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Development of Guidelines and Specifications for Low Volume Sealed Roads through Back Analysis

Progress Report 1

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TRL Limited

ReCAP Project Ref: RAF2069A

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TRL THE FUTURE OF TRANSPORT

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Cover Photos: Field testing during the Mozambique Back Analysis Project – AFCAP 1

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Abstract

This report covers the progress period from 1st December 2017 to 28th February 2018 under the project on the Development of Guidelines and Specifications for Low Volume Sealed Roads (LVSR) through Back Analysis. The project is being carried out in 3 phases and is scheduled for completion on 30th April 2019.

Phase 1 of the project involved a review of previously constructed experimental sections and back-analysed LVSR going back four decades, collection of data and information, development of a LVSR database, partial population of the database, and a preliminary information and data gap analysis. Phase 2 involves further development of the database architecture and structure, a more detailed gap analysis, extensive review of other existing reports and data, training of counterparts from participating countries on the use of the database, and further population of the database. A detailed gap analysis or a meta-analysis (depending on the volume of data) will be carried out on the data to determine any critical information and data gaps. Such additional information, if required, will be collected through limited fieldwork.

Phase 3 may involve field and laboratory work to collect the additional information to cover the data gaps derived from the gap analysis if necessary. Other key activities will include dissemination of outputs, preparation for the hosting of the database and preparation of publications.

Key words

Regional Back Analysis, Sub-Saharan Africa, Low Volume Sealed Roads, Performance of Low Volume Roads

Acronyms, Units and Currencies

AADT	Annual Average Daily Traffic
AADTT	Annual Average Daily Truck Traffic
ADT	Average Daily Traffic
AfCAP	Africa Community Access Partnership
CBR	California Bearing Ratio
CSIR	The Council for Scientific and Industrial Research (South Africa)
DCP	Dynamic Cone Penetrometer
DFID	Department for International Development
esa	Equivalent Standard Axles
HGV	Heavy Goods Vehicle
HVS	Heavy Vehicle Simulator
kN	Kilo Newton
LGV	Large Goods Vehicle
LHS	Left Hand Side
LTPP	Long Term Pavement Performance
LVR	Low Volume Roads
LVSR	Low Volume Sealed Roads
Mesa	Million Equivalent Standard Axles
ReCAP	Research for Community Access Partnership
RHS	Right Hand Side
SEACAP	South East Asia Community Access Programme
TMH	Technical Methods for Highways
TRL	Transport Research Laboratory
TRRL	Transport and Road Research Laboratory
UCS	Unconfined Compressive Strength
UKAid	United Kingdom Aid (Department for International Development, UK)
UNRA	Uganda National Roads Authority
vpd	Vehicles per day

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1 Executive Summary

This report covers the period 1st December 2017 to 28th February 2018, under Phase 2 of the project.

During the training of participants from the AfCAP countries carried out in the previous reporting period, suggestions for improvements to the database were identified. The majority of these improvements have been incorporated during this reporting period.

Information from twelve studies has been acquired during this reporting period. Ten of these studies have been reviewed and four of the reviewed studies have been added to the database. Of the 10 reviewed studies, three have been found to be unsuitable for addition to the database. This is because they do not contain any data or have only a limited amount of data. Three of the studies reviewed and other studies yet to be acquired will be added to the database in the next reporting period. Two studies will soon be reviewed.

Currently, two challenges exist, first is the limited availability of studies from western Africa. Fortunately, two studies from Ghana have been acquired and will soon be reviewed. The second challenge is that participating countries have not yet begun adding data to the database. They are being urged to do so.

2 Introduction

The "Development of Guidelines and Specifications for Low Volume Roads through Back Analysis" project commenced in April 2016, and is scheduled to be completed in April 2019. The project is divided into three phases.

- Phase 1 involved the identification of data sources, creation of the database structure, collection of historical performance data from previous studies, processing of the data and the creation of a database for LVRs.
- Phase 2 (current phase) involves further development of the database architecture and structure, extensive review of other existing reports and data, capacity-building activities conducted through training of counterparts from the road research centres of the 12 participating AfCAP countries, and further population of the database with studies identified in Phase 1. A detailed gap analysis will be conducted at the end of Phase 2 and this will inform the activities to be carried out in Phase 3.
- Phase 3 will involve field and laboratory studies (if gaps exist), dissemination, preparation for hosting the database, and production of a scientific paper.

This report describes the activities carried out between 1st December 2017 and 28th February 2018, under Phase 2 of the project. The activities carried out in this reporting period are described under the major chapters of:

- updates to the database,
- studies added to the database,
- next batch of studies to be added to the database,
- other notes, and
- conclusions.

Appendices include project summaries of the studies added to the database during this period, the current project execution schedule, and an explanation as to why one study reviewed was not added to the database.

3 Updates to the database tool

3.1 User interface

Changes to the user interface were mainly centred on making it easier to use the website, as well as updating some of the terminology used to make the terminology consistent and up to date. By logging onto the website lvroadsdata.com one is able to view the new interface.

- When a new user registers, it now clearly states the password requirements at the top of the page (see Figure 3-1). Previously these requirements were only shown to the user if the password entered did not meet the requirements – although they were not told what the requirements were. Therefore, this change makes the process more efficient for new users registering which is crucial as this is the first time many people will interact with the tool.
- When a new user registers, it now also asks them for their organisation and country (see Figure 3-1) as this information is now used in the data approval and deletion processes.

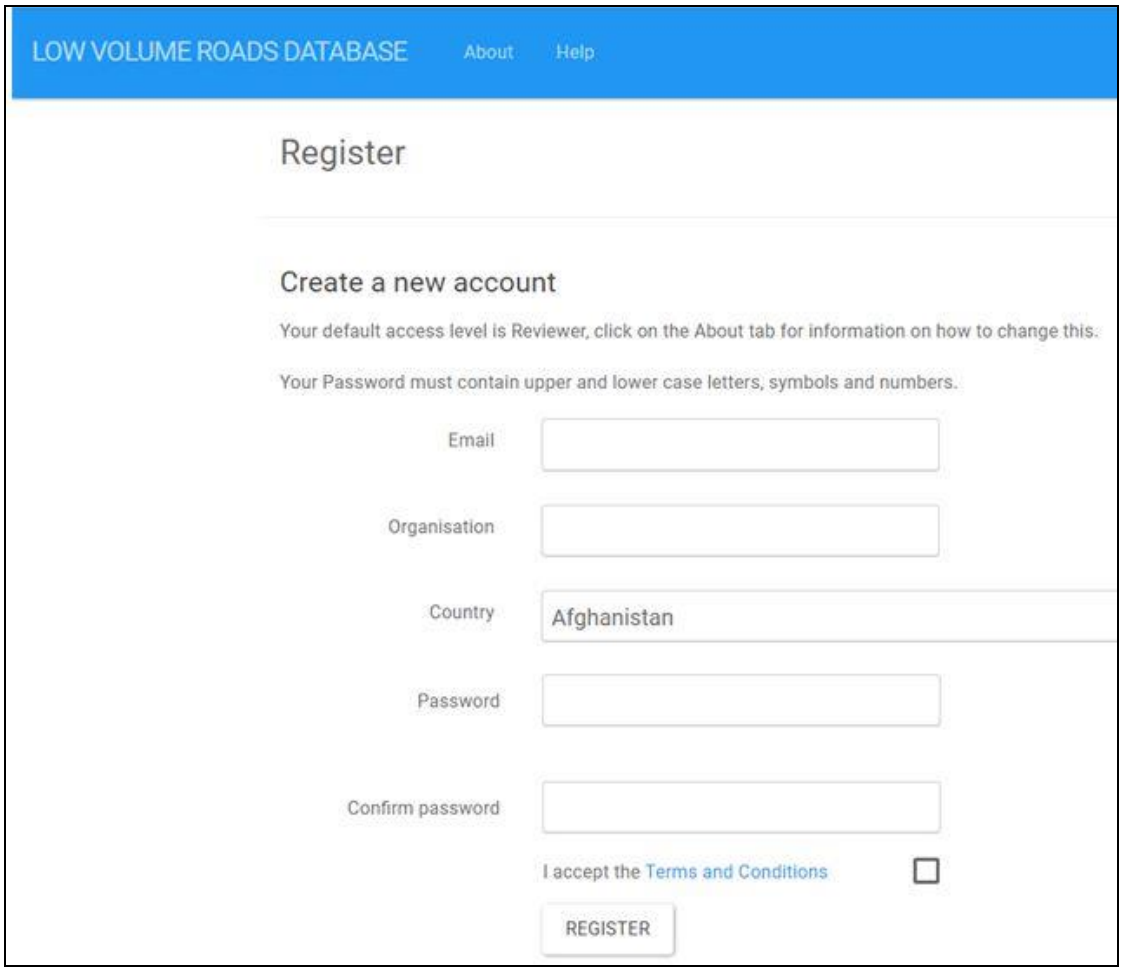

Figure 3-1: Screenshot showing password requirements, organisation and country

- 'Test Results' has been renamed 'Performance Data' in the tool and the data template following feedback on using clearer terminology.
- References to 'Weather' have been replaced with 'Season'.
- Mandatory data is now marked on each page by a red asterisk next to the entry cell (see Figure 3-2). This is as per standard website functionality and prevents any guessing from the user as to what data is required or optional.

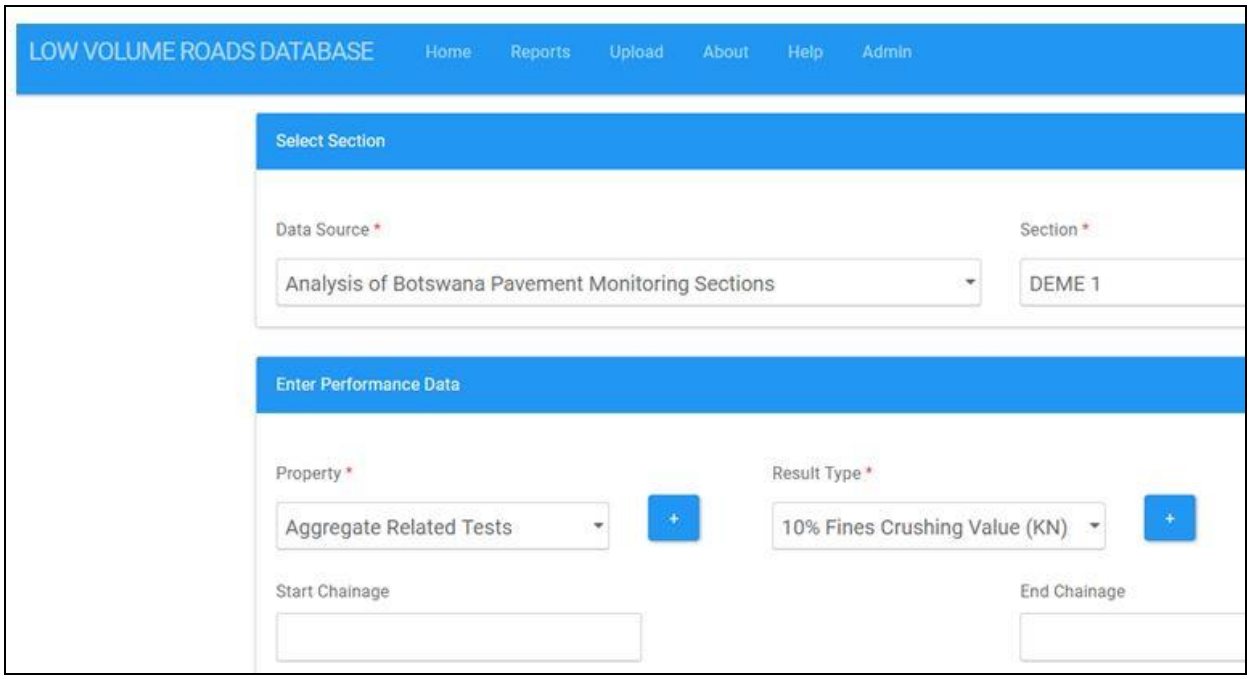

Figure 3-2: Asterisk showing mandatory data fields

- When creating a new data source as part of the Upload process, the user is now presented with a pop-up message to clarify the successful creation of the data source. This was updated because it was not clear if the data source had been successfully created.
- If any user wants to raise an issue with the data they have been looking at, there is a now a 'Raise Data Query' button on the report page. This opens up an email to send to either the data uploader (see Figure 3-3), or the main administrator for the tool. This means that users at any access level can highlight potential data errors in the system.

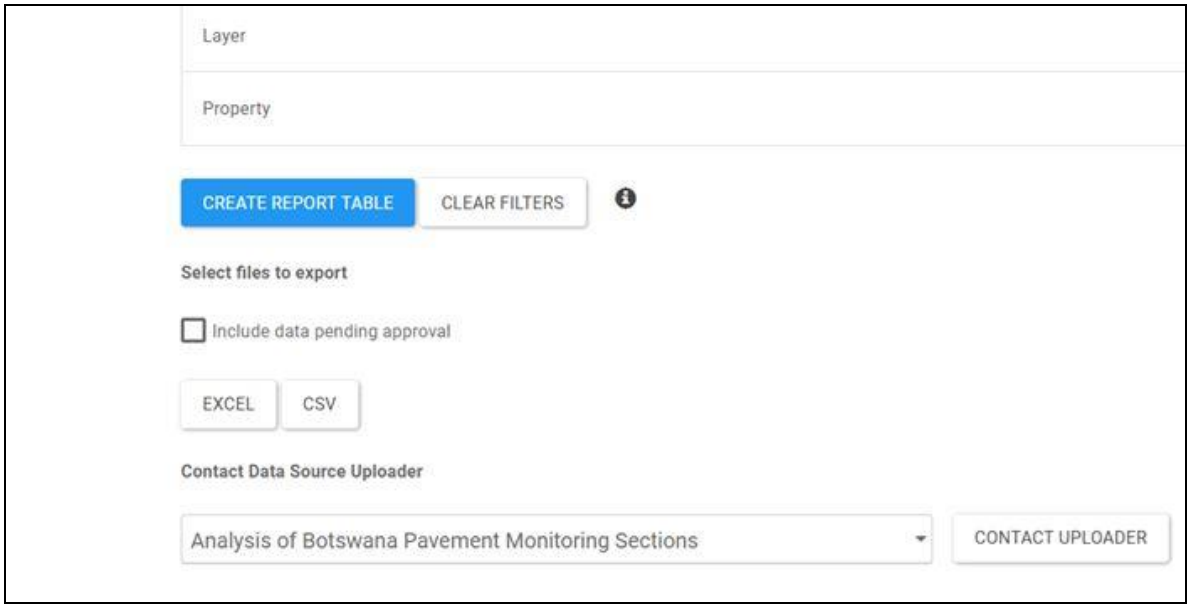

Figure 3-3: Option to contact data uploader

3.2 Data and Database structure

Some of the identified changes meant revisions had to be made to the structure of the database and how data is stored.

- Following the trail of data being entered, one of the differences observed between studies was that some studies collect single readings per road section and others collect multiple readings per road section. In order to make this distinction clearer, new fields of 'Chainage From' and 'Chainage To' have been added to the database tables for site information and test results. This means that any value recorded against a specific chainage can now be clearly stored against the correct chainage values in the database. If no chainage values have been recorded by the study then these optional fields can be left blank.
- Through the website, data can now only be deleted by someone in the same organisation or country as the original uploader of the data. This is to prevent people from deleting data from studies that they know little about. On the 'Admin' page, for those that have access, there is now a new table showing the most recently deleted data – if data has been deleted incorrectly it can now be reinstated through this table as it is never actually permanently deleted from the database.

3.3 Data upload process and template

Following the three workshops held between October and November 2017 (See Capacity Building and Training Workshop Report 12th December 2017), a number of improvements to the data upload process and data template were identified. These are listed in detail below.

- The 'Upload' process has been simplified into four clear steps on the upload page in the tool to guide the user through the required stages more clearly.
- A new Instructions page has been created in the data template. This clearly outlines all the steps, processes and definitions used in the template. This change was made following feedback that if the data template is passed to other staff members for data population (who may be unfamiliar with the tool) there were no clear instructions. Additionally, the data template has now got colour coded instructions to clearly show in the template what data are mandatory for entry and which are optional and all column headers now remain frozen at the top of the screen if a user scrolls down the page.
- The data template has drop-down lists for selecting test property and result types. However, it was not always clear if a particular result type already existed in any of the test property groups. To overcome this a new search box functionality was added to the template so that a user can begin to enter the first few characters of the result type they are searching for and the box returns all matching entries, whilst also showing the user which property group the different result types belong to.
- When entering data in the template that is the same for all sections (e.g. rainfall) there is a new option in the Sections drop-down list entitled 'All'. If this is selected, the user only needs to enter the data once and when the template is uploaded, the system will automatically assign the data to every section.
- The columns for 'Year From' and 'Year to' have been updated to drop-down lists to prevent incorrect data being added to those columns. This will help increase the robustness of the data and therefore the reporting. In addition, a 'Month From' and 'Month To' column has been added to allow multiple values to be entered in one year, as per some studies.
- When uploading data templates into the database if there is an error preventing the data from being uploaded there are now enhanced error messages given to the user, which highlight the rows in the data template that are causing the errors. This is because previously there were no row numbers included in the error messages and it was a time-consuming

task for a user to search through multiple rows of data to look for a possible error. Therefore, the process is much more efficient than it was.

- The data approval process has been refined so that all data uploaded into the system is now instantly available to all other users to query and report upon. However, until it is approved it will have an 'unapproved' flag against it and the user can choose to exclude unapproved data from their reports if they wish. The reason for making all data instantly viewable was to prevent time-lags in data being available if someone is not available to approve it quickly. In addition, data can now only be approved by someone in the same organisation or country as the original uploader of the data – this is to make sure that the data approval process is completed by the most relevant user with data approval privileges.
- When approving data, there is a new button which allows a user to approve all data, as opposed to approving sections, site information and performance data separately.
- Changes to the manual will be made to reflect clearer guidelines for procedures such as deleting a row of data from the template.

3.4 Miscellaneous

- If a data source has a summary link included, the link is now included as part of the data download process so the user can access it when not directly on the Low Volume Roads Database site.
- The earliest year a data source can be set against has been updated to be 1950.
- There is a now a clear warning message that the data template needs Microsoft Excel 2010 or later. In some of the training sessions some errors where encountered by users running an older version of Excel, although this was only for a small number of people and so this restriction is unlikely to cause problems. Those that were affected in the training workshops were happy to update their version of Excel, not least because older version of programs will become unsupported with time.
- Changes to the manual will be made to reflect all the changes in the system. More minor changes are likely to be made to the tool throughout Phase 2, whenever it is deemed appropriate. Therefore the final version of the User Manual will be available for review together with the Phase 2 Final Report.

4 Studies added to the database

Table 4-1 shows the studies reviewed for inclusion in the database during the reporting period. Data from four studies were added to the database. The four studies represent a combined sum of over 16,000 data points (excluding associated attributes – over 48,000 points including attributes) representing various parameters. The study summaries are included in Appendix A.

Table 4-1 also shows a fifth study that was reviewed but not added to the database. This was due to the lack of quantification of many aspects of performance and details of the actual pavements themselves, hence the conclusion that, at the present time, there is insufficient information to warrant inclusion in the database. Access to original reports of the 16 HVS tests sites may provide the missing information but any analysis would be inherently difficult because of the complex nature of the tests carried out. This, in itself does not disqualify the data from being included but the task of extracting it from the HVS study reports, assuming they are still available, would be prohibitive within this current project. See Appendix B for further explanation.

Table 4-1: Studies reviewed for inclusion into the database over the reporting period

No.	Title	Organisation	Author(s)	Remarks
1	Performance Review of Design Standards and Technical Specifications for Low Volume Sealed Roads in Malawi (2011)	AfCAP 1	M. I. Pinard	Added to the database
2	The Hoopstad stabilized Kalahari sand LTPP experiment after 55 years (2017)	ReCAP	F. Netterberg	Added to the database
3	The Kenya road transport cost study: research on road deterioration LR673 (1975)	TRRL	J. W. Hodges, J. Rolt and T. E. Jones	Added to the database
4	Investigations of subgrade conditions under roads in East Africa (1968)	TRRL	M. P. O'Reilly, K. Russam, F. H. P. Williams	Added to the database
5	*Impact of the Heavy Vehicle Simulator (HVS) programme of the Gauteng Provincial Government 1978 to 1996 (updated to 1998).*	*CSIR*	*E. G. Kleyn, S. V. Kekwick and R. Sutton*	*Reviewed but not added (see Appendix B)*

5 Next batch of studies

Table 5-1 shows the next batch of studies for consideration for inclusion into the database over the next reporting period.

Table 5-1: Studies for consideration in the next reporting period

No.	Title	Organisation	Author(s)	Remarks
1	The Kenya maintenance study on unpaved roads LR 1111 (1984)	TRRL	T. E. Jones	Reviewed and appropriate to add to the database
2	Evaluation of weak aggregates for surface dressing on low-volume roads TRR 1291 (1991)	TRRL	M. E. Woodbridge, P. A. K. Greening, and D. Newill	Reviewed and appropriate to add to the database
3	Concrete pavement trials in Zimbabwe TRL RR381 (1993)	TRRL	J. D. Parry, N. C. Hewitt, T. E. Jones	Reviewed and appropriate to add to the database
4	Performance of Sealed Test Sections WP113 (1981)	TRRL	P. W. D. H. Roberts	Soon to be reviewed
5	Performance of Unsealed Test Sections WP114 (1981)	TRRL	P. W. D. H. Roberts	Soon to be reviewed
6	Promoting the use of marginal materials TRL, PR/INT/205 (2002)	TRL	J. R. Cook, C. S. Gourley and E. C. Bishop	Reviewed, does not contain data but contains references to studies that may be useful
7	Ghana highway research programme. Road maintenance study: Measurement of running surface characteristics. TRL WP111 (1981)	TRRL	P. W. D. H. Roberts	The report is not about road or material performance and has no data suitable for the database

6 Other notes

Change of key staff: the Data Management Specialist on the project, Thomas Buckland, will no longer be part of the project as he left the employ of TRL on 28th February 2018. Kevin McPherson has been approved by PMU as his replacement. A handover/takeover between the two was completed on the 27th February 2018 at TRL offices.

Dominic Leal, who replaced Deepu Prabhakaran as a Field Engineer, has now been trained in navigating through the database, data extraction from reports, and data entry using the Data template. He will therefore contribute to compiling data from reports and inputting it into the database.

7 Conclusions

The project is progressing well; several members from partner countries have been trained on the use of the database. Following the training workshops, suggestions for enhancement of the database were received and most of them have been implemented. Studies are being gathered and entered into the database by the TRL team.

Two challenges are currently being faced:

1) During the training workshops, studies from specific AfCAP-participating countries were identified. The essence of the training was so as to enable the countries to enter their data into the database. Despite these reports being available in some of the countries, data entry is not forthcoming. The cause of this appears to be that the research units in the various countries are overstretched with other activities. The countries are continuously being urged by the project team to carry out data entry but challenges still remain. We propose that the ReCAP PMU should assist as best as they can through their normal channels in getting the countries more active in uploading data (where it exists) into the database.

2) There is a limited availability of studies from western African. Fortunately, two studies from Ghana (No. 4 and 5 in Table 5-1) have been acquired and will soon be reviewed. In addition, materials testing data for up to 454 borrow pits in Ghana exists. However, this will require site investigations on the existing roads where these materials are known to have been used in order to link the materials data to performance. It is proposed that field investigations be carried out on some of these sections in Phase 3.

Appendix A: Project summaries of added studies

Performance Review of Design Standards and Technical Specifications for Low Volume Sealed Roads in Malawi by M. I. Pinard (Private Consultant), (AfCAP 2011)

The study was done in Malawi between 2009 and 2010 and the report published in May 2011. This was a one-off study not an LTPP. The main objective of the study was to undertake a review of performance of existing low volume sealed roads, existing design standards and specifications used for the construction of low volume sealed roads in Malawi. Four roads were studied. There were a total of 6 road sections spread between northern, central and southern Malawi.
The roads studied were between 6 to 25 years old. The test sections for field-testing were about 100 m long. No periodic maintenance was applied on any of the roads because the roads did not require them.
The roads were monitored in 2009 and 2010. There was both wet and dry season monitoring. Traffic volumes ranged from AADT 220 to 764. The roads had carried between 26,000 and 237,000 esa by the time of monitoring. One of the roads studied is in a region of mean annual rainfall between 600 – 800 mm, Weinert's Number > 4 and Thornthwaite Moisture Index 0 to +20. The other 3 roads were in regions of mean annual rainfall between 800 – 1200 mm, Weinert's Number <2 and Thornthwaite Moisture Index +20 to +100. Cape seal of 19 mm was used on all the roads. In constructing the seal, two layers of slurry were used. Base materials include Laterite, weathered granite, and quartzitic gravel. Base layer thicknesses ranged from 100-150 mm. The materials test methods used in the study were British Standards, with BS Heavy Compaction used in the laboratory.
Drainage Classification is based on product of crown height (h) and distance (d) from the centreline to the centre of the side drain. The product d x h is greater than 7.5 drainage classified as good, 5.1-7.5 classified as moderate, 2.6 -5.0 is classified as poor and less than 2.5 is classified as very poor.
In the analysis, traffic growth rates assumed were:

Class	Description	Average esa	Growth rate % by year		
			1-5	6-10	11-15+
LGV	2-axle	0.7	3	4	5
Bus	2-axle	0.75	3	4	5
MGV	3-axle	1.75	2	3	4
	4 axle	1.75	2	3	4
HGV	5-axle	2.8	1	2	3
	6-axle	2.8	1	2	3

Load equivalence factor, n used in computing esa was 4.2.

The Hoopstad Stabilised Kalahari Sand LTPP Experiment after 55 Years by Frank Netterberg (Private Consultant), (AfCAP 2017)

The project report covers experimental work carried on the Hoopstad-Bultfontein Road situated in the Free State Province of South Africa. The main objective of the research was to investigate the performance of Aeolian Kalahari Sand in road pavements with different types of stabilisation. The trial sections were built in June 1962 and the pavement consists of roadbed, selected subgrade of red sand (150mm) and subbase of red sand stabilised with 3% Portland Blast Furnace Cement (PBFC). The base consists of 10 trial sections of stabilised sand; Section B (3% Ordinary Portland Cement – OPC), Section C (5% OPC), Section D (10% OPC), Section E (5% PBFC), Section F (5% PBFC) Section G (2% Sulphite Lye), Section HA on LHS (8% bitumen emulsion), Section HB on RHS (4% bitumen emulsion), JA on LHS (4% tar) and JB on RHS (8% tar). There are 2 control sections; Section A (neat sand) and Section K (crusher run).
All layers are 150mm thick.
AADT in 1963 was 150 and the AADT determined in 2013 was 850. The number of heavy vehicles (AADTT) was 15 and 150 respectively. Traffic loading after 55yrs is 1.5M equivalent standard axles per lane. The road standard is assumed to be 0.3M equivalent standard axles. The climate is generally dry with an average annual rainfall of 530mm, which is semi-arid. Rainfall data was obtained from a nearby rain gauge at a farm.
Materials tests were carried out on stabilised materials. However, the CBR of the neat sand was not measured at the beginning (or was not reported), but recent measurement of the neat sand showed that the CBR is approximately 36%, which is common for red sands. TMH1 standard methods were used for materials testing. Tests on the crusher run involved replacing of oversize material. The materials such as OPC and PBFC and bitumen emulsion (SS60) and tar conformed to SA standards (SABS) of the time. In-situ strengths were assessed using the DCP. WinDCP 5.1 was used to provide both the CBRs and UCS values. Deflection, roughness, and visual condition surveys were carried out and recorded as per guidance and procedures given in TMH series (TMH 9 in particular). Site and laboratory measurements were recently carried out in 2013, 2016 and 2017.
All sections performed well structurally over 55yrs and the main defects were cracking due to aging of surfacing and edge break due to wider trucks trafficking the road. The best performers were Section D and K. Section A (neat sand) also performed as well as the others structurally albeit with more superficial failure of the surfacing. It is reported that all cement-stabilised sections had fully carbonated with the exception of Section D (10% OPC). The report final indicated that the road is under rehabilitation.

The Kenya Road Transport Cost Study: Research on Road Deterioration by J. W. Hodges, J. Rolt and T. E. Jones. TRRL (1975)

The study (Laboratory Report 673) was conducted in Kenya. The main objectives of the study were: 1) to relate the deterioration of several types of road common in developing countries to the original design and construction standard of the roads, the traffic loading carried by the roads and the characteristics of the natural environment. 2) To derive relationships between the variables described in (1) suitable for use in a computer model. 3) To investigate the effects of different maintenance policies on the deterioration of the roads.

The dates of study were not stated in report. A total of 96 test sections were carried monitored.

- 39 surface dressed with cement stabilised bases
- 11 sections are on Nairobi-Mombasa Highway. (3 no. AC with crushed stone base and stabilised gravel subbase; 8 no. surface dressing with cement stabilised base and natural gravel subbase)
- 38 gravel roads
- 8 sections on earth roads

The length of each test section was 2 km made up of 1 km main section with 0.5 km with similar character on either side for run-in. The duration of monitoring ranges between 2 and 4 years. The frequency of monitoring was 2 monthly except for gravel loss on unpaved roads which was monitored every 4 months. For paved roads there were three pavement types monitored in the study:

- category I (OB sections). Old surface-dressed roads with cement-stabilized bases and natural gravel sub-bases constructed to acceptable standards more than three years before the start of the study and showing no obvious signs of failure. Range of thickness
- category II (NB sections). New surface-dressed roads with cement-stabilised bases and natural gravel sub-bases constructed to acceptable standards less than two years before the start of the study.
- category III (P sections). Roads with premixed asphaltic concrete surfaces on crushed stone bases and stabilized sub-bases constructed to Ministry of Works specifications less than two years before the start of the study.

For unpaved roads two categories were monitored:

- Engineered gravel roads
- Earth roads

Pavement layer thicknesses were:

Sections P1-P8

- Asphaltic concrete surfacing (thickness ranges from 18-113 mm)
- Granular base (thickness ranges from 115-180 mm)
- Cement stabilised subbase (thickness ranges from 138-370 mm)

Sections NB1-NB14

Constructed less than 2 years before the study

- Surface dressing (thickness ranges from 15-27 mm)

- Cement stabilised base (thickness ranges from 131-178 mm)
- Natural subbase (thickness ranges from 114-243 mm)

Sections 0B1-OB25

Constructed more than 3 years before the study

- Surface dressing (thickness ranges from 15-27 mm)
- Cement stabilised base (thickness ranges from 131-178 mm)
- Natural subbase (thickness ranges from 114-243 mm)

Sections G1-G42

Engineered gravel roads. No information on construction available

Surfacing Types

- 10 sections with asphaltic concrete
- 39 sections with surface dressing
- 38 sections on engineered gravel
- 8 sections on earth road

Traffic volume during monitoring

- Most of the counting periods were for 7 days or more
- Frequency/dates of traffic surveys not provided in report
- Paved Roads: 24 hour manual classified count data available for all sites BUT no information on the specific dates given. Only total number of counting days for each site. Survey days range from 3 to 36
- Unpaved Roads: 24 hour manual classified count data available for all sites BUT no information on the specific dates given. Only total number of counting days for each site. Survey days range from 3 to 16

Axle Load Surveys Prior to Monitoring

MESA data available for paved roads for each section. Year of opening varies from 1960 to 1971

Sections P1-P10

- Ranges from 0.019-1.018 MESA

Sections NB1-NB14

- Ranges from .018-.184 MESA

Sections OB1-OB25

- Ranges from .048-.920 MESA

Average Annual rainfall

Divided into two categories

- Annual rainfall greater than 1000 mm
- Annual rainfall less than 1000 mm

Major Events

Vehicle licensing regulations were changed in about 1967 to permit heavy goods vehicles to haul goods which had previously been transported by the railways. This resulted in a rapid increase in the average equivalence factor of heavy goods vehicles on trunk roads and this continued for several years.

Pavement Design in the Tropics: Investigations of Subgrade Conditions Under Roads in East Africa by M.P. O'Reilly, K. Russam, and F.H.P. Williams. TRRL (1968)

Road Research Technical Paper No. 80 published in 1968, contained information on studies undertaken between 1958 and 1959 in Kenya, Uganda and Tanzania. The main aim of the studies was to determine the moisture conditions in the subgrade soils under sealed pavements in tropical countries. Other objectives were to determine:

1) Whether there are common features in the moisture conditions occurring under bituminous-surfaced roads in this type of climate and terrain that could be used by the engineer in designing road pavements.

2) Whether satisfactory procedures could be established to simulate the conditions that were found and enable general recommendations to be made on the design and construction of roads in tropical and sub-tropical areas.

3) Whether a theory could be formulated to explain the conditions found.

The investigation comprised:

- Sampling of Insitu moisture conditions at 7 major sites over a completed climatic cycles
- Laboratory testing for both disturbed and undisturbed samples
- Testing of 48 sites to establish application of findings on areas where water table was 10ft or more below the road surface.

The number of sites studied was 55 in total; 7 major sites (5 near Nairobi and 2 near the Rift valley) and 48 minor sites scattered throughout Kenya, Tanzania and Uganda.

Field investigations were carried out in two phases; Phase 1 for major sites and phase 2 for minor sites. The 7 major sites were located on typical bituminised main roads. Terrain conditions encountered level, cut, and fill conditions. The soil types encountered varied from heavy clay to volcanic ash of low plasticity.

Description of major test sections

1) Sites No. 1 and 2:
    a. Road for Site No. 1 constructed in 1949 – 1950.
    b. Road for Site No. 2 was completed in February 1957.
    c. Located along Limuru and Thika Sagana road respectively
    d. Had friable red clay soil.
    e. Three sub site locations of level, cut and fill condition investigated.

2) Site No 3:
    a. Road for Site No. 3 constructed in 1949 – 1950.
    b. Located in Embakasi plains along Nairobi-Mombasa road
    c. Had typical black clay soils
    d. Two sub sites on level ground investigated
3) Site No. 4
    a. Road for Site No. 3 constructed in 1947.
    b. Located along Ngong road
    c. Had typically black clay soils
    d. One site was investigated
4) Site No. 5
    a. Road for Site No. 3 constructed in 1956.

b. Site located along Nairobi-Mombasa road
c. Site had both black clay soils and sandy soils
d. Two sub sites were investigated
e. Both sub sites in fill areas

5) Site No. 6 – Road completed in 1944. Located South of Naivasha along Nairobi-Nakuru road
6) Site No. 7 – Road constructed in 1951. Located along Nakuru-Eldoret road

Soil sampling

Disturbed samples

a) Major sites

- Sampling done monthly
- Three positions including the verge, 3ft form pavement edge and road centreline considered.
- Depth of sampling: 6 feet
- Samples obtained from subgrade and road construction layers.
- Tests included moisture content and plasticity determinations

b) Minor sites

- Samples taken from random points
- Tests included moisture content and plasticity determinations

Undisturbed samples

a) Major sites

- Monthly undisturbed samples of subgrade material taken.
- Depths of sampling: 1 to 2ft and 3 to 4ft,
- Where possible, one sample taken at centreline 6ft below surface
- 3 positions of sampling: Verge, 3ft from pavement edge and rad centreline.

b) Minor sites

- Samples taken at random points

Field measurements

Water table record

a) Major sites

- Lined boreholes sunk at depth of 12ft or until hard lay was encountered.
- Only Major site 2, sub site c) had a water table encountered.
- At Major site NO. 4, seepage from, borehole lining was noted after raining.

b) Major sites

- Likely water table estimated from nearby streams and waterholes.

Density measurements

- Two sets of Insitu density measurements married out at all major sites
- And replacement method used on subgrades
- Water displacement method used on murram base and subbase materials in accordance to B.S. 1377.
- Insitu densities not measured to minor sites

CBR measurements

- Three sets of Insitu CBR measurements made at all major sites an sub sites
- Two sets of tests carried out during 1958 and 1959 rain periods
- Other measurements carried out in October and November 1958.
- Measurements carried on all subgrades, bases consisting of gravel sandy clay
- At minor sites, measurements carried out on only subgrade level

Traffic counts

- 16 hour traffic counts carried out from 5.00a.m. to 3:00p.m on twice on each major site

Meteorological data

Daily rainfall figures for the period 1st January 1958 to 31st July 1959 were supplied by the East African Meteorological Department

Appendix B: Study reviewed but not added

Project Report CR-96/086 *'Impact of the Heavy Vehicle Simulator (HVS) programme of the Gauteng Provincial Government 1978 to 1996 (updated to 1998*). E. G. Kleyn, S. V. Kekwick and R. Sutton. Transportek CSIR (1997)

Summary

This report provides a summary of the work undertaken with the Gautrans' Heavy Vehicle Simulator from its commissioning in 1978 through to 1996 (updated to 1998). The report provides details of the background and philosophy regarding the project, the underlying motivations, and the more significant findings. It concentrates on understanding the behaviour and performance of roads and their cost effective design and construction but is largely descriptive rather than quantitative in nature**.**

Details

16 roads were investigated with the HVS. The report contains details of their design in terms of the material classifications and specifications for each layer and their nominal thicknesses but very little about actual constructed thicknesses or strengths or their variability.

An important note that is emphasised in the report is an explanation as to why the wheel loads were varied during each test:

> *The reader will note that the wheel load did not always start off at 40 kN. The reason for this is that the research team sometimes needed an early indication* of *what to expect from the pavement in order to plan ahead and thus used the 100 kN wheel load for* a *short period to gauge the pavement strength. This procedure,* of *course, has the potential* of *affecting the pavement condition and thus the behaviour* of *the pavement under subsequent lighter wheel loads. However, each test with* a *specific wheel load is considered to deliver* a *unique* ***short term performance window****, associated with that particular pavement under specific test conditions. It is important to remember this when comparing the behaviour and performance of different sections and/or wheel loads with one another. Initially, the tests were done with the then current tyre pressures associated with heavy vehicle traffic. It was only later decided to alter the pressures after the difference in pavement behaviour associated with tyre pressure came to light during the HVS test on road* 1932.

Thus several 'performance windows' for each pavement using different loading conditions were examined. These also included watering the pavement to measure the effect of water inundation on the performance of different materials. Although such methods would make analysis quite complicated, this in itself would not prevent the studies being a useful addition to the database. The main problem arises because the report does not include sufficient details of the deterioration that took place during each 'performance window'.

Much of the performance information is simply not quantified at all. For example

> *'Initially the 70 kN load produced a more rapid rate of deformation than that observed under the 40 kN load, which levelled off to a slightly higher rate than that experienced with the 40 kN load ("the bedding in phase"), after which there was a sudden and marked downward displacement of the surface of the pavement. '*

There is one example (Figure 10) that shows deformation against traffic in equivalent standard axles illustrating the changes in the rate of deformation as the wheel load and watering conditions were

varied for each performance window. It is assumed that the original HVS study reports contain such information and details of the analyses that were carried out, but such information is largely absent from this summary report.

We conclude that with the lack of quantification of many aspects of performance and details of the actual pavements themselves, at the present time there is insufficient information to warrant inclusion in the database. Access to original reports of the 16 HVS tests sites may provide the missing information but any analysis would be inherently difficult because of the complex nature of the tests carried out. This, in itself does not disqualify the data from being included but the task of extracting it from the HVS study reports, assuming they are still available, would be prohibitive within this current project

Appendix C: Project Schedule