
- **Kenya:**
  Kenya is the only country with an arid landscape and very little vegetation, in the north of the country. The climate here differs greatly from the rest of the country with much lower rainfall. Kenya has not indicated if resources are available, but previous research with AFCAP suggests that they may be. This will be explored in more detail during future communications.

  The choice for this category fell between Kenya and Tanzania. Both countries have shown interest, but we have not yet received any details on the capacity of either to take part, which could be a significant factor in deciding which should be the partner country. We have provisionally selected Kenya, based on the information provided below.

  Kenya was also selected because it has a remote sensing centre that is a department of government, whereas we could not find any evidence of a remote sensing centre in Tanzania, although both countries do come under the RCMRD. In addition the reginal headquarters of RCMRD are in Nairobi, and we hope that this organisation will play a key role in the project. So from this perspective Kenya also has an advantage.

  In terms of climate Kenya and Tanzania are similar, as can be seen in Figure 3. As Kenya is on the equator, it does have more desert and semi-arid type climate. The climate in these countries is also affected by altitude, which is apparent in the highland areas where the two countries share a border.

Figure 3: Koppen climate map of Kenya and Tanzania

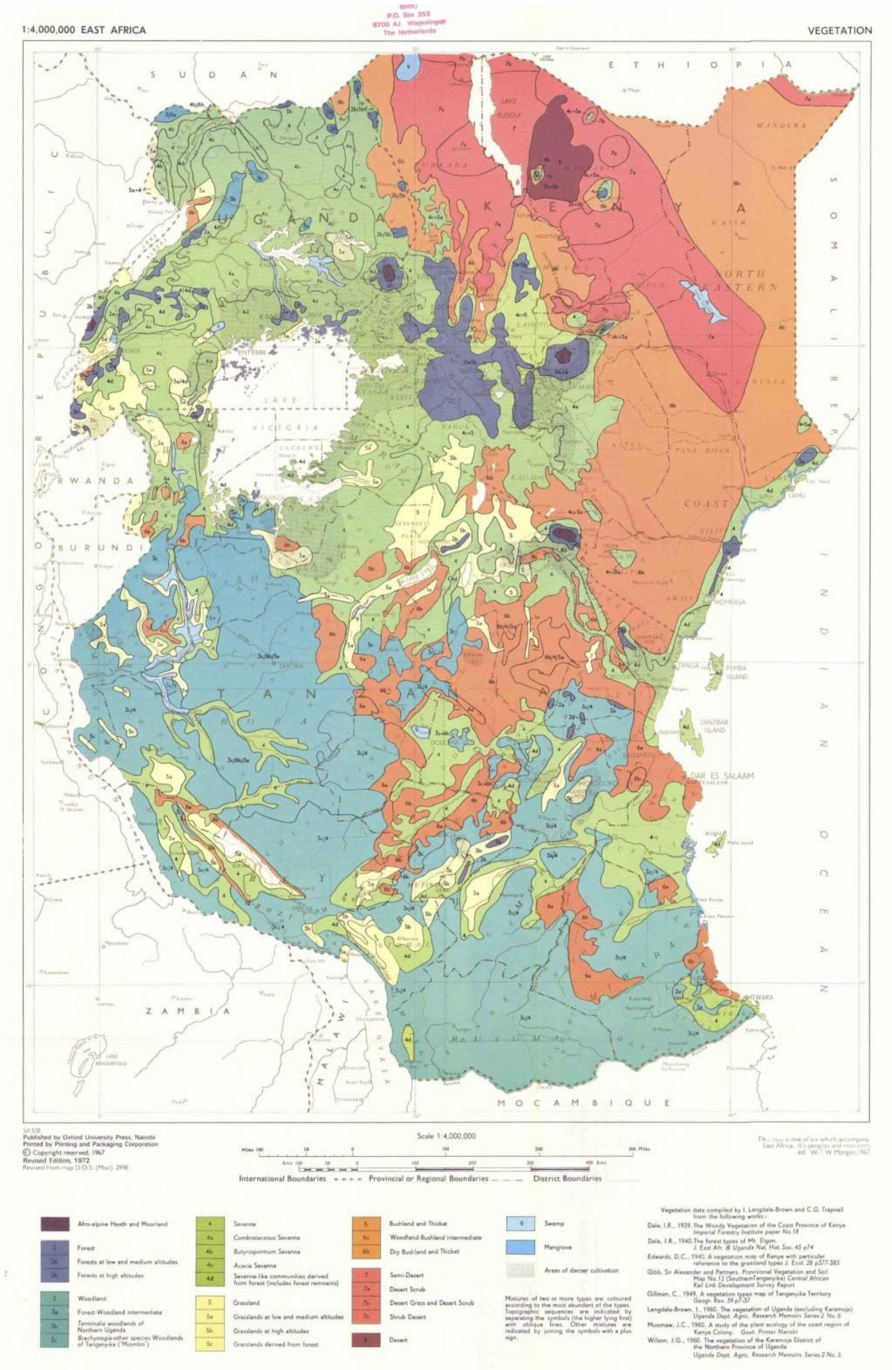


Source: Wikipedia

The wet seasons for Kenya and Tanzania are both similar and are both appropriate for the planned research, with the dry seasons falling within the main ground truthing period. However, more important than the climate are the vegetation conditions in each country.

Kenya has been provisionally selected over Tanzania primarily because it has arid, semi-desert, areas. This can be seen in Figure 4, which shows the type of vegetation across East Africa, with the red areas in the north of Kenya representing desert and semi-desert. Initial reviews of available mapping on the internet show that there are areas with roads that could be used for mapping and road condition research.

Figure 4: East Africa Vegetation



Source: Oxford University press, Nairobi

The topography of both countries is similar. In both the mountainous areas tend to be national parks with low populations and road densities, so would not be suitable for study. It is therefore expected that a flat or rolling landscape will be selected.

Also the Kenya research department, who it is assumed would be our main point of contact, is larger and more established than that of Tanzania. On this basis it is assumed they would be more able to cope with a project at short notice, although this will be verified in future correspondence with both countries.

As neither country provided feedback at the steering committee, the final decision will be made following communications with Kenya to confirm their ability to commit resources to the project.

When we have agreement in principle to the recommended partner countries we will communicate with the relevant organisation within each country, in association with the PMU, to confirm our recommendations. By the end of the desk study we expect to have a confirmed list of partner countries and to have established resources to be provided and a programme of implementation.