



AfCAP
Africa Community Access Partnership



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

Tanzania report



Robin Workman

TRL Ltd.

*AFCAP Project Reference
Number. GEN2070A*

30th April 2018

TRL THE FUTURE
OF TRANSPORT

AIRBUS DEFENCE AND SPACE

The views in this document are those of the authors and they do not necessarily reflect the views of the Research for Community Access Partnership (ReCAP) or Cardno Emerging Markets (UK) Ltd for whom the document was prepared

Cover Photo: TRL Ltd / Airbus defence and space

<i>Quality assurance and review table</i>			
Version	Author(s)	Reviewer(s)	Date
1	Robin Workman	Will Throssel- (internal TR)	27/04/2018
		Nkululeko Leta Les Sampson,	7/5/2018

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



AfCAP Database Details: The use of appropriate high-tech solutions for road network and condition analysis, with a focus on satellite imagery			
Reference No:	GEN2070A	Location	Ghana, Kenya, Uganda, Zambia, Tanzania
Source of Proposal	TRL	Procurement Method	Comp. Tender
Theme	Regional	Sub-Theme	High-tech solutions
Lead Implementation Organisation	TRL Ltd	Partner Organisation	Airbus DS
Total Approved Budget	£380,000	Total Used Budget	
Start Date	25/04/2016	End Date	31/05/2018
Report Due Date	30/04/2018	Date Received	27/04/2018

Key words

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

AFRICA COMMUNITY ACCESS PARTNERSHIP (AfCAP)

Safe and sustainable transport for rural communities

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

See www.research4cap.org

Acknowledgements

Airbus DS

Acronyms, Units and Currencies

AfCAP	African Community Access Partnership
AoI	Area of Interest
ARMP	Annual Road Maintenance Plan
DEM	Digital Elevation Model
DFID	Department for International Development
DMI	Distance Measuring Instrument
DROMAS 2	District Road Management System 2
FTL	Frontier Technology Livestreaming
GIS	Geographical Information System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HD	High Definition
IRI	International Roughness Index
LGA	Local Government Authority
OSM	Open Street Map
PO-RALG	President's Office – Regional Administration and Local Government
QGIS	Quantum Geographic Information System
RAMS	Road Asset Management System
RCMRD	Regional Centre for Mapping of Resources for Development
ReCAP	Research for Community Access Programme
RFB	Roads Fund Board
SDI	Surface Distress Index
TARURA	Tanzania Rural and Urban Roads Agency
UAV	Unmanned Aerial Vehicle
UK	United Kingdom
VHR	Very High Resolution

Contents

Key words	4
Acknowledgements	6
Acronyms, Units and Currencies	6
Executive Summary	8
1. Introduction	8
2 Background	8
2.1.1 <i>Requirements of the RFB</i>	9
2.1.2 <i>Use with a RAMS database</i>	9
3 Tanzania status	9
4 Tanzania research	10
4.1 High-tech solutions	10
4.1.1 <i>Range of options</i>	10
4.1.2 <i>Complementarity of options</i>	19
4.2 Satellite imagery condition assessment methodology	19
4.2.1 <i>Purpose</i>	20
4.2.2 <i>Appropriateness of the methodology</i>	20
4.2.3 <i>Integrating with existing systems</i>	21
4.2.4 <i>Use with DROMAS 2</i>	21
4.2.5 <i>Satellite imagery acquisition</i>	22
4.2.6 <i>Local remote sensing partner</i>	24
4.2.7 <i>Ground truthing</i>	24
4.2.8 <i>Correlation of results to ground truthing</i>	25
4.2.9 <i>Training</i>	26
4.2.10 <i>Development of assessment guidelines</i>	26
4.2.11 <i>Condition assessment</i>	27
4.2.12 <i>Providing relevant outputs</i>	27
5 Conclusions	27
6 Recommendations	31
Annex 1: Distance measurement exercise	34
Annex 2: Training feedback	36
Annex 3: Ground Truthing exercise	39
Annex 4: Calibration Guide for Tanzania	42
Annex 5: Condition Assessment exercise	56
Annex 6: Training Assessment Report	57
Annex 7: Minutes of Final Presentation	64

Executive Summary

This report assesses the suitability of some technologies used in the high-tech solutions project to the road network in Tanzania. An extension was granted to test the methodology in an appropriate environment and in a roll-out scenario for a specific situation, as defined by the Roads Fund Board (RFB). A guideline has been completed and is available on the ReCAP website, which outlines potential high-tech solutions, and gives specific guidance on the inventory and condition assessment methodology from satellite imagery and the situations in which it should and should not be used. Guidance is also provided on how different technologies can work together.

The satellite imagery has been procured, the ground truthing was completed using existing data and videos for the two sites and the training was undertaken from 9 to 13 April 2018, in Dar es Salaam. The RFB invited the participants to the training and it was held at Ardhi University. This report assesses the relevance of the methodology to Tanzania and is based on the results of the training, training exercises, feedback from workshops held at the training and formal course feedback.

1. Introduction

This report is designed to assess the suitability of the methodology from the GEN2070A High-tech solutions project to the local conditions in Tanzania, with respect to rolling out the methodology on a wider scale. Specifically, the Roads Fund Board (RFB) would like to see the capability to:

- Check road lengths
- Determine road condition
- Learn how it can interact with the existing Road Asset Management System (RAMS) called District Road Management System version 2 DROMAS 2, which is in place for all rural roads in Tanzania.

The project was granted an extension to specifically test the satellite condition assessment methodology.

Research has been carried out in four countries previously to test high-tech solutions and condition assessment from satellite imagery, and the project has produced a guideline on the use of high tech solutions for road network and condition analysis in Africa. This guideline includes a detailed methodology on how to use satellite imagery to assess the condition of rural roads, paved and unpaved, and in which situations it would and would not be appropriate. These guidelines will be drawn upon to assess the suitability of the methodology for the current situation in Tanzania.

Tanzania is at present in the process of re-assessing its rural road network and is interested in a system that can rapidly assess the network, check the accuracy of data already collected and fill any gaps that may exist.

2 Background

The project has completed its original mandate, to identify high tech solutions for increasing knowledge of rural road networks and to develop a methodology for road condition assessment using satellite imagery. Research was carried out in Ghana, Kenya, Uganda and Zambia in 2016/17, and a guideline has been produced which sets out the applications and methodology for using such technologies.

The original research trials were to test the satellite condition assessment system in different environments and conditions and to determine how sustainable and appropriate it is in terms of

providing the information that is required by each country. Results were encouraging and can be seen in the trials reports for the GEN2070A project, which are available on the ReCAP website.

The logical next step is to test the methodology by rolling it out to assess a larger area of road network. An opportunity arose in Tanzania to test the methodology and to assess how the satellite condition assessment system works with a Road Asset Management System (RAMS), as well as determining whether the system provides the information that is specifically useful to the Roads Fund Board (RFB) in Tanzania. An extension of the project was therefore granted and the Tanzania trials are under way.

2.1.1 Requirements of the RFB

At present the RFB requires more, and better quality, information on the Local Government Authority (LGA) network in order to equitably prioritise the funding of urban, district and feeder roads. A formula is used to allocate funds, based on the outputs from DROMAS 2. The RFB believe that there is a need to check all aspects of the road network for completeness and accuracy, but more specifically the length of roads, their status and their condition should take priority. With this in mind the RFB intends to launch a tender for a comprehensive inventory and condition survey for all rural roads, which will include a re-classification exercise for all roads in the country. There is potential for the high tech solution options to contribute towards that goal.

2.1.2 Use with a RAMS database

The DROMAS 2 database has been established to assist The Tanzania Rural Roads Agency (TARURA) in Tanzania to manage their rural road network, and is in the process of being populated. The database includes road network and mapping features, as well as providing information for the Annual Road Maintenance Plan (ARMP) and contract management tools.

Road condition is collected visually as a general condition, but specifically the International Roughness Index (IRI) and Surface Distress Index (SDI) are also collected, along with a speed rating and traffic information. DROMAS 2 is an on-line facility, which works with other applications such as QGIS (a freely available GIS program that is also used by the satellite condition assessment system), Google Maps and SW-Maps. DROMAS 2 is still in the process of being developed, and faces some challenges ahead in terms of collecting the full inventory for roads and presenting it in an appropriate format for the RFB.

3 Tanzania status

At present in April 2018 the status of rural road network knowledge in Tanzania can be summarised as:

- Surveys for road inventory have now been carried out for the whole country and there is a reasonably complete database for rural roads. These surveys have established the road network length, which is now estimated at 122,000 km for all rural roads, classified and non-classified. The previous length was approximately 109,000 km.
- There is no independent way to verify the accuracy of the network figures as they are carried out by district staff, using local resources without direct supervision from the centre.
- There are issues with uploading the data to DROMAS 2. This is often due to a problem with the internet, but can also be technical issues where the database is housed. District staff in particular can encounter problems in uploading data.
- There is some cleaning of the DROMAS 2 database to be carried out. A check of the existing mapping shows that some roads are not fully connected, some are duplicated and can have different road numbers for the same road, and some appear to be missing. This is most likely

to be as a result of data entry issues, which can be resolved by double checking the raw data. Where there are data collection or data recording issues it will be necessary to re-survey the affected roads.

- Road condition data is less complete. An initial interrogation of DROMAS 2 shows that less than half of the districts in Tanzania have entered road condition data. For some this is a database internet connection issue, but some are also yet to complete condition surveys.
- TARURA have recently revised the road condition levels of assessment from three, to four, as shown in Table 1. Apparently the ‘Poor’ category has been split into two categories, ‘Poor’ and ‘Bad’. Most of the data entered into the previous system has been based on the three levels, so new surveys will be necessary to determine the split between ‘Poor’ and ‘Bad’. It is unlikely that the previous survey notes contain enough information to be able to split the information in the previous ‘Poor’ category and divide it into the current ‘Poor’ and ‘Bad’.

Table 1: TARURA road condition levels

	Condition Levels			
Previous	Good	Fair	Poor	
Current	Good	Fair	Poor	Bad

4 Tanzania research

This chapter summarises the technical status and progress of the research in Tanzania.

4.1 High-tech solutions

Although there were limited practical trials of high-tech solutions in the ReCAP high tech solutions project, some technologies have been used to contribute towards the ground truthing of satellite imagery assessment. The following technologies were demonstrated in Tanzania and used during the training. This is a very rapidly changing field, so the solutions assessed below can be subject to change and development within a short time of this report.

4.1.1 Range of options

The range of options initially identified are shown in the ‘Guideline on the use of high tech solutions for road network inventory and condition analysis in Africa’, which is available on the ReCAP website: <http://www.research4cap.org/SitePages/Regional%20Projects.aspx>

The main technologies that have been used to assist in the ground truthing for satellite road condition assessment are:

- **DashCams:** These were used to provide a visual record of the roads so that the data collected could be checked and a technical audit could be undertaken. They were used as the primary source of ground truth condition in Tanzania, because the satellite imagery was taken at the end of the dry season and a record of the road condition at that time was essential for accurate ground truthing. The High Definition (HD) videos take good quality video images from within the vehicle, so they are protected from dust, rain and other potentially harmful influences. They also record audio, so the surveyor can make oral records of the road condition; this audio is embedded within the video and therefore is automatically geo-referenced. The HD videos are GPS enabled so that the video can be located in GIS software, and the road track can be extracted from the movie file and downloaded. The video also records speed, average speed and direction. In addition the X, Y

and Z movement of the equipment is recorded and displayed on a graph in the video software (Figure 1), which has the potential to be linked to road roughness. These DashCams were found to be very useful and there would be scope to develop a low-cost product specifically for this use.



Figure 1: Accelerometer readings from DashCam

It was noticed that the distance measured by the GPS in the DashCam can vary slightly. Upon further investigation it was found that when the recording is turned on too early whilst the vehicle is stationary the GPS experiences creep as the satellite connections change. This is demonstrated in Figure 2, which shows the start of the GPS track as a red line when the vehicle was stationary for approximately two minutes. The result is that the camera should only be turned on when the vehicle is ready to move, and not before, and should be stopped immediately as the vehicle comes to halt.

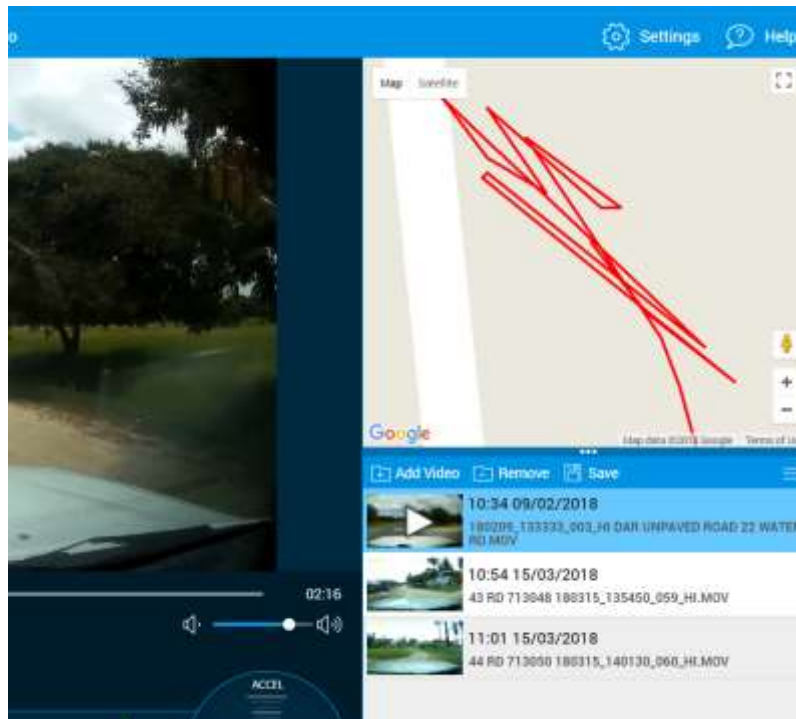


Figure 2: GPS creep

- Smartphone apps: A number of different Smartphone apps were trialed. All are available free from the internet and do not require internet connection, which can be a limitation in the remoter rural areas.
 - The RoadLab app to measure International Roughness Index (IRI) was used to provide an approximation of road roughness. The results from the RoadLab app are more appropriate for paved roads and good condition unpaved roads, because accuracy declines significantly on fair and poor condition unpaved roads. As a low cost solution this is only appropriate within defined conditions. The appropriateness of this app has been covered in detail in previous reports, which are available on the ReCAP website.
 - An app called ‘GPS odometer’ was used to record road length. This does not require connection to internet or data, so was effective in rural areas, so long as satellites were readily contactable (some issues could arise in very hilly areas). This records the horizontal distance travelled, as well as the displacement between the start and end points (distance ‘as the crow flies’) and time. It also records the current or average speed travelled. The frequency of GPS signals received and the probable accuracy are also shown. The odometer can be set to record in miles or kilometres, Figure 3 shows the app logo and a sample of the app readout.

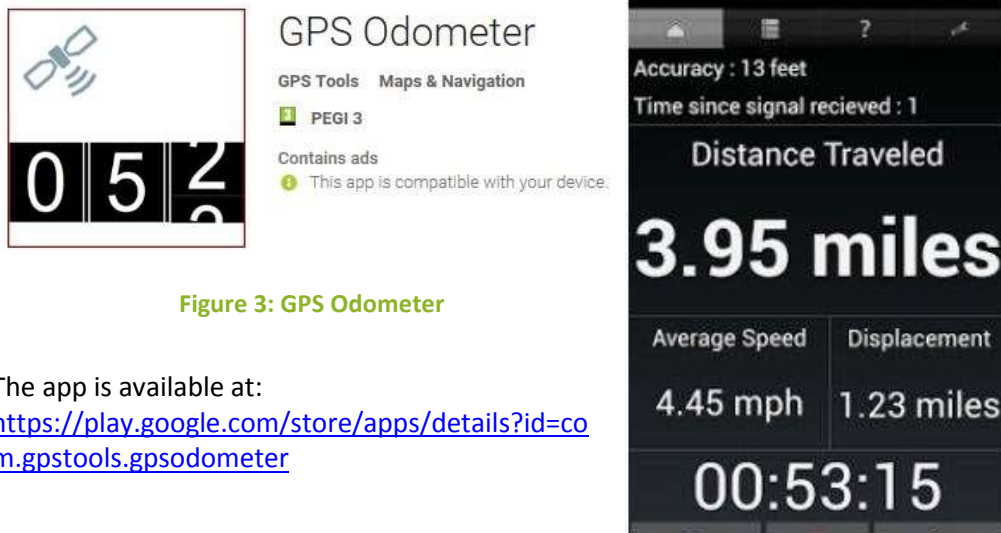


Figure 3: GPS Odometer

The app is available at:

<https://play.google.com/store/apps/details?id=com.gpstools.gpsodometer>

It is assumed that the GPS odometer will also suffer from ‘creep’, as noted in the DashCam review above. This cannot be demonstrated visually as there is no facility to download the GPS track from this app, but the exercise carried out during the training to gauge the accuracy of GPS distance measurement would seem to support this theory (Annex 1), where slightly different readings of distance were achieved for the same road. This can be confirmed by starting the GPS odometer and monitoring it’s readings when it is not in motion. Loss of satellite connectivity can also produce erroneous results, especially in hilly or mountainous areas.

- An app called ‘My GPS Coordinates, shown in Figure 4, was also used to determine geographical coordinates at a certain location. This app simply shows the coordinates of the smartphone in both Longitude/Latitude and UTM Easting/Northing and does not require an internet connection. The frequency of GPS signals received and the probable accuracy are also shown.

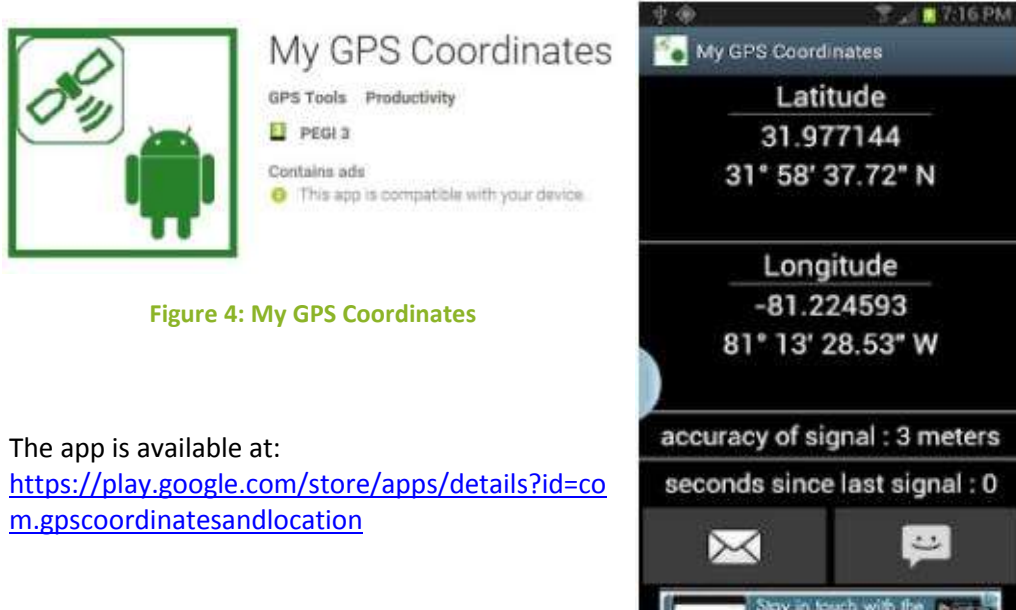


Figure 4: My GPS Coordinates

The app is available at:

<https://play.google.com/store/apps/details?id=com.gpscoordinatesandlocation>

- Mapping Apps such as Google, Bing, Here Maps and OpenStreetMap were also used; of which there are many available. Most allow the user to download maps in advance, which is useful in rural areas when internet connection may not be available.
- Terrain apps such as Terrain Navigator Pro were also used. These enable the user to use topographic maps and view mapping contours. The length of a road that takes into account the changes in gradient and altitude can be measured in this app, as opposed to just a horizontal distance. Again the maps can be downloaded for use without internet.
- Accelerometers: Some accelerometer readings have been taken using off-the-shelf accelerometers, alongside other measures of roughness. The accelerometers essentially measure movement in the X, Y and Z directions. These results have not yet been analysed.

A number of other technologies are already established, or are being researched and developed by other organisations. The main research that is relevant to Tanzania is the use of Unmanned Aerial Vehicles (UAVs), in particular the Frontier Technology Livestreaming (FTL) project in Zanzibar. The use of UAVs has been covered in previous reports, and the project team are maintaining liaison with DFID in Dar es Salaam in order to track progress of the FTL project and see if it has implications on the satellites methodology. The results of this project will be Open Source and are expected to be published, along with the algorithms used, towards the end of 2018.

The World Bank has also provided UAV imagery for the area of Dar es Salaam that overlaps the satellite imagery, so that synergies can be explored. This imagery was collected during the training in April 2018 and a comparison of the imageries is shown below. These high-tech solutions and their potential application in Tanzania were discussed at the training, as noted in Annex 2. In all of the following images the drone image is shown on the left, and the satellite image is shown on the right.

The imagery in Figure 5 is a typical semi-urban road in Dar es Salaam, which is in poor/bad condition. There is more definition in the drone image, for example the roofs are well defined and the areas of dark on the road in the satellite image, can be identified as piles of materials on the drone image.



Figure 5: Comparison on semi-urban roads

Figure 6 shows a road in a more rural area. Because of the processing of the image, and the lower zoom, the details of the road surface are as clear, if not clearer, in the satellite image on the right. This demonstrates how the processing affects the clarity of the image. It is important to have the imagery processed to suit the purpose at hand. As the drone imagery is intended for monitoring the Bus Rapid Transport (BRT) roads in Dar es Salaam, it is assumed that it has been processed for an asphalt surface, whereas the satellite imagery has been processed specifically for use with rural unpaved roads.



Figure 6: Rural road comparison

Figure 7 again shows a rural area, where the unpaved road appears as too light to be able to see details of the surface of the road. There are of course tools available in QGIS to adjust the brightness, contrast, etc. of the imagery, but the original processing (in the case of the satellite imagery the pansharpener process) is also important.



Figure 7: Comparison on brightness on rural roads

The processed drone imagery of paved roads does appear to be clearer, as opposed to the satellite imagery on paved roads. The pictures in Figure 8 show that more detail can be gained for the paved road.



Figure 8: Paved road comparison

Figure 9 shows a mainly rural road. There are clearly some defects on the road surface, which are visible on both images. As the drone image is lighter, it is arguably harder to define the defects in a manual assessment. It will be interesting to see how the project in Zanzibar manages to distinguish road surface defects using machine learning and whether that has potential for automated condition assessment. Also the drone imagery may have variable lighting as the drones fly below the clouds and the images could therefore have different brightnesses. As the drone imagery is essentially a mosaic of different images, this could make it difficult to assess the varying imagery consistently.



Figure 9: Unpaved road surface defects

Figure 10 shows the same road, but zoomed in so that the defects are more visible on the drone imagery. At the same zoom, the defects on the satellite image appear to be less clear and have become pixelated. The width of the road and the edges are also clearer in the drone image, but can still be distinguished on the satellite image.



Figure 10: Close-up of unpaved road defects

The difference in processing can clearly be seen in the images in Figure 11. Particular features that vary between the images are the lines on the football field and the definition of the road edges and footpaths. Given that the images were acquired within a few days of each other, this is quite a striking difference.



Figure 11: Processing differences between drone and satellite imagery

A similar effect can be seen in the images in Figure 12 where at this scale, 1:450, there appears to be little difference in the clarity of imagery. However, when the image is zoomed in the drone image will retain more and clearer detail.



Figure 12: Differences in processing for unpaved roads

Figure 13 shows a paved main road, which is the focus of the drone imagery project in Zanzibar. The drone image shows the road surface and road lining more clearly. Features such as side drains and road signs are also clearly visible.



Figure 13: Main paved road comparison

When the image is zoomed in, as per Figure 14 the drone imagery stays clear and the satellite image distorts to the extent that features become pixelated and difficult to define. It would be difficult to identify defects with the naked eye from the satellite images at this zoom.



Figure 14: Main paved road, close-up

One of the main challenges of satellite imagery is to identify drainage features and other inventory. Figure 15 shows that the culvert headwalls and sidewalls are clearly visible on the drone image, but are indistinct and could easily be missed on the satellite image.



Figure 15: Identifying drainage structures

Likewise, the images in Figure 16 clearly show an overhead traffic light in the drone image, but this is not an obvious inventory item from the satellite image on the right. The scale of this image is approximately 1:100.



Figure 16: Identifying other road inventory features

In summary, the higher resolution of the drone imagery at 7 cm provides more detail and clarity than the satellite imagery at 30 cm resolution. However, the drone imagery needs to be appropriately processed to maximise its use and there may be some issues with varying brightness of the images. In some cases the satellite imagery is comparable to the drone imagery, but this is probably because it was initially processed with the assessment of unpaved roads in mind.

Inventory items, such as road furniture, road lining and culvert headwalls are more clearly visible on the drone imagery. The drone imagery is the result of more than one image merged together, which is the result of at least two passes along the road with the drone. This has resulted in some vehicles appearing as shadows on the imagery, although this is unlikely to be a problem for rural roads due to the low volumes of traffic. Costs to provide drone imagery are not yet accessible as the projects are still ongoing, but financial data should be available within six months.

4.1.2 Complementarity of options

The status of existing technologies and how they can be complementary to each other is shown in the 'Guideline on the use of high tech solutions for road network and condition analysis in Africa', available on the ReCAP website. Due to the rapid advancement of many technologies this table should remain flexible, and subject to adjustment as new technologies are developed, and as new uses are found for old technologies.

4.2 Satellite imagery condition assessment methodology

The methodology developed to assess road condition from satellite imagery formed the main part of the practical trials undertaken by the main ReCAP project. That methodology will now be applied to Tanzania in a roll-out scenario. It will be necessary to adjust the methodology to the local situation to ensure that the outputs are appropriate and useful.

4.2.1 Purpose

The purpose of this Tanzania extension is to test the methodology in a roll-out situation, to see if it meets the requirements for Tanzania in terms of the level of detail it provides, the accuracy with which it is undertaken and the information it provides for prioritisation and planning of maintenance, specifically through the DROMAS 2 database. So the accuracy of the system was not tested again, as it was with the previous four countries, but the issue was assessed throughout the training to gauge the main purpose and how the methodology could work with DROMAS 2 and the RFB maintenance planning mechanisms.

The Researcher made an initial visit to Tanzania in September 2017 to introduce the project to RFB and other stakeholders and explain the inputs and resources required from the local counterparts. This included agreeing the geographic areas to be researched and informing the stakeholders of the requirements to be provided by the counterparts, which included carrying out ground truthing and providing the necessary facilities for the training course. RFB agreed and decided that Tanroads would be the most appropriate agency to carry out road condition surveys. They also agreed to use Ardhi University facilities in Dar es Salaam for the training. RFB agreed to take the lead in arranging the event.

4.2.2 Appropriateness of the methodology

As determined from previous research under this project and mentioned in the High-tech Solutions Guideline, the methodology has been shown to be most beneficial where there is a lack of information on rural roads, where there are inaccessible or difficult to access areas and where a large spatial area needs to be assessed in a short time. The user needs to be fully satisfied that the system will provide the outputs that they require with adequate detail and quality, for a cost that is affordable and within the time it is required. They also need to check that they have the capacity to use the system.

Tanzania has already been identified as a potential area for use of the technology, and its effectiveness is judged on the following factors:

- Cost: Whether this is a cost effective solution or not.
- Detail: Whether the system satisfies the requirements of the local roads organisation in terms of the level of detail gained for road inventory and condition.
- Acquisition of imagery: Whether the weather will be suitable for image acquisition at particular times of the year.
- Resolution: The resolution of the imagery is important to consider as there can be a trade-off between different aspects of resolution. Spatial resolutions are consistently improving with improved technology, so the technical feasibility of the system should continue to improve. The Dar es Salaam and Kilosa imageries are different resolutions and from different suppliers; with the spatial resolution for Dar es Salaam being higher and therefore providing a more detailed image. Cost also has to be considered, as higher resolutions are invariably more expensive.
- Accuracy: The level of accuracy that can be achieved should also be considered. Tanzania has recently moved from a three-level to a four-level assessment system on rural roads, and therefore an accuracy (agreement between ground truthing and satellite assessment) of between 65% and 80% should be possible, based on the previous research.
- Time: Satellite assessment is a rapid way of gaining a large amount of information and large areas can be assessed rapidly if enough staff are trained and assigned.
- Resources: Assess the resources necessary to carry out the assessments, which is an important consideration.

- Record: Decide whether a permanent record is required, or not. Satellites provide a clear, dated and georeferenced record of the road.
- Licencing: Check the licencing agreement to ensure that the use to which the imagery is to be put is not contrary to the agreement.

4.2.3 Integrating with existing systems

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

4.2.4 Use with DROMAS 2

An important aspect of the detailed methodology for road condition assessment from satellite imagery is the ability for it to link with a GIS based Road Asset Management System (RAMS) or database. As a standalone system using QGIS it is feasible, as proved during the research to date, but the utility and user friendliness could be greatly enhanced by linking with a GIS based RAMS. The Tanzania extension has tested the appropriateness of the system to provide information to the DROMAS 2 database and an assessment of the compatibility has been made.

An initial review of the DROMAS 2 database has confirmed that it collects the following network features:

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

A review of the entered network has uncovered some small errors in network information, for example:

- Some roads are shown as incomplete
- Some roads overlap, so sections have been entered twice as different road numbers
- Some roads appear to be missing

The rural network is showing in DROMAS 2 as being approximately 122,000 km, about 12,000 km more than the previous audit. However, with the errors noted above, this cannot be taken as a completely reliable figure. Also it is not clear whether the additional lengths of road are classified or unclassified.

Road lengths are determined by handheld GPS, which is subject to errors of satellite communication and inherent accuracy. The engineers managing DROMAS 2 recognise that this is essentially a horizontal measurement that does not take into account the vertical alignment of the road. In very hilly or mountainous areas the actual road length could vary. TARURA are proposing the use of Distance Measuring Instruments (DMI), but these need calibration and are susceptible to a number of variables that need to be closely managed, such as tyre size and pressure, vehicle maintenance, tyre slippage, driving style and driving line, etc. This would also necessitate the re-survey of the 122,000km network. The programmer has initiated a feature in DROMAS 2 that will convert the

existing road lengths into actual road lengths, taking into account changes in the vertical alignment, but this is not in operation yet. It is presumed that some sort of 3D mapping or orthorectified imagery may be necessary to achieve this.

The potential for use with DROMAS 2 is good. Both systems are based on QGIS and try to collect similar data.

4.2.5 Satellite imagery acquisition

Very High Resolution (VHR) Satellite imagery has been acquired for the two agreed Areas of Interest (Aoi):

- Dar es Salaam: approx. 100km² in northern Dar es Salaam, 0.3 m resolution from DigitalGlobe (Worldview).
- Kilosa: approx. 587 km² in the Kilosa/Kimamba area, 0.5 m resolution from Airbus DS (Pleiades).

The imagery areas were defined in consultation with RFB/TARURA and were acquired in November 2017 (Dar es Salaam) and December 2017 (Kilosa); the acquired Aols can be seen in Figure 17 and Figure 18, outlined in orange.

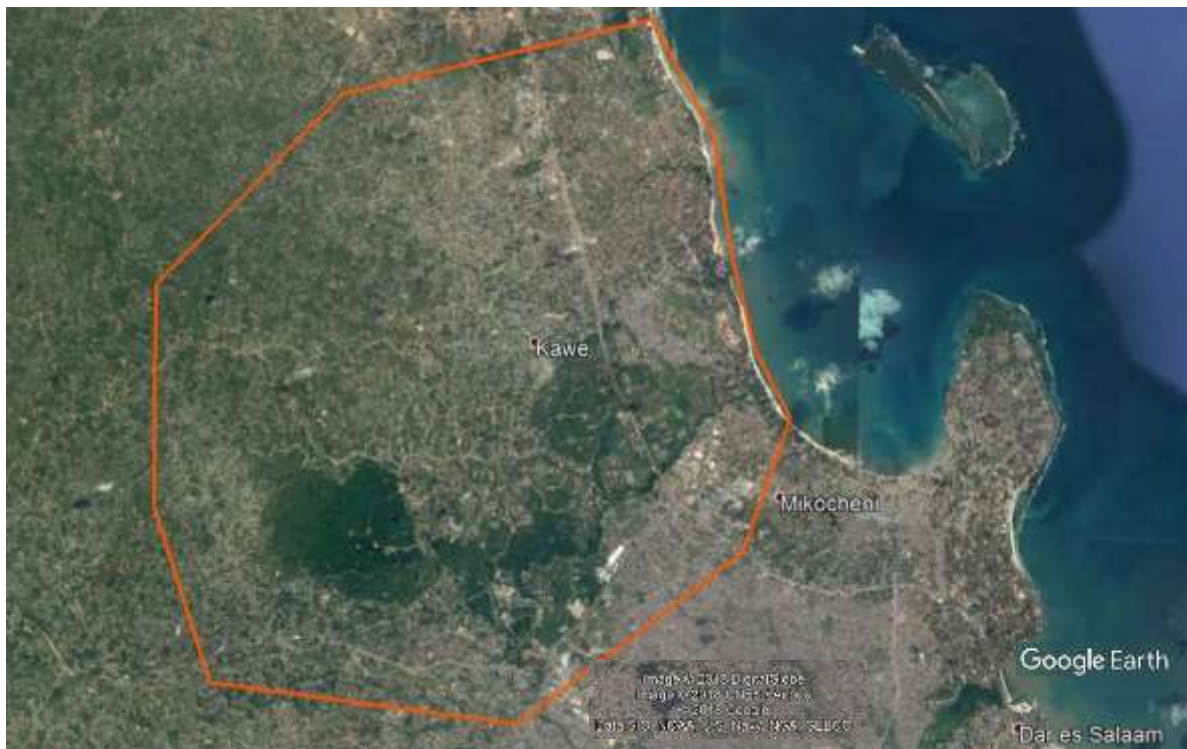


Figure 17: Dar es Salaam Aoi

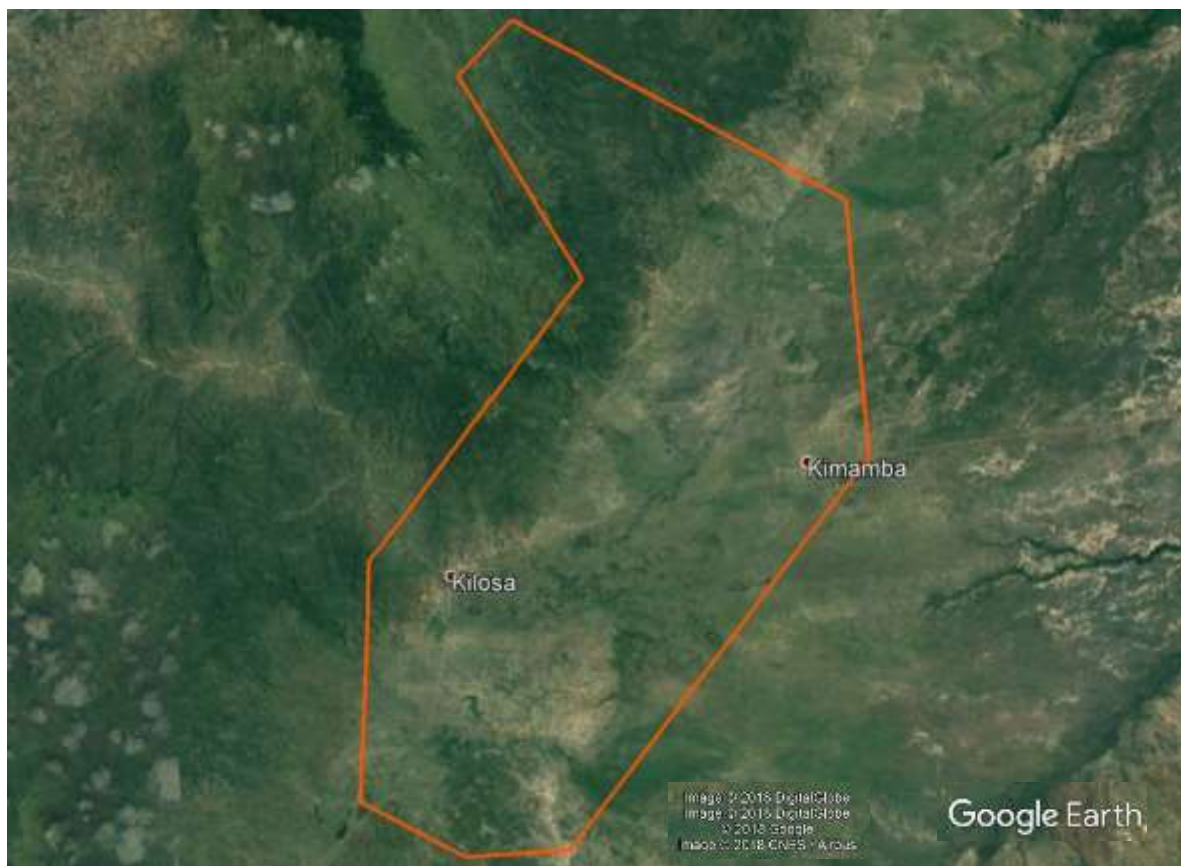


Figure 18: Kilosa Aol

There were some initial delays in ordering the imagery, as the Aols were only agreed at the initial visit of the Researcher in September 2017. It then took some time to sign the necessary licence agreements, which is a common issue with legal documents for satellite imagery. This meant that the onset of the wet season made image acquisition more difficult because a maximum of 10% cloud cover was specified. The imagery was acquired satisfactorily, but in Kilosa two sets of imagery had to be cut and aligned to provide the necessary level of quality across the whole area.

Some initial enquiries have been made with Airbus DS as to the possibility of acquiring VHR satellite imagery that only follows the road alignment, with a corridor of 1 km, which would dramatically reduce the cost of the imagery. At present the following restrictions apply to VHR imagery across all suppliers (<http://www.landinfo.com/satellite-imagery-pricing.html>):

- Archive imagery: Minimum width of acquisition of 0.5 km (2 km for some other suppliers)
- Tasked imagery: Minimum width of acquisition of 5.0 km (consistent across all suppliers)

Airbus have indicated that if a large acquisition was required, some negotiation on the minimum width and price could be possible. Recent indications are that it may be possible to reduce the width to 1 km and also negotiate on the price, if the order was for a network as large as the 120,000 km of rural roads in Tanzania.

It should be noted that with a minimum width of 5.0 km, all minor roads of less than 2.5 km should be included in the width acquired for the roads from which they originate. The number of such roads can be checked in DROMAS 2, but there could be significant savings there.

4.2.6 Local remote sensing partner

In each project partner country a local remote sensing partner has been found. These partners were included in the training and assessment as they can provide a long term, local partner to the local roads organisation and can provide the specialist knowledge in remote sensing that is lacking in most roads organisations. The principle is that they will be able to support the roads organisations until they have built their own capacity in remote sensing, image interpretation and GIS software. In Tanzania Ardhi University has been identified as an appropriate partner as they have a strong urban planning and geography department with good GIS knowledge and experience of working with the World Bank and other donors on image interpretation type projects.

4.2.7 Ground truthing

The satellite imagery was 'tasked' in September 2017; this means that the requests for acquisition were made at that time. The RFB requested Tanroads to carry out ground truthing for the defined areas, as shown in 3.2.4, as soon as the imagery was acquired, which was ultimately during November and December 2017. This task was to involve carrying out visual surveys on selected roads and using a Roughometer if possible, to be supplied by TARURA. Tanroads were visited on 27th October 2017 to explain the requirements of ground truthing and how to collect the information. A project video camera and smartphone holder were also provided for this purpose and provided instruction and practical demonstration of their use. This visit was in addition to the scheduled visits.

Unfortunately, due to work pressures Tanroads were unable to complete the ground truthing at this time. As it is important to record the road condition as close to the time of satellite acquisition as possible, so as a result a second visit to Tanzania was made in late January 2018 to make DashCam video recordings of the ground condition. These videos had the advantage of recording the condition at a time when the condition would be similar to the date the satellite imagery was acquired, and could therefore be used to assess the condition at a later date. Importantly, the road condition was captured at a time as close as possible to the satellite image acquisition.

Approximately 3 days were spent on capturing the ground truth videos in Kilosa and Dar es Salaam. The roads that were captured can be seen in Figure 19 and Figure 20. The Aol is shown in orange, with unpaved roads shown in blue and paved roads shown in red.



Figure 19: Kilosa roads



Figure 20: Dar es Salaam roads

In the latest visit to Tanzania in March 2018, meetings were held with TARURA and the Municipal Councils in Dar es Salaam, who are responsible for the roads in the Aoi shown in Figure 20. There was some existing condition information available for the Aoi shown, but it was in the previous format of 3 condition levels, not the new 4 level format recently adopted by TARURA/RFB. This condition information is useable as ground truthing information to some extent, but some differentiation or re-surveys are required for the 'Poor' condition roads, to separate them into 'Poor' and 'Bad'.

4.2.8 Correlation of results to ground truthing

The correlation of satellite manual assessments of road condition, as compared to the ground truthing baseline, is the principal method of assessing the accuracy of the satellite assessments. In this research the assessment of roads with fewer condition levels (Good, Fair and Poor) was so far found to be more accurate, approximately 80%, than assessments with more levels (e.g. Very Good, Good, Fair, Poor and Very Poor) at between 60% and 70% (see GEN2070A Trials Reports). As Tanzania now uses four levels (Good, Fair Poor and Bad), it should provide a reasonable level of accuracy, estimated to be between 70% and 80%, although this will not be overtly assessed during this research. The DROMAS 2 database is transforming from a three level to a four level system, so the data is not yet all available in the new format, or has not yet been entered.

The consistency of previous results have so far given a level of confidence that suggests the system can be used on a larger sample, such as Tanzania.

A small exercise was undertaken during the training to see how consistent the ground truthing would be using the high tech solutions available, such as the DashCam, GPS odometer, RoadLab, etc. The results of this exercise can be seen in Annex 3. It was difficult to compare the results to existing road conditions, as the conditions in DROMAS 2 were still based on the three level assessment, but the exercise was carried out using the new system of four levels.

4.2.9 Training

The training carried out so far on the project in other countries has been very successful. Initially the detailed training materials were developed by Airbus DS, which proved to be very appropriate and needed very little adjustment through the course of the project for different countries. These consisted of a Powerpoint presentation and a Training Manual. Airbus DS delivered the first training courses, but the Regional Centre for Mapping of Resources for Development (RCMRD) attended the Uganda training and delivered the final training in Kenya. This proved that training can be sourced and carried out using local suppliers and RCMRD have been procured to carry out the training in Tanzania. The present training model and materials are a good basis for replicating the system, and were therefore tailored for the Tanzania environment.

In order to plan and organise the training an additional visit of the Team Leader was necessary. Previously this was managed remotely with just the kick-off meeting, but in this case with a larger training group and a much wider range of participants, it was found to be necessary to visit Tanzania to ensure that all parties were in agreement and understood the purpose of the training. RFB invited the participants as agreed and the training took place from 9th April to 13th April, 2018.

As agreed in the Tanzania extension proposal, one participant from the Ugandan National Road Authority (UNRA) also attended the training in order to build further capacity in Uganda. The UNRA Research Centre manager was also included following a request to attend, due to the potential of extending the use of high-tech solutions on rural roads in Uganda.

The training was held at Ardhi University in Dar es Salaam and the RFB supported Ardhi to provide the facilities. There were a total of 17 participants from the following organisations, the list for which can be seen in Annex 2:

- RFB
- TARURA (including representatives from Kilosa, Kinondoni and Ubungu)
- Tanroads
- PO-RALG
- Ministry of Works
- Ardhi University
- UNRA (Uganda)

4.2.10 Development of assessment guidelines

Local engineers and technicians were trained to interpret the satellite images and assess the road condition. However, in previous trainings it was noted that there were some inconsistencies if assessors tried to carry out the task too quickly or with insufficient care. It was also predicted that the accuracy of the assessors would improve with practice, as they only had a relatively small sample to work with.

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

An assessment guide for Tanzania was developed during the training and was used to assess the roads in the satellite imagery. This can be seen in Annex 4.

4.2.11 Condition assessment

The condition of roads in Kilosa was assessed during the training. The participants split into three groups, using the assessment guide and the TARURA condition assessment guideline. The assessment guide is based on ground truthing provided by Kilosa district, plus some additional information gained from the videos taken by the project team as there was only information on two roads in Kilosa district.

The results of this assessment can be seen in Annex 5. Five roads were selected for assessment in total. Teams 1 and 2 managed to assess all five roads in the time provided, two and a half hours, which is a total of 45 km. Team 3 managed to assess two roads of 15 km and 12 km respectively, totalling 27 km. There is clearly a difference in the amount of road each team could assess. Given that the roads being assessed were the same and they had the same resources, it can be assumed that this difference is down to confidence, capability, experience and familiarity with such type of roads.

Team 1 shows the condition of each road as the same along the entire length of the road, except for a short section of about 100m at the start of two of the roads. Team 2 identified several sections of different condition on two of their roads, but showed the other three roads as having consistent condition throughout. Team 3 shows several different condition sections on both of the roads they completed. Team 1 took longer to assess a shorter total length of road, but identified more sections of different condition. Their assessment was more consistent with Team 2, who identified more different condition sections than Team 1. At present, there is no definitive condition for the roads assessed, but when Kilosa district has completed their surveys it will be interesting to compare to the results from this exercise.

This exercise shows that assessment of satellite imagery can achieve a higher rate of assessment than the stated rate for drive through surveys of 6 km to 8 km per day for urban roads and 35 km to 40 km per day for rural roads. The local surveyors in Kilosa achieved about 28 km per day on drive through surveys using a three man team, plus a driver. At the training the participants achieved 27 km in two and a half hours, so it should be possible for one person to assess at least 75 km per day, and probably more with practice. This is in line with the findings from the previous research and represents 10 – 15 km per person per day for traditional assessment, as opposed to 75 – 100 km per person per day for satellite assessment on rural roads. This would be a good argument for using satellite assessment to cover large areas quickly, if this was a requirement of the RFB. The costs shown in the Final Trials Report show that the overall cost of satellite assessment can be comparable to traditional surveys, due to the speed of assessment and lower reliance on logistics.

4.2.12 Providing relevant outputs

It is also important that the outputs from the system are useful to the local roads authority. The High-tech Solutions Guideline sets out the factors to consider when selecting such a system, so the local roads organisation needs to consider these very carefully. The Tanzania trial was designed to specifically test the areas of data collection and knowledge generation that are important to the RFB. This was discussed throughout the training and will also be discussed at a presentation of the final results at the end of the project.

5 Conclusions

The following conclusions can be drawn from the Tanzania trials:

- The appropriateness of the methodology for Tanzania is judged against the original factors included in the High-tech Solutions Guideline:
 - **Cost:** At headline prices the use of satellite imagery for Tanzania is not cost effective. It would cost approximately £10 M to procure enough imagery to cover all rural roads in

the country. At 50% discount the cost becomes more affordable, but is still expensive for the information provided, which is less detailed than the existing inventory. Airbus have recently indicated that they could be willing to negotiate the minimum width of acquisition down to 1 km (from the standard 5 km), and also negotiate on price. With a potential 122,000 km of rural road, this would equate to approximately £1,800,000, without any discount on the headline rate of €17 per km² (about £15 per km²). If significant negotiations on the minimum width and rate can be made, the cost becomes more feasible as the RFB spends more than £1,800,000 per year on driven condition surveys.

- **Detail:** Whether the system satisfies the requirements of the local roads organisation in terms of the level of detail gained for road inventory and condition. This issue was discussed during the training. It was the opinion of Tanroads that there is not enough detail for their requirements on the main road network, and they are already collecting much more detailed information than this which is necessary for the maintenance of such roads. The level of detail for rural roads is also less than is already collected. When the level of knowledge of rural roads in Tanzania was relatively low, this would have provided sufficient information to complete the network. However, since the scoping study for this project in March 2017, TARURA had managed to develop a relatively complete picture of its rural road network by supporting the districts to carry out traditional vehicle-driven surveys. The additional information that can be gained from satellite imagery is therefore now limited. As mentioned in the High-tech Solutions Guideline, the highest benefits come where there is limited knowledge of the network and there are also areas that are difficult to access due to remoteness, lack of resources or conflict. In addition, it is difficult to determine the condition of drainage structures, unless they have completely failed. There are some areas where the satellite imagery would be useful, for example filling in the missing connections of roads, checking existing information or providing a central standardisation of road condition, but it is unlikely that the cost of the satellite imagery would be cost effective for this purpose.
- **Acquisition of imagery:** Whether the climate will be suitable for image acquisition at particular times of the year. Experience has found that the best time for acquisition is during the dry season, which in the case of Tanzania is from June/July to October/November. This is a relatively long dry season and is certainly enough to acquire good imagery, so long as the tasking information is provided in advance.
- **Resolution:** The Dar es Salaam and Kilosa imageries are different resolutions and from different suppliers. Dar es Salaam is 0.3 m resolution, whereas Kilosa is 0.5 m resolution. The Dar es Salaam imagery has shown to provide more detail and was easier to identify the necessary features that represent road condition. However, a sample of 0.07 m resolution drone imagery was also acquired for Dar es Salaam, which proved to be much clearer in terms of the detail that could be seen on the road surface. Figures 4 to 15 show the differences between the imagery.
- **Accuracy:** Tanzania has recently moved from a three-level to a four-level assessment system on rural roads. Given the results from previous research, an accuracy (agreement between ground truthing and satellite assessment) of between 65% and 80% should be possible, based on the previous research. However, a small exercise was carried out during the training to test the reliability of ground truthing (condition assessment by traditional means, such as drive through surveys), using the established TARURA guidelines and the experience of the training participants. This exercise showed that the ground truthing can be inconsistent. The results can be seen in Annex 3.

- **Time:** One of the main advantages of this methodology is that roads can be assessed rapidly and consistently over a wide area using satellite assessment. It is a quick way of gaining a large amount of information and large areas can be assessed rapidly if enough staff are trained and assigned. This was compared to traditional assessments. The TARURA guidelines report that only between 35 km and 40 km of rural road can be assessed using that system per day (or 6 km to 8 km of urban roads). Thus, to survey the entire network of rural roads would take approximately 3,500 days per team (assuming a team of 2 or 3 technical people, a driver and vehicle), so up to 10,500 person (technical) days per year. To carry out this many surveys every year is a significant undertaking. Satellite assessment has been shown to achieve at least 50 km per day per person, but it is assumed this would increase if the assessors were given time to practice (this figure is taken from previous training events). The training in Tanzania included an exercise on condition assessment, which showed that the assessors could interpret at least 75 km per day, and possibly more than 100 km. Accuracy and consistency would also likely increase over time, and with practice the assessors could increase their speed of assessment. Even given the high cost of satellite imagery, it can be competitive against traditional surveys due to the high speed of assessment and minimal logistics required.
 - **Resources:** The resources necessary to undertake the satellite assessment are simpler than the traditional surveys, and involve less administration. It was noted that when the consultants visited Kilosa the local district did not have an operational vehicle, so their condition surveys were inevitably delayed. The logistics involved in arranging and resourcing driven surveys are often a reason for their delay or omission.
 - **Record:** Satellites and other high-tech solutions can provide a clear, dated and geo-referenced record of the road. This can be useful in certain circumstances, particularly if the data is challenged or if the satellite imagery can be used for purposes other than road condition, such as landslide or climate change monitoring.
 - **Licencing:** The licencing agreement is so far consistent with the use to which the imagery is to be put. However, the relevant institution needs to be aware that they do not own the imagery and are using it under licencing, and that any publication or public display will need to be authorised with the consent of the supplier.
- There are a number of high tech solutions that can be applied to the rural roads sector, including DashCams and a variety of smartphone apps. Of these the feedback during the training course was as follows:
 - Tanroads were of the opinion that none of the technologies would be useful for their purposes. This is consistent with the advice given in the High-tech Solutions Guideline which notes that networks which require higher levels of information, or already have a complete inventory and condition database would not benefit from such methods.
 - There was some interest in the smartphone apps that were demonstrated and trialled for rural roads, such as 'GPS odometer' and 'My GPS coordinates'. They are all free to download and easy to operate, and do not need internet on site, so there was interest for use on the rural road network where the level of detail of information is not as high as the national paved network.
 - There was less interest in the RoadLab app because of its lack of accuracy on fair and poor condition roads. It was also not as user friendly as the other apps. Some positive comments were however received in the end of course questionnaires (see the

questionnaire summary in Annex 6), and there is a possibility that it could be used in controlled conditions to provide an approximation of IRI.

- The quality of satellite imagery for Dar es Salaam was very high. The resolution was 0.3 m, which is the best available commercially. This made the condition assessment easier than Kilosa, which had a lower resolution at 0.5 m and the condition was consequently harder to define.
- Ground truthing was not carried out locally, as requested. The ground truthing that was available for Dar es Salaam was based on the previous three-level system, not the new four-level system. Consequently the videos taken by the consultant were used to supplement the ground truthing. Ground truthing was available for only three roads in Kilosa, based on the new four-level system, however there was not a very good range of conditions within those three roads (no 'Good' condition was found), so the development of the assessment guide was limited. The participants again had to rely on the videos taken to provide a full ground truthing.
- Ardhi University was identified as the local remote sensing partner and participated in the training as a supplementary trainer. They have good experience in the sector and are currently working on the World Bank drones project. The training was also carried out at their campus in Dar es Salaam.
- The QGIS and image interpretation aspects of the training course were delivered by RCMRD, with TRL providing insights into the methodology, condition assessment and high tech solutions aspects of the research. This combination worked well and is a good model for the future.
- The DROMAS 2 database has been assessed and there is good potential for links with the satellite methodology:
 - Accurate mapping can be achieved using the satellite imagery by digitising road centre lines, or by dragging an existing GPS track to the road centre line, as DROMAS 2 operators do at present. Hand-held GPS equipment and other sources of GPS tracks such as DashCams and smartphones will only provide a track to a certain accuracy, normally between 3 m and 5 m horizontally, so the digitisation process is important to provide accurate mapping.
 - There is some doubt over the accuracy of GPS and the continuity of satellite connectivity in hilly or mountainous areas, as it may not take into account the contours of the road, as shown in Annex 1. Digitisation can suffer from similar elevation problems. This can be overcome in certain ways, usually by using orthorectified maps or Digital Elevation Models (DEMs) in ArcGIS, which has a set of 'mensuration' tools that enable the user to measure the '3D' length of the road. Some proprietary apps are also able to provide ground distances directly. This would be expected to be at least as accurate as a vehicle odometer and would not need to be calibrated. DMIs can measure road lengths more accurately, but have the disadvantage of needing calibration and a good quality vehicle to operate in, with the added inaccuracy due to tyre slippage on roads with loose gravel or with slippery surfaces. With the scale of surveys required every year in Tanzania, several would need to be procured, with the cost of the instruments in the region of \$1,000 each.
 - The satellite methodology is able to provide condition assessment information in line with the TARURA condition assessment guidelines. The information will be less detailed than the traditional surveys undertaken at present and will provide only limited

information on drainage, given the Tanzania road environment. The main advantage would be the speed with which the satellite assessment could be carried out, savings in the cost of staff and logistics, and the potential for it to be consistent across the country by being undertaken centrally. The cost assessments shown in the Final Trials Report show that satellite assessment can be comparable to traditional surveys in terms of cost, if discounts can be negotiated and speed of assessment is desirable.

- Existing information in DROMAS 2 is comprehensive in its coverage of the country, but there are some anomalies in the data that need to be checked and corrected. This is in process by TARURA and the district staff. Condition data is not complete for the whole country and is not fully revised for the four levels currently adopted by TARURA; at present less than half of the districts are displaying condition data in DROMAS 2. The gaps in the information could be filled by using satellite imagery, but it would be more cost effective to achieve this by referring to freely available online mapping, if it is recent enough and high enough resolution. Satellite imagery would probably only be economically feasible if there were a large area of missing information with a relatively high density of roads. Archive imagery could probably be used for this purpose, if available, as it is significantly cheaper and only has a minimum procurement area of 25 km².
- There is the potential to explore synergies with the DFID funded FTL project in Zanzibar, which is using UAV imagery. At present the project is finalising the ground truthing, but has not started the machine learning aspects yet. This connection will continue to be explored.
- UAV imagery has been provided by the World Bank project that is monitoring the BRT. This overlaps with the satellite imagery procured under this project. A comparison of the two types of imagery has been made in section 4.1.1.
- At the final workshop the RFB accepted the potential value of satellite condition assessment, but recognised that it is less cost effective at this moment in time because of the volume of data that has recently been collected by TARURA for DROMAS 2. However, RFB are still interested in the technology and other high tech solutions and are keen to stay abreast of developments in the sector. They appreciated being involved in the high-tech solutions project and would like to be appraised of such technologies in the future.
- The minutes of the final presentation to RFB on 23rd May 2018 can be seen in Annex 7.

6 Recommendations

The following recommendations can be made for the potential of roll-out in other countries that are considering using satellite imagery for road condition assessment.

- First step is to consult the High-tech Solutions Guideline, Satellite Methodology section 2.1 'Deciding whether to use this Methodology'. This will help the user to decide whether the methodology will be appropriate for use in the situation proposed. If all criteria are fulfilled then the user can proceed with the methodology to assess the road network using satellite imagery.
- Of particular interest should be the detail and accuracy provided by using satellite imagery. If the data produced is not going to be appropriate for the needs of the user, then there is no need to consider the other factors of cost, time, resources etc. It should be noted that many roads organisations collect large amounts of data that are not used, so the user should

critically review the data they presently collect and consider whether similar outputs can be produced with less detail. In Tanzania the condition of the drainage is a key factor, but the data in DROMAS 2 shows that the majority of drainage condition entered is the same, or only one level different, to the surface condition. In such a situation, can the drainage condition be assumed from the surface condition, and to what extent is this data used every year in prioritising maintenance? In reality it is very rare for a 'good' road to have 'poor' drainage, and vice versa. So, if the user is willing to compromise on the detail provided in the data, then the use of satellite imagery becomes more feasible.

- From the final presentation to stakeholders in May 2018, the Road Fund recognised that there are potential uses for the satellite assessment methodology, but that the information entered in DROMAS 2 over the past year and the knowledge incorporated in the database limits the use of satellite imagery as a tool to assess the whole network, simply because most of the data has already been collected. However, there are some areas where it would be useful, such as to audit the existing DROMAS 2 data and fill any gaps/correct errors. This would probably only be economically feasible if there were large areas of data that needed checking/revising. The satellite assessment does, however, offer a rapid option to update condition annually, or as required.
- It was also recognised that the satellite methodology could provide a level of consistency in condition assessment that is hard for TARURA to guarantee across the country. Because the satellite assessment could be carried out centrally and can be audited due to the permanent visual record of the road, it is easier to maintain quality control and consistency than using local engineers/technicians doing drive through surveys which are difficult to audit. Although the engineers/technicians are trained consistently and are working to the same standards/guideline, it is not possible to check all of their outputs for accuracy and completeness. This is a factor that should be carefully considered when deciding whether the satellite methodology is appropriate or not.
- RFB also recognised that some of the high tech solutions that were demonstrated through the project could be applied in Tanzania. During the training they were mainly used for ground truthing of the satellite imagery roads, but there is scope for them to be used in regular data collection. If the satellite methodology is accepted it is recommended that tools such as DashCams, smartphone apps for IRI, GPS monitoring and measurement etc. be considered to assist in ground truthing. It should be noted that RoadLab have just released an update of their roughness app, which now assesses five condition levels and allows the user to select paved or unpaved roads, as well as providing more calibration options for the type of vehicle. Preliminary trials of this improved app are encouraging that it will produce more accurate outputs.
- It was encouraging that a wide range of stakeholders were present at the training in Tanzania, including RFB, TARURA, Tanroads, PO-RALG and Ministry representatives, as well as Ardhi University and stakeholders from UNRA in Uganda. It should be remembered, however, that the technologies trialled are designed for rural roads and they should be considered in that context, with the restrictions on access for surveys and resource constraints. As set out in the Guideline there are specific instances where this technology is useful, and others where it is not. It is recognised that the high-tech solutions and satellite condition assessment trialled in this project are not appropriate for strategic networks where there is generally a large volume of existing information and where road conditions need to be assessed structurally and in more detail than for rural roads. If the strategic level network agencies are included in such trainings and workshops they need to be cognisant of the context within which the technology is to be deployed and the level of results that are

required and utilised by the rural road agencies. There could therefore be a role for strategic level organisations to share their experience and technologies with rural road agencies, but within an environment that recognises the limitations and requirements of rural roads. This would potentially foster innovation and highlight the importance of the rural road network, which often suffers from a lack of investment and status.

- Research is continuing in the area of automated assessment of visual imagery, by drones, satellites and videos, using machine learning and other such high-tech tools. For example the FTL project in Zanzibar, internal research within TRL on remote sensing and road condition, and independent research in South Africa. If these computer based technologies prove to be able to improve accuracy, then the increase in speed of assessment that they will undoubtedly bring has the potential to transform the feasibility of condition assessment using visual imagery. Users interested in being involved in such research should keep abreast of developments by visiting the relevant websites (ReCAP, DFID, etc.) and attending conferences when appropriate. RFB and TARURA are both interested to be involved in the automated research that is currently under way.
- As the technologies reviewed in this project are constantly changing and updating, it is likely that such high-tech options will become more feasible in the near future. For example Airbus DS are about to launch a new website that provides for streaming of satellite imagery, which is high resolution and updated regularly (potentially at 6 month intervals). This could provide a very cost effective alternative to procuring satellite images and has the potential to transform satellite assessment into a competitive technology for road condition assessment. It is recommended that all new advances are explored before deciding on a particular course of action.
- There are also additional uses that the satellite imagery could be put to, for example identifying features or issues off the road. Landslides, areas of erosion and locating sources of road materials are obvious examples. The user should consider whether there are other potential uses for the satellite imagery before selecting this option, which could make it more attractive. Other ReCAP projects have used satellite and aerial imagery to identify materials sources, these reports for Mozambique and Ethiopia can be found on the ReCAP website.

In summary, the user should carefully consider whether the satellite methodology is appropriate to produce the outputs they need. The High-tech Solutions Guideline provides guidance on this issue in section 2.1. As was the case in Tanzania, it is unlikely to be cost effective if small areas or isolated information is required, but for assessing large areas in a short time it does become more attractive. The high cost of satellite imagery can be offset against time savings and the cost of staff and resources to carry out traditional surveys. Due to the rapidly changing nature of these technologies, the user should always consider the most up to date options available as it is likely to become more feasible over time.

Annex 1: Distance measurement exercise

GPS Odometer exercise

On the first field trip one exercise was for the participants to download the 'GPS Odometer' app to their phones, so that the results could be tested. It was only possible to test three roads, as the fourth road was inaccessible with the bus used for the field trip. All of the participants were travelling in the same vehicle, but made the measurements individually. The results were as follows:

Road 1 in km	Road 2 in km	Road 3 in km	Comments
0.88	0.28	8.5	
0.83	0.30	8.47	
0.87	0.27	9.18	
0.82	0.28	8.55	
0.87		8.0	
0.88			
0.858	0.283	8.540	Average of measured lengths
0.880	0.285	8.908	Digitised length in QGIS

Given the ranges shown above, it would appear that some measurements could have been erroneous, perhaps the participants started the recording late, or stopped it late, which could explain the differences. For example on Road 1 there are four readings at 0.88 and 0.87, and the GPS track shows 0.88. The readings of 0.82 and 0.83 are inconsistent. This could be due to an error in the recording, or in the equipment used. It could also be due to intermittent loss of satellite signal, which would be possible as the participants were travelling inside a bus, which is not the ideal vehicle. Normally the GPS receiver would be mounted on the front window or have a connected aerial outside the vehicle. The road is flat and relatively straight so there would be minimal error in rise and fall, and horizontal alignment.

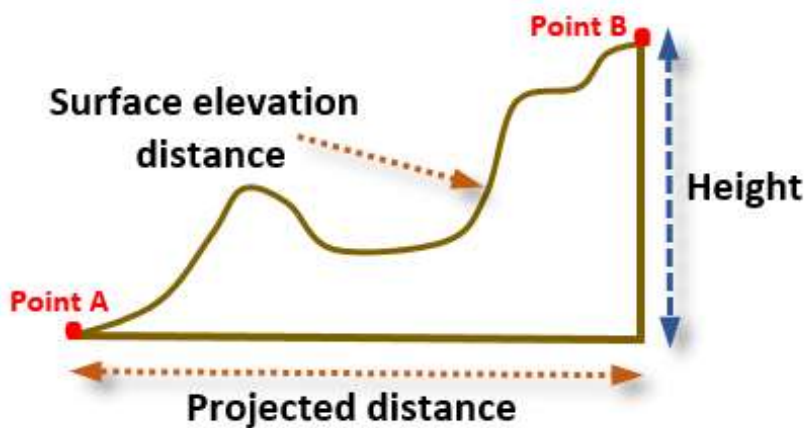
Road 2 was quite consistent in the readings, although there were less lengths measured. As noted before, there is always the possibility of creep if the smartphone is started too early or stopped too late.

Road 3 was much longer and was also subject to significant variations in horizontal and vertical alignment. Despite this, there are three readings that appear to be consistent: 8.5, 8.47 and 8.55. The readings of 9.18 and 8.0 appear to be outside what would be a normal expected error. So these readings are questionable, but more research would be necessary to determine the actual length so that any errors can be clearly defined. It was noted that there were several sharp speed bumps on the road, which may have contributed to some of the inaccuracies. This is again something that would need to be accounted for if it is found to contribute to inaccuracies in readings. The QGIS measured length also has a significant variation to the average, with a difference of about 4%. This is most likely because the WGS 84 projection was used (see note below).

Overall it is clear that more research is necessary to determine the most accurate and effective way to measure road lengths. The RFB should also specify the accuracy they require for the purposes of prioritising maintenance funds. Since the training DROMAS 2 has not been available online to check the road lengths against those measured by the team in Dar es Salaam and Kilosa. This will be done when the program becomes available again.

Note: It is also worth noting that the correct projection should be used to gain accurate road length measurements in QGIS. The general WGS84 projection is only accurate close to the equator, so it is important to determine the correct projection for the area in question and set the layers to that projection. If the correct projection is not used, the longer the road is, then the larger the error will be.

The diagram below shows the process of measuring the surface elevation distance, which can make a difference to the planar distance in hilly or mountainous areas. Tools are available for this in some GIS software, but the image also needs to have the appropriate information. DEMs can be used to measure surface elevation distance as they are essentially a 3D image of the earth's surface. In ArcGIS this is called the 'mensuration' tool.



This is explained at the following website:

<https://pro.arcgis.com/en/pro-app/help/data/imagery/making-measurements-using-imagery.htm>

Annex 2: Training feedback

Organisers and hosts agreed that it was good that so many different agencies were involved in the training, even those that do not deal directly with rural roads.

TARURA reported that they have an android interface being developed for inserting road condition during driven surveys. This can then be downloaded directly into DROMAS 2. Also an addition to DROMAS 2 is planned which will incorporate the road planning and prioritisation process within the program, rather than separately as it is now. DROMAS 2 uses SW maps, which is developed by the same programmer who developed DROMAS 2.

QGIS, as presented in the training, has the potential to make data analysis and manipulation easier.

The potential for filling in missing areas in DROMAS 2 was discussed. Some screenshots of DROMAS 2 were shown where roads clearly had some sections missing, so the satellite imagery could be used to add this information, rather than having to drive the road a second time. This would however not be a cost effective use of satellite imagery alone.

The consultant suggested that satellite imagery could provide a consistent assessment of condition across the country, as it could be managed centrally and the assessments could be easily checked. Also the imagery will always be available for auditing and checking in the future, providing a permanent record of the roads at a set point in time.

It was noted that Tanzania is in the process of establishing a GeoNode, which is an open source platform for sharing geospatial data and maps. This is being established with the assistance of World Bank and others. This could make certain imagery, such as that from drones, and other such resources more accessible and affordable in Tanzania. The consultant reminded the participants that the large satellite suppliers are also starting to provide satellite imagery as a streaming service, which has the potential to reduce the price and increase the accessibility.

There was also a comment that a Distance Measurement Indicator should be used by TARURA to measure the length of all rural roads, as this is an accurate tool for distance measurement. The consultant pointed out that the DMI requires regular calibration and vehicles in good condition to work properly. TARURA would also have to procure several sets to cover all of their roads in a reasonable time. The DMIs can be shared amongst the districts, who have the responsibility to carry out accurate surveys, but they would need recalibrating each time they are used in a different vehicle. GIS measurements however can be checked using QGIS or freely available maps, whereas the DMI measurements would not be 'checkable'.

There was also a discussion over the accuracy of GIS tracks being measured over terrain. A small error is likely by measuring distance over terrain using 2D imagery. If orthorectified imagery or DEMs are used, these errors can be effectively eliminated by taking measurements that account for the rise and fall in the terrain. Existing imagery such as Google Earth and Terrain Navigator, which were both demonstrated during the training, have this capability. Accurate terrain adjusted distances can also be achieved in QGIS by using the DEMs, which were also demonstrated during the training.

It was noted that specific small defects are not visible on the satellite imagery, such as cracks and potholes. This would therefore not be appropriate for the roads that Tanroads maintain. The methodology was designed for rural roads, specifically those where little information is existing and where driven surveys may be difficult or impossible, so the application of the methodology and where it is/is not relevant is noted in the Guideline, available on the ReCAP website.

It was noted that satellite imagery could be useful for identifying and monitoring landslides, although these are less common in Tanzania. The consultant noted that there has been much international research in this area, dating back from at least 1998, especially in areas that are susceptible to landslides such as the Himalayas.

Climate change monitoring was also mentioned, and it was learned that German Aid is supporting some climate change programmes that could be relevant to rural roads. There were suggestions that existing specifications should be adapted for resilience, to take into account for climate change. This could include road design.

Materials sources were also discussed, and the possibility of using this technology to identify scarce road building materials. The consultant noted that TRL has carried out several projects which map road building materials, often using satellite or aerial imagery and spectral reflectance to view the geomorphology and predict where certain materials are located. ReCAP is also undertaking a project in this area.

It was noted that where roads are located in a cutting or on an embankment, the width is fixed and will vary minimally. This was accepted, although the consultant pointed out that variation in width was only one of the indicators.

It was also noted that wheeltracking was not always visible on unpaved roads. The consultant agreed, but responded that where it was visible, it could be a good indicator of condition. He also noted that there is potential for automated assessment by computer using machine learning to identify condition more accurately than humans can. There is a project on Zanzibar that is using drone imagery to research this concept.

The DashCams were seen as a potential tool for rural roads, although they would not be used by Tanroads.

The participants on the course are shown below:

Participants:

No.	Name	Designation	Organisation
1	Fatuma M Majengo	District Engineer	TARURA-KMC
2	Challambo Grayson	District Engineer	TARURA-UMC
3	Donati Deodati	Planning Engineer	TARURA HQ
4	Daki RN	Planning Technician	TARURA HQ
5	Gloria Rweyendela	Civil Engineer	RFB
6	Mark Henry Rubarenzya	Head of R&D	UNRA (Uganda)
7	Moikani Mollel	Civil Engineer	MOWTC-HQ
8	Immaculate Katutsi	Senior GIS officer	UNRA (Uganda)
9	Subira R Lukume	Technician	TARURA - Kilosa
10	Jacob D Mukasa	Civil Engineer	RFB
11	Ronald A Mwajeka	Civil Engineer	PO-RALG
12	Francis Mushobozi	Maintenance Engineer	TANROADS
13	Jonas Makyara	Civil Engineer	RFB
14	Emmanuel Tang'ale	RMNS Engineer	TANROADS
15	Joshua Tenga	Planning QS	TARURA HQ
16	Ndaji S Mayige	RMMS Engineer	TANROADS
17	Aidan Mhonda	Assistant Lecturer	Ardhi University

Annex 3: Ground Truthing exercise

The participants were split into 5 groups for this exercise. They were given two roads to assess for overall surface condition, using DashCam videos that were taken around the same time as the satellite imagery was taken. The field trip also visited these two roads, although it is recognised that the condition would be based on video assessment from the dry season and that the roads would probably have deteriorated somewhat during the rainy season.

Following instruction in the classroom in how to assess the roads, the groups were trained in how to carry out the assessment and were able to use RoadLab, the DashCam video and GPS odometer to assist. The basic assessment was carried out as per the TARURA guidance manual on how to assess road condition, which is used for all condition assessments on rural roads. An extract of the relevant part of the manual can be seen below.

The roads were all short lengths, selected so that a change in condition within the length of the road would be unlikely (but would still depend on the assessment of the groups). The field trips were carried out in a bus, which was not ideal as the bus was not able to travel fast enough on the second road to record IRI with RoadLab.

The groups carried out the assessment in isolation and did not consult with each other over the results. The results were kept secret until all results had been collected and were available for distribution.

The following table shows the results obtained. The following categories were used for assessment:

- 1 = Good
- 2 = Fair
- 3 = Poor
- 4 = Bad

These results were then compared to the results already existing in the DROMAS 2 database for Kinondoni MC. However, all of the Kinondoni results were based on a three level condition assessment, of Good, Fair or Poor. The 'Bad' condition has been recently added but the existing conditions in the database have not yet been adjusted to suit. It is the intention of TARURA to replace these conditions with a four-level assessment over the coming year or so, as all roads have to be re-assessed annually.

Road 1: This road is actually a University maintained road, but was the only road that could be found within the scope of the satellite imagery that was in a potentially good condition. There was therefore no existing condition in the Kinondoni database for this road.

Road 2: This road is a TARURA road, gravel surface and located off the Bagamayo road north of the University. It was assessed within the DROMAS 2 database as 'Poor', which in the new assessment regime would be 'Poor' or 'Bad'. The groups had the option of selecting one of four condition categories for this road.

Road 3: This road was also a TARURA road with a gravel surface. Unfortunately the condition was too bad for the bus to access it at the time of assessment. It would have been

possible to drive the road in a 4WD, but it is highly likely that it would have been assessed as 'Bad' condition.

Group No.	Road 1 Condition	Road 2 Condition	Road 3 (not accessible)
1 (Joshua)	2	4	
2 (Deodati)	1	2	
3 (Rosie)	2	4	
4 (Emanuel)	2	3	
5 (Gloria)	2	4	
Average	1.8	3.4	
Kinondoni Existing	N/A (2)	3	

The results for Road 1 are relatively consistent, with only group 2 finding the road in Good condition, rather than Fair. Group 2 also assessed Road 2 as a higher condition than all of the other groups. Road 2 results were less consistent, which shows the subjective nature of road condition assessment.

An extract showing the methodology and revised condition assessment criteria from the Defect Identification and Data Collection Manual can be seen below:

12.5 Methodology

The techniques used are all observational, i.e. no measurements are required, and require scores to be entered from a list of options for each particular item. The content of the surveys takes into account the key performance factors in the provision and maintenance of unsealed roads.

For unsealed road surveys, Form C "*Link Definition and Unpaved Road Condition*" is used. This form is also used to record the road inventory data which will be surveyed at the same time as the condition survey.

12.6 Condition data

For items where a code, 0, 1, 2, etc., is employed the representative or *average* condition should be recorded. In all other cases, the appropriate quantity or score should be noted.

12.6.1 Overall Surface Condition

Overall surface condition is determined through the subjective assessment of the pavement roughness. Roughness is visually assessed in accordance with World Bank Technical Paper 46 – “*Guidelines for Calibrating and Conducting Road Roughness Measurements*” and as detailed in Section 3 of this Manual. The 4 point scales for sealed and unsealed roads are included in the overall condition rating scale.

To provide an overall measure of pavement condition, and to provide a simple means of estimating roughness, an estimate is made of the overall condition roughness of the link using the following criteria.

1 - GOOD	<p>Shape and condition of surface in 'as built' condition. IRI less than 5.</p> <p>Recently bladed surface of fine gravel, or soil surface with excellent longitudinal and transverse, profile (usually found only in short lengths). Ride comfortable up to 80 - 100km/h, aware of gentle undulations or swaying. Negligible depressions and no potholes.</p> <p>Positive camber or crossfall with no ponding of water, with low frequency of defects of low severity. The camber or crossfall will usually be greater than 4%. (Light grading capable of maintaining surface condition). IRI 5 – 10.</p> <p>Ride comfortable up to 70 - 80km/h, aware of sharp movements and some wheel bounce. Frequent shallow - moderate depressions or shallow potholes . Moderate corrugations.</p>
2 - FAIR	<p>Camber or crossfall at minimum required to shed water. Insignificant ponding of water with low frequency of defects with medium severity.</p> <p>Medium frequency of defects with low severity. (Light grading capable of restoring surface condition unless extensive potholing and concave shape exists, otherwise heavy grading required to restore surface condition). IRI 10 to 15.</p> <p>Ride comfortable at 50km/h (or 40 - 70km/h on specific sections). Frequent moderate transverse depressions or occasional deep depressions or potholes. Strong corrugations.</p>
3 - POOR	<p>Camber or crossfall insufficient to shed water and water ponding in ruts or areas of concave shape up to 150mm deep. Medium frequency of defects with high severity, or high frequency of defects with medium severity. (Reprocessing suitable under most conditions, otherwise light or heavy reshaping required). IRI 15 – 20.</p> <p>Ride comfortable at 30 - 40km/h. Frequent deep transverse depressions and/or potholes; or occasional very deep depressions with other shallow depressions. Not possible to avoid all the depressions except the worst.</p>
4 - BAD	<p>Substantial loss of camber or crossfall and water ponding in ruts or areas of concave shape in excess of 150 - 300mm. High frequency of defects with high severity. (Light or heavy reshaping essential to restore shape). IRI greater than 20.</p>

Annex 4: Calibration Guide for Tanzania

Calibration Guideline for road condition assessment – Tanzania

R Workman, TRL, April 2018

UNPAVED ROADS - 2017 Pleiades Imagery and 2017 WorldView imagery

The satellite assessment methodology will need to be calibrated. Each country, and sometimes each region, have different road condition parameters, environments and processes. The methodology will need to be calibrated to fit with the prevailing system, which involves a process of calibration. This guideline explains the calibration process and includes a guideline for assessing the condition of roads in Tanzania.

The first step is to identify a small number of roads or road sections that can be used for calibration. Ideally these roads should cover the full range of conditions, from ‘Good’ to ‘Bad’, and that are typically found in the area being assessed. If condition assessments are already available, these can be used, so long as they are accurate, recent and in line with national practice and regulations. If no conditions are available then surveys will need to be carried out to establish the ground truthing.

When the ground truthing information has been collected, it is necessary to create a condition map of the roads surveyed for ground truthing and selected for calibration. This is achieved by digitising the roads with condition, showing the colours assigned to condition, as shown in Figure A. This range of conditions should then act as a guide to the assessment of condition by satellite imagery.



When the ground truthing map has been completed for the sample roads, as shown in Figure B, the assessor should note the features of each condition that are common and can be identified easily from a satellite image. A guideline can then be built up that will assist the assessor in determining the condition of the roads from the satellite imagery.

The simplest way to do this is to take three or four screen-shots of the road for each condition, and provide explanations as to what the assessor needs to look for.



Figure B

Wherever possible this guide should use measurable indicators, such as variation in the width of the road. The manual system of assessment is fairly subjective, so any information that can reduce that subjectivity is welcome.

Elements of Image Interpretation

The principles of image interpretation fall into the following categories:

- Location
- Size
- Shape
- Shadow
- Tone and colour
- Texture
- Pattern
- Height and depth
- Site/situation/association

The criteria for assessing road condition are based on the following features that are visible on the satellite imagery:

- **Edges of road:** The edges of the road can indicate the road condition, depending on whether they are clear, broken, faint, etc. If the edges are straight and well defined it suggests that there are drainage channels alongside the road, and that drivers are not driving over the shoulder to avoid poor or damaged areas. If the edges of the road are broken, unclear or difficult to define, it suggests that the drainage is not functioning properly and the road is not well maintained.
- **Width of road:** The width of the road and how much it varies can be a good indicator of the condition of an unpaved road. On unpaved roads drivers tend to drive over the shoulders to avoid poor areas and potholes, which has the effect of widening the road. This is more prevalent in arid areas where there is no vegetation to prevent drivers leaving the road, but it also happens in lightly vegetated and savanna areas.
- **Surface:** A certain amount of detail can be seen on the surface of the road. Different colours, textures, patterns and shading can be identified from the imagery. If the surface is uniform, with consistent colour and shading, it suggests that the road is in good condition. However, if differing colours and shading can be seen it suggests that the condition is not so good.
- **Wheel tracks:** On gravel or earth roads it is often possible to see wheeltracks of vehicles. Generally, if the wheeltracks are straight it suggests that vehicles are travelling in a straight line at a reasonable speed and there are no defects to avoid. However, if wheeltracks are winding or irregular it suggests that drivers are driving to avoid damaged areas on the road such as potholes or soft spots. The more the wheeltracks vary, the more likely it is that the road is in poor condition.



<u>Description</u>	<u>Example</u>
<p>Good (Green):</p> <p>Some slight differences in surface colour and texture can be seen, but generally very even.</p> <p>Negligible or slight variation in width, up to 10%.</p> <p>Edge of road consistent and straight, but may vary slightly in isolated areas.</p> <p>See Figures 1.1 to 1.4.</p> <p>Condition can be relative for earth and gravel roads. If the surface can be determined, the condition of earth roads can be shown as good when the width and edges vary slightly and some surface irregularities can be seen.</p> <p>For unpaved roads this category will normally apply to recently constructed or rehabilitated roads, or roads that have received regular maintenance and grading.</p>	<p>Figure 1.1</p>  <p>Figure 1.2</p> 

Figure 1.3



Figure 1.4



Fair (Blue):

Different shading and colours visible on road surface, but not dramatic.

Width varies slightly, in the region of 10% to 20% and edges appear more broken, although can maintain a relatively straight appearance.

Where wheel tracking is visible, it tends to be fairly straight, indicating that vehicles are travelling quickly with no obstacles to avoid.

See figures 2.1 to 2.6.

Figure 2.1



Figure 2.2



Figure 2.3



Figure 2.4



Figure 2.5



Figure 2.6



Poor (Red):



Significant variation in the colour and shading of the surface.

Width variable, in the region of 20% – 30%.

Edges of road not clear, variable and often not straight or broken and can be indistinguishable from the surrounding land.

Some wheel tracking visible, usually winding, which indicates drivers are driving to avoid defects.

See Figures 3.1 to 3.6.

Note: These roads can be narrow so details of the surface may be difficult to see.

Figure 3.1



Figure 3.2



Figure 3.3



Figure 3.4



AIRBUS

Figure 3.5



Figure 3.6



Bad (Amber):

Very significant variation in the colour and shading of the surface.

Width variable by more than 30%.

Edges of road unclear, highly variable and often very broken. Can be indistinguishable from the surrounding land and often overgrown by vegetation.

Wheel tracking often visible, winding to avoid defects and realignments common to avoid particularly bad areas.

See Figures 4.1 to 4.7.

Note: These roads are often very narrow and/or overgrown, so details of the surface will be difficult to see.

Figure 4.1



Figure 4.2



Figure 4.3



Figure 4.4



Figure 4.5



Figure 4.6



Figure 4.7



Miscellaneous

This category covers any anomalies or features that cannot easily be identified. This should be built up year on year by adding new features that are identified on satellite imagery.

Examples include figure 5.1, which is a road under rehabilitation, and Fig. 5.2, which is a railway line, which could be mistaken for a poor condition road. The features that identify the railway line are the regular parallel lines and the perpendicular lines, which represent the railway sleepers.

Figure 5.1 – Road rehabilitation site



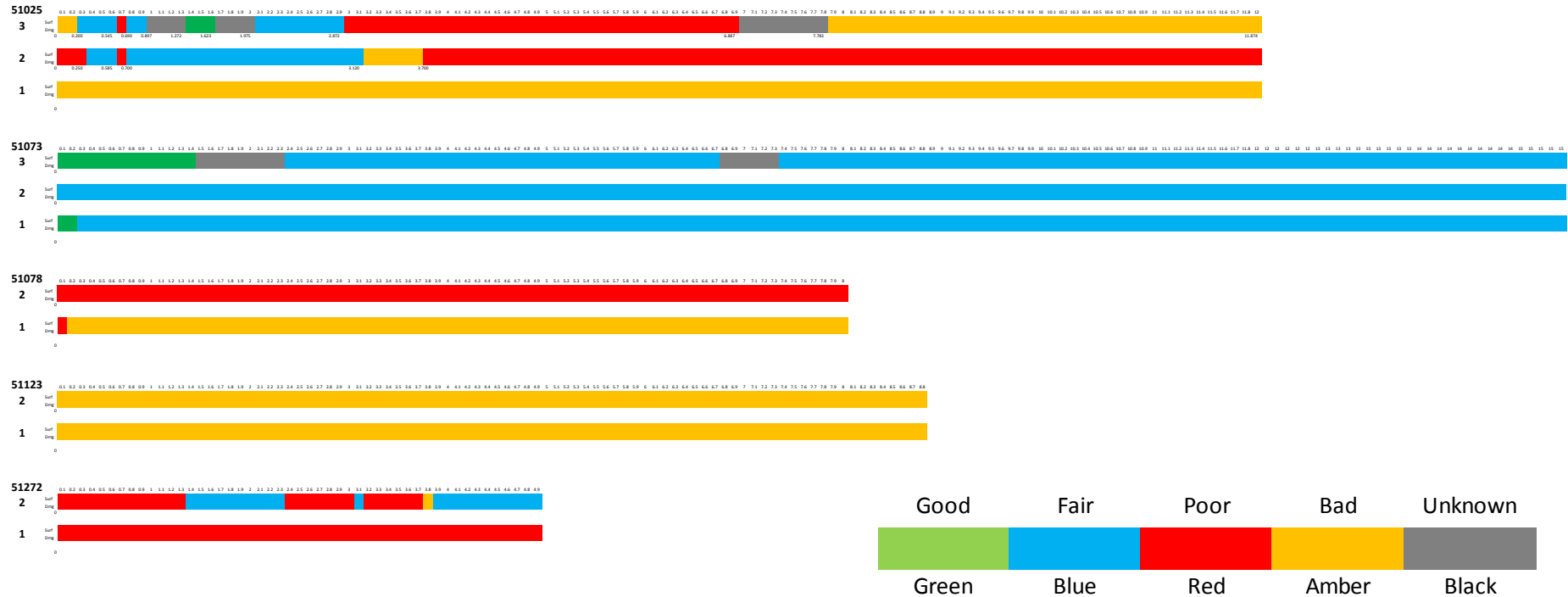
© Airbus Defence and Space – Tanzania, December 2017

Figure 5.2 – Railway (disused)



© Airbus Defence and Space – Tanzania, December 2017

Annex 5: Condition Assessment exercise





The results shown above represent five roads from Kilosa that were assessed during the training. The standard DROMAS 2 colour coding has been used to indicate condition. The road numbers and the group numbers are shown on the left. Where there are disagreements it is mostly between Poor (red) and Bad (amber) condition, which is the new distinction introduced by TARURA recently. For many participants this was the first time they had to assess using four conditions, and some were not familiar with the condition assessment guide of TARURA, so it can be concluded that more practice should improve the overall accuracy of the assessment. In addition only two roads were available for ground truthing, plus some video, and the range of conditions was limited, so better ground truthing should also improve the accuracy of assessment.

Annex 6: Training Assessment Report

This report summarises the feedback provided following the training course in Dar es Salaam from 9 – 13 April 2018 and is based on ‘end of course’ questionnaires that were completed when the training finished.

Question 1: How much have you learned from this course?

Course No.	Title of Course	Q: How much have you learned from this course?					Score
		Nothing  A Lot					
		1	2	3	4	5	
1	Tanzania Training						3.6

Comments accompanying Answer 1:

The trainees were asked to comment on why they selected that particular rating, based on what they chose. They were given a choice on a sliding scale from 1 (Nothing) to 5 (a lot). For example the answers were divided into three groups, those who chose rating 4 or 5, those who chose 2 or 3 and those who chose 1. In this way the answers are more aligned to the actual ratings given. A summary of the comments is shown below:

For those who chose Rating 4-5:

- The course has been very useful especially in the application of mobile tool for road inventory. This is a new technology which is going to bring changes to the road sector in the country.
- Introduction to QGIS
- Introduction to mobile apps, i.e. GPS Odometer, Roadlab, Dash cams, etc.
- Because I am now familiar with QGIS technology and I know how to use it, how to run it, how it works.
- Because I was not having a knowledge of using and assessing the road by using satellite image.
- The new technology which can be used on monitoring of road condition, though with some limitations.

For those who chose Rating 2-3:

- Introductory material on DEMs
- The task/training was limited by access to internet, we were not able to download some files.
- It can help to minimise time and fast for moving through sire for inspection.
-

For those who chose Rating 1:

- No one rated the training as 1.

Question 2: What part/s of this course will be most useful for you in your work?

This question is designed to relate the training to the work that the participants carry out, to provide some insight into how practical and applicable the training could be for the participants in their regular jobs. The use of QGIS, with or without satellite imagery, and the mobile phone apps all appeared several times in the answers. There was no one particular aspect that stood out as being more useful than others in this feedback.

- Application of RoadLab and odometer as a tool for road inventory and application of QGIS and spatial analysis tool.
- QGIS, DEM and assess the road condition by using videos

- Road digitising by using QGIS, uses of Raster/Vector layers
- QGIS
- Use of mobile apps like GPS Odometer, RoadLab etc.
- Application of QGIS
- Using the Odometer, camera and other tools for more accurate and recordable ground truthing. Then using the satellite interpretation for quick monitoring and planning together with drones.
- GIS analysis and database creation.
- Use of Roadlab pro app to assess road condition, use of DashCam, 'Nextbase' player to assess the data from the site/field.
- QGIS, for Road network mapping.
- Condition assessment
- QGIS, RoadLab, DEM
- Use of QGIS in road condition monitoring, though not detailed, especially in monitoring of drainage structures and conditions.

Question 3: What part/s of this course will be least useful for you in your work?

This question is essentially the opposite to Question 2, and is designed to find out what aspects of the training will not be useful to the participants in their regular jobs. In this feedback there were four comments that referred to the satellite imagery analysis as being least useful for their work, but the other high-tech solutions featured very little here.

- Every part is useful, however depends on the situation.
- Assess the drainage condition and surface condition by using image because it's very difficult to differentiate between good and fair condition.
- Satellite imagery.
- Satellite imagery in condition assessment for unsealed roads.
- Use of QGIS picture to assess the reality of the road conditions.
- No any part of the course that is useless. I suggest you should arrange a second week to acquire the knowledge to all participants practically. Or arrange the way of communicating with us on how we keep on using the satellite images.
- RoadLab Pro app, Nextbase software.
- Satellite images.
- None
- Using of satellite image.
- Creation of databases.

Question 4: Are there any subjects you feel should be included (added)?

There was a perception from two participants that the QGIS aspect of the course, and the practical aspects such as ground truthing, RoadLab use, smartphone applications were not well enough connected. This course differed from previous courses because it was not necessary to establish the full QGIS database, as we were no longer testing the accuracy of the system, but more the potential for roll-out. So the inputs may have seemed a bit disjointed, especially for those who joined late and missed the first morning introduction which explained the course and the agenda.

- QGIS should be more connected to the application of IRI measuring app.
- QGIS aspect and the high tech aspects should be more closely linked.
- How to assess drainage structure condition.
- Include ArcGIS.
- Include Remote Sensing.
- Road maintenance
- Bridge assessment

Question 5: Are there any subjects you feel should be omitted (left out)?

There were two participants who thought that the system was not accurate enough for their needs. The review forms were anonymous, but it is presumed based on discussions that these comments were from staff who worked on the strategic network, not on rural roads.

- Road condition by satellite imagery does not give realistic condition compared to ordinary road condition surveys.
- Road condition by satellite imagery should be omitted as not seen clearly.

Question 6: Summary

Question 6 was split into three main areas, which give an overall rating for the course/s. The first part deals with how ‘useful’ the course was, the second deals with how ‘interesting’ the course was, whilst the third asks if the course was too basic or too complicated.

Question 6a: How do you rate the course overall? ‘Not Useful’ to ‘Useful’?

These questions are important in determining how well the course was delivered and how much the participants were able to apply it to their jobs. For this scale ‘1’ is Not Useful and ‘5’ is Useful, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the course overall?					Score
		Not Useful Useful					
		1	2	3	4	5	
1	Tanzania training						3.8

There was a wide range of participants in the training, and the feedback shows that most found at least some aspects of the course to be useful for their present work or future tasks. During discussions there was feedback from Tanroads that none of the technologies would be useful for them. This is consistent with section 2.1 of the Guideline ‘Deciding whether to use this Methodology’, which sets out the conditions where it could be useful. Generally the methodology would not be suitable for the type of roads that Tanroads are responsible for, so this feedback is entirely appropriate.

Question 6b: How do you rate the course overall? ‘Not Interesting’ to ‘Very Interesting’?



For this scale ‘1’ is Not Interesting and ‘5’ is a Very Interesting, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the course overall?					Score
		Not Interesting Very Interesting					
		1	2	3	4	5	
1	Tanzania Training						3.9

This question deals with the issue of the course being ‘interesting’. The course scored well at 3.9 overall, despite the fact that many of the participants were not very familiar with QGIS and how to establish databases with it.

Question 6c: How do you rate the course overall? ‘Too Basic’ to ‘Too Complicated’?

For this scale ‘1’ is Basic and ‘5’ is Complicated, with a sliding scale in between. Hence, out of a possible 5 marks the ideal answer would be 2.5, which would be a good balance between being too basic or too complicated.

Course No.	Title of Course	Q: How do you rate the course overall?					Score
		Basic  Complicated					
		1	2	3	4	5	
1	Tanzania Training						2.9



The score was close to the ideal score of 2.5. It was reported to be slightly on the ‘complicated’ side, but this is not surprising given the fact than most participants were not very familiar with the more in-depth aspects of QGIS. In general participants were able to keep up with the course content and did not get left behind.

Question 7 - Summary of Training Facilities

These questions rate the overall training environment, which can have a significant effect on how well the training is taken up by the participants and how much they learn.

Question 7a: How do you rate the Facilities of the Course? ‘Poor’ to ‘Very Good’? - Room Facilities



For this scale ‘1’ is Poor and ‘5’ is Very Good, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the Room Facilities?					Score
		Poor  Very Good					
		1	2	3	4	5	
1	Tanzania Training						3.3

This question relates to the room and the training facilities provided. The first day was delivered in a computer room, which was too cramped and quite hot because there was only generator electricity, which could not run the A/Cs. This could have contributed to the lower score. Facilities were quite basic and internet was very intermittent, which could also have contributed to the relatively low score.

Question 7b: How do you rate the Facilities of the Course? 'Poor' to 'Very Good'? - Food/Refreshments

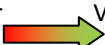

For this scale '1' is Poor and '5' is Very Good, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the Food/Refreshments?					Score
		Poor  Very Good					
		1	2	3	4	5	
1	Tanzania Training						4.2

Quality of refreshments provided can make a difference to the motivation of staff attending the course. In general the food and refreshments were very good, which reflects the high score. They were also provided on site, which prevents delays and disruptions when people have to leave site to find lunch.

Question 7c: How do you rate the Facilities of the Course? 'Poor' to 'Very Good'? - Comfort of Seating



For this scale '1' is Poor and '5' is Very Good, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the Comfort of Seating?					Score
		Poor  Very Good					
		1	2	3	4	5	
1	Tanzania Training						3.3

The feedback on comfort of seating is quite consistent with the room facilities and probably reflects the problems on the first day. There are potential health and safety issues if participants are asked to use uncomfortable or inappropriate seating. Many people develop back problems for this very reason, and although this is unlikely on a short-term course the participant will be able to concentrate more and learn more if s/he is comfortably seated and able to view the presentations easily.

Question 7d: How do you rate the Facilities of the Course? 'Poor' to 'Very Good'? - Convenience / Location?

For this scale '1' is Poor and '5' is Very Good, with a sliding scale in between.

Course No.	Title of Course	Q: How do you rate the Convenience/Location?					Score
		Poor  Very Good					
		1	2	3	4	5	
1	Tanzania Training						3.4

The assessment of the convenience of the location is also fairly consistent. Ardhi University is in a rural setting, not too far from the city centre, so convenience of location will be dependent upon how difficult it is for the participants to reach the facility, which depends on traffic as well as the proximity to their home.

Question 8: Further comments

Final comments provided from the participants are shown below:

- The course should be well connected with the applications of QGIS
- The satellite imagery will only be useful as Raster in connection of roads, not condition survey (mapping).
- Research should be focused on the use of satellite imagery in evaluating most of the road condition and structures, not only the surface. Should also try to focus on how to analyse climate change in altitude of the analysed area.
- The imagery assessment apart from its limitation in defect identification such as potholes, corrugations, for unsealed roads, cannot reveal side drainage which is considered very important element of road condition.
- Thanks for the coordinators and the instructors who gave us a good assistance during the training. During training I suggest to choose 2/3 roads which shall be used in the assessment of training period. i.e. Kilosa district roads were used and we did not manage to see the roads physically during the training.
- To go deeper in how to identify ditches, side drains, drainage by using satellite image for unpaved gravel and earth roads.
- Road condition by satellite imagery cannot be useful due to the following: not possible to view cracks, potholes, ravelling; drainage structures like mitre drains; High cost of imagery.
- Satellite image should be modified because during wet season is cloudy, some of road can not be seen clearly.
- Feature like drainage culvert can not be seen at all in satellite image so they should find an alternative way of being seen.

Analysis

This section of the report covers the analysis of the participant's feedback, the feedback from the trainers and general issues.

The Trainers

Trainers

The trainers were:

- Robin Workman, Byron Anangwe, supported by Mordecai Daniel and Aidan Mhonda (Ardhi)

Trainer's feedback

The trainers fed back that in general the participants were of a varied standard in QGIS, but had good knowledge of roads technology and had been well educated to degree level. Given that the trainees were from different backgrounds and qualifications, and worked for different roads agencies, they interacted well and were able to support each other, especially in the use of the QGIS software.

There were some negative comments from the trainers on various aspects of the training:

- The training venues and facilities were adequate, but suffered from minor issues such as electricity failures and intermittent internet service.
- Some participants arrived to the course late, two missed the first day. Participants were sometimes late arriving, but generally the course was able to start at a reasonable time and this was not a

significant issue during the training. Participants did not tend to leave the course early, which was appreciated.

- One or two missed days through illness or personal issues. This cannot be avoided, but it is hard to pick up again with this type of course if a whole day is missed.

Resources

The two trainers from RCMRD and the Ardhi GIS expert were able to keep the participants up to speed and ensure that no one fell behind. Given the range of abilities, the number of trainers was appropriate.

The Participants

Level of Participants

Although most participants had some experience in QGIS, most were not proficient in the database aspects and manipulating spatialite files. Most staff had used the DROMAS 2 interface, but did not have any deeper understanding of QGIS. In some cases the varied levels of QGIS proficiency made it harder for the trainers to carry out the basic QGIS tasks and maintain all participants at the same level.

Attendance

The courses were designed to be delivered to 15 participants. There were 15 official attendees, as well as two observers/participants from Uganda, but with the assistance of the Ardhi University the trainers were able to cope.

Staff Motivation

In general the motivation of staff to attend the courses in full and on time was good. All participants took the course seriously and showed very good application to the tasks given during the course.

The course

Course Content

Overall there were some comments on the content of the course. The feedback indicated that overall the participants were happy with the content, they learned some new ideas and found the training useful for their work to some extent.

In the course feedback there were no significant areas where the participants requested additional course content, but there were two or three comments to omit subjects like satellite assessment.

Exercises:

There were some comments that more practical exercises should be included and that the assessment should be carried out closer to the area of interest. This would require an extension of the course duration, so it is something that could be considered for future courses. Some requested an additional week to finalise the road assessment for Kilosa.

Field Trips:

The field trips were recognised as an important aspect of the training, and were useful in demonstrating various aspects of the training and use of high tech equipment. There were some comments that the field trips should have included Kilosa, but this was too remote to be feasible. Also due to delays in ground truthing and image acquisition the roads would have deteriorated somewhat since the imagery was acquired.

Timing and Duration

Some comments on the course duration suggested extending the course, possibly to a second week. This would be feasible if the participants were given some time in between to practice the skills they learned during the course.

Location

Overall the location of the courses seemed to be appropriate.

Annex 7: Minutes of Final Presentation

Presentation of Final Study Report – Satellites Project – Road Fund Board, Dodoma, Tanzania

Date: 23rd May 2018. Time: 10:00-12:00 hrs

Attended by:

1. Aureus Mapunda - PHRO – RFB
2. Rashid Kalimbaga – Acting Road Fund Manager – RFB
3. Donati Deodati – Planning Engineer – TARURA
4. Jacob D. Mukasa – Principal Engineer – RFB
5. John R. Aswile – DMFA – RFB
6. Ayub James – Chief Internal Auditor – RFB
7. Emmanuel Mwakajinga – HICT – RFB
8. Jonas Makyara – PME – RFB
9. Anna Mesan – Accountant – RFB
10. Andrew Otto – Consultant – TRL
11. Robin Workman – Principal Consultant - TRL

Presentation:

Robin Workman presented the background on the project, from the initial feasibility in Nigeria, to how the ReCAP project was developed and the results that have been achieved. Questions of clarification were taken throughout the presentation and a plenary discussion was held at the end.

Discussions:

1. Q: Can't the same information contained in Satellite imagery be obtained from the cheaper Google Maps or Google Maps Pro?

Google Maps are not updated regularly, some are as old as 2008. Google does not replace maps as long as they are clear. It was found that Google Maps Pro does not exist, but Google Earth Pro exists but may not be up to date for survey/assessment purposes since the condition of gravel roads changes rapidly. Research in this project has tried to procure imagery within 1-2 months of the ground truthing to ensure that road conditions were similar. Google products do not update at this frequency.

2. Q: What is the level of accuracy received?

The level is between 62-85%, depending on the levels of assessment. This is comparable to the level obtained by the World Bank team that used drone imagery

where very initial results show the potential to gain 61-80% accuracy, again depending on levels of assessment. The question that RFB and TARURA need to consider is whether the level of accuracy is good enough for RFB purposes.

3. Q: Can satellite imagery be used to locate material sources?

Yes, TRL has used the imagery for locating materials sources of calcrete, laterites and cinder gravels in a number of countries, e.g. Mozambique, Ethiopia.

4. Q: Since the images are affected by areas of high vegetation, how can it be used to locate materials sources?

Actually the presence of vegetation acts as an advantage since different vegetation types, elevation contours, and climatic information are used in remote sensing for materials.

5. Q: The satellite image cannot be used to identify particular defects on the road surface such as reverse camber, and potholes, yet these defects are used to decide the condition of a road. At least in paved roads one can see potholes. The method is therefore not applicable?

There was good correlation achieved between condition determination by ground truthing and by satellite imagery. *Moreover, for gravel roads once the condition of a road is decided they usually receive the same treatment, e.g. a road in poor condition will often require heavy grading and recompaction regardless of whether the defect was rutting or reverse camber. It is for paved/sealed roads that it is important to know the exact defects because treatments vary. The Guideline notes that this methodology is more appropriate for unpaved roads.*

6. Q: What is the cost of using the satellite imagery to survey roads?

The cost can be negotiated with Airbus or other suppliers, but the breakdown from the previous countries was shown. For dense road networks like Uganda and Zambia it costs about the same with actual manned surveys. Costs will come down as the technology develops. Donati to work out the cost of surveying 1 km of road by manned method, Robin to estimate the cost using Satellite imagery.

7. Statement – R Kalimbaga: RFB does not want to be left behind and needs to be aware of these technologies and continue collaborative research with TRL and other donors. Further collaboration will continue with a TRL reinvestment project to investigate possibility of change detection through machine learning, using the area of Kilosa.