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

Phase 1 Final Report

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Abstract

The *Development of Guidelines and Specifications for Low Volume Sealed Roads (LVSR) through Back Analysis* project involves the review of previous LVSR studies on the design and performance of pavements and materials in a variety of environments. The project is in three Phases. Phase 1 involved the collection and processing of evidence relating to the performance of existing and previous LVSRs over the last forty years. This report provides a record of activities completed in Phase 1, comprising a preliminary gap analysis of long term pavement performance metrics following a review of existing data and identification of potential gaps in the knowledge base. The main activity during this phase was development of a Low Volume Roads (LVR) database containing data on LVSR sections in Sub-Saharan Africa and South East Asia that were collected over a number of decades, including aspects of their design, construction and maintenance that have influenced their in-service performance. Phase 1 of the project involved development of a research strategy for Phases 2 and 3 that will investigate the most significant data and knowledge gaps identified, and will undertake training and capacity building of regional researchers and practitioners in the use of the database.

Key words

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

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Michael Pinard	Consultant Expert	
Phil Paige-Green	Consultant Expert	

Acronyms, Units and Currencies

AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADB	Asian Development Bank
AFCAP	Africa Community Access Partnership
ARTReF	African Road and Transport Research Forum
ASCAP	Asia Community Access Partnership
ASTM	American Society for Testing and Materials
CBR	California Bearing Ratio
DCP	Dynamic Cone Penetrometer
GPS	Global Positioning System
HVS	Heavy Vehicle Simulator
LTPP	Long Term Pavement Performance
LVR	Low Volume Road
LVSR	Low Volume Sealed Road
MESA	Million Equivalent Standard Axles
MTPP	Medium Term Pavement Performance
ReCAP	Research for Community Access Partnership
RRST	Rural Road Surfacing Trials
SEACAP	South East Asian Community Access Programme
STPP	Short Term Pavement Performance
T2	Transportation Technology Transfer
TMH	Technical Methods for Highways
UK	United Kingdom (of Great Britain and Northern Ireland)
UKAid	United Kingdom Aid (Department for International Development, UK)
VPD	Vehicles Per Day

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1 Executive Summary

Research has shown that it is possible to improve sustainability in the provision and maintenance of low volume gravel roads by sealing the surface with a waterproof layer, usually comprising bitumen and stone chippings. The costs in life cycle terms can be much lower for such sealed roads where appropriate standards for low trafficked roads are used. The sealing of many low volume roads was initiated some years ago, and on some of these roads non-standard materials and designs were applied. Some of these roads have performed very well and lessons have been learnt as a result. The majority of the road networks in Africa are low volume, having annual average daily traffic of less than 300 vehicles per day (vpd). The cost effective sealing of these roads and provision of all-season access is paramount to the development of communities in Sub-Saharan Africa, where 63% of the population live in rural areas.[1]

This project involves the review of previous low volume sealed roads (LVSR) studies on the design and performance of pavements and materials in a variety of environments. The project is in three Phases. This report provides a record of activities completed in Phase 1, comprising a review of previous research on the design and performance of LVSRs over the last 40 years; development of a low volume roads database; selection of data from suitable research studies and population of the database; and review of the research and identification of potential gaps in the data and knowledge base. Finally, Phase 1 of the project involved development of a research strategy for Phases 2 and 3 that will investigate the most significant data and knowledge gaps identified.

The database has been developed on a web based platform and populated with data from twenty three historic studies, and has undergone testing by a pool of experts and other end users. The database was demonstrated to ReCAP member countries (11 from Africa and 2 from Asia) and representatives of the African Road and Transport Research Forum (ARTREF) at a workshop in April 2017, and the methodological approach for Phase 2 and 3 of the study was presented. The methodology outlined in this report sets out how we intend to populate the database further with data captured mainly from across the Sub-Saharan Africa region, to train practitioners on the use of the database, and how to interrogate the data within it. Once all the available data has been exhausted, and an in-depth gap analysis has been conducted, some field investigations on existing LVSRs in selected AfCAP countries may be undertaken to collect any missing data on condition performance from a design, construction, and maintenance perspective. The database will be populated with new data collected from the field to provide a comprehensive breadth and depth of knowledge on low volume roads to be provided for use as an open source archive for researchers.

The Low Volume Roads Database will be the first repository of its kind, containing data about LVSR sections on roads in Sub-Saharan Africa and South East Asia that was collected over a number of decades, and including aspects of their design, construction and maintenance that have influenced their in-service performance. The database will enable engineers and researchers to add new data collected from LVSR monitoring and use it to identify key factors associated with good or poor performance. Lessons learned from the database can then be used by recipient countries to update existing specifications or

[1] Rural population as a percentage of total population for Sub-Saharan Africa in 2014 (World Bank, 2016)

develop new documents to improve the quality of future LVSR design, construction and maintenance.

2 Introduction

The Development of Guidelines and Specifications for Low Volume Sealed Roads (LVSR)[2] through Back Analysis is a ReCAP regional research project seeking to provide a consolidated knowledge base related to the performance of LVSRs. This has been achieved through the development of a database for the capture of historic performance data on LVSRs over the past four decades in Sub-Saharan Africa and South East Asia. An important component of the project is to obtain performance data from a large sample of roads, especially roads that have been constructed using local and more readily available materials that do not meet the higher specifications that are applied to the construction of more heavily trafficked roads but are considerably less expensive.

This report describes activities undertaken in Phase 1 of the project. The report provides information on the purpose of the project, including the aims and objectives, the methodology, key activities and outputs, and the proposed approach for Phases 2 and 3.

In response to the challenges of providing sustainable rural access, African governments and international organisations have been searching for more cost effective methods of providing rural roads. In particular, there has been a focus on sealing rural roads in order to eliminate the need for regravelling and to reduce maintenance requirements over the life of the road. The sealing of low volume roads went against the conventional thinking that it is only economically viable to seal roads at relatively high traffic volumes (normally more than about 200 vehicles per day). However, this advice was based on conventional design standards for roads, including highly engineered road alignments and the use of high quality materials for the road pavements. Low volume sealed roads (LVSR) were often built using non-conventional standards using materials that did not meet conventional specifications. This enabled significant reductions in construction costs and competitive life cycle costs when compared with the gravel road option. For the most part these roads have performed well. Many are now more than 20 years old.

Research has shown that it is now economical in life cycle cost terms to seal roads with average annual daily traffic (AADT) of less than 200 vehicles, with the precise margin often being very much lower depending, amongst other things, on the availability of suitable materials. With this understanding came a paradigm shift in the approach to the design and construction of LVSRs. However, gaps in knowledge and data, and the inadequacy of technical tools for implementation emphasised the need for further research into the viability of LVSRs.

Phase 1 of the Back Analysis project involved the collection and processing of evidence relating to the performance of existing and previous LVSRs. The key output of Phase 1 is an initial database containing data about the performance of a reasonable sample of LVSR sections of roads in Sub-Saharan Africa and South East Asia that were collected over a number of decades, including aspects of their design, construction and maintenance that have influenced their in-service performance. The data should be of sufficient detail for users of the database to carry out additional analyses in future, possibly combined with new data. Thus, for each research project entered into the database during Phase 1, a basic set of information is required. An additional output from Phase 1 is an initial review of the database to identify gaps that could be filled from projects not yet included in the database

[2] Low volume roads (LVR) are defined as roads with average annual daily traffic (AADT) of <300 vehicles and cumulative traffic loading of not more than 1 million equivalent standard axles (where a standard axle weighs 80kN or 8 tonnes).

but which will be added during Phase 2. These outputs will shape the methodology for more data collection and entry into the LVR database in Phase 2 and fieldwork and further population of the database in Phase 3. This will be followed by analyses which will lead to revised guidelines and specifications for LVSRs covering a considerably wider range of conditions than hitherto.

The project began in April 2016 and Phase 1 culminated with the Final Report submitted in June 2017, based on discussions of the draft report at the stakeholder workshop of 4-6 April 2017 in Tanzania.

3 Research Objectives

The main aim of the overall project is to create a knowledge base on the performance of LVSRs, especially where non-conventional materials and designs have been used, and to capture existing and future information in a data repository. The database will form the main information resource for any future undertakings in the following areas:

1. Research – the database will provide the necessary historical data on the performance of LVSRs in different environments and conditions for use in future research work,
2. Design and construction of LVSRs – using performance based specifications,
3. Identification of knowledge gaps which will inform Phases 2 and 3 of the project and for the determination of any future research needs.

The objectives of this project are categorised into research, capacity building, knowledge exchange, uptake and embedment. The overall research objective is to undertake a review of the performance of LVSRs constructed in the last four decades in order to:

1. Create a database of performance specifications in relation to pavement design, pavement materials, and climatic conditions etc. and to use this information for the review and refinement of the specifications and guidelines for LVSRs,
2. To verify or refine catalogues which are currently being used in the design of LVSRs based on performance criteria,
3. To provide the basis for the use of non-conventional designs and materials on future projects in the provision of LVSRs.

4 Phase 1 Methodology

The methodology for Phase 1 of the project was focused on identifying and collating the wealth of research data on low volume sealed road sections obtained over many years and providing a database to store all the data in a suitable format to facilitate further analyses of their performance. However, many comprehensive studies were concerned with gravel roads and it was agreed that some of these would also be included. The following activities were undertaken to meet the objectives of Phase 1, and are described in more detail in Sections 5 to 10.

1) Identification of a pool of experts.
2) Desk study of potential data sources.
3) Workshops with pool of experts:
    (i) Identification and ranking of research projects.
    (ii) Assessment of suitability of projects for the database.
    (iii) Initial testing of draft database.
    (iv) Identifying ‘knowledge gaps’.

4) Development of the database and user manual.
5) Proposed methodology for Phases 2 and 3.

5 Pool of Experts

TRL engaged six key experts with an in-depth understanding and historical knowledge of LVSRs in all regions of Sub-Saharan Africa to support the project. Their tasks were primarily to identify and prioritise key research studies and datasets for inclusion in the database, to assist with a subsequent gap analysis, and to test and help improve the draft database. The pool of experts comprised the following low volume road practitioners, Table 5-1.

Table 5-1 List of Pool of Experts

Name	Organisation	Contact
Mike Pinard	InfraAfrica	mipinard@global.bw
Phil Page Green	Private Consultant	paigegreenconsult@gmail.com
Tony Greening	Private Consultant	tonyk.greening@sky.com
Gamalihle Sibanda	Private Consultant	gamasibanda@gmail.com
Frank Netterberg	Private Consultant	fnetterberg@absamail.co.za

Adekunle Olowosulu, a consultant from West Africa, was invited to be in the pool of experts, but was unable to join the team.

6 Summary of Desk Study Report

The performance of road pavements depends on many factors that differ from region to region, based primarily on soils, geology, materials and climate. As a result, the engineering knowledge is neither comprehensive, in full agreement, nor sufficiently well known throughout Africa. Indeed, there are some apparently contradictory results that undermine confidence in the data, but illustrate the difficult nature of road performance analysis and the need for the widest possible data set covering the full range of conditions.

Many good research projects have been carried out over the past years by research organisations. Road investigations and trials have also been carried out by road authorities, universities, individual engineers and others. These projects have been reported in different ways and different places and many are considered to be extremely valuable resources that need to be brought together and made available to all. However, not all such studies have equal merit or are equally accessible.

The purpose of this project has been to review these data sets and to 'capture' as much of this knowledge and the data on which it is based as possible. These data are to be made available to engineers, scientists and researchers to study, analyse and improve in the future and to enable comprehensive Regional Guidelines and Specifications to be updated for low volume roads, making use of all proven innovations.

The review of data sources identified numerous issues that need to be considered and dealt with. The principal issues are:

Data format. Electronic format is straightforward but data from various forms of hard copy sources are more difficult to extract and add to an electronic database. They require considerably more effort to such an extent that a classification system was developed based on the ease and resources necessary to prepare the data for entry into a database. Thus some data sources had to be rejected at this stage.

Data quality. There are very many data sources, but only scientifically 'sound' ones will be entered into the database. Initially the reliability of data sources largely depends on the credibility and reputation of the authors but care should be taken to scrutinise the data and a more quantifiable classification scheme was developed during the pilot phase of this project.

***Data content and compatibility*.** Compatibility between variables has to be obtained if data sources are to be combined and analysed together. Authors use variables that differ substantially but comparisons and combined analysis can only be done if the variables can be related to each other. The problem is compounded by the use of a variety of different test methods and standards.

Statistical problems. Although rarely discussed, statistical problems are surprisingly common in the analysis of road performance. Perhaps the most common problems are assigning an incorrect causative reason for a correlation and also the assumption of linearity when several key relationships are very non-linear.

***Good data sources and the Pilot Study*.** The selection and prioritisation of data sources is essential. It requires a good assessment of several aspects including scientific quality, amount of data, range and scope, and ease of preparation for entry into the database. A marking/ranking scheme that takes account of all of these issues was developed and used to identify the best data sources. Forty examples of good data sources were initially identified. At the first workshop of the expert pool, more studies were added and a selection was made for a Pilot stage for the project to test the methodology developed so far. For the Pilot stage 15 data sources were selected but this included several detailed country studies that were later defined as separate studies because of their range and scope hence the final total was 23 sources of data.

The desk study is more fully described in Annex A.

7 Workshops with Expert Pool

Workshops with the expert pool and other interested parties were held at CSIR in Pretoria on 26th and 27th September 2016 and on 6th February 2017. The workshops are described in detail in Annexes B and C.

The main issues debated at the first workshop were those that were identified during the desk study (see Annex A). Additional research studies were also suggested by the expert group followed by a detailed discussion about each of the research studies with the objective of classifying them all and selecting the best options for initial entry into the database as part of the Pilot stage.

The second workshop is described in detail in Annex C. There were three main issues for the workshop:

- Feedback on testing the draft database and identifying initial problems,
- Further discussion about potential studies for inclusion,
- Identifying knowledge gaps that could form future research projects.

The knowledge gaps are summarised in Section 9.

The database is briefly described in Section 10.

8 Summary of Projects Entered into the Database

The projects are listed in Table 8-1 and further details for each are shown in Annex D.

Table 8-1 List of Existing Projects Proposed by the Pool of Experts

	Country	Project/ Report	Authors	No. of sections	Format
1	Botswana, Malawi, Zimbabwe	Performance of Low Volume Sealed Roads: Results and Recommendations from Studies in Southern Africa	C Gourley, P A K Greening (TRL)	55	Digital
2	RSA	LVR performance study-paved	P Paige Green (CSIR)	54	Digital
3	RSA and Namibia	LVR performance study - Unpaved	P Paige Green (CSIR)	110	Digital
4	Vietnam, Cambodia, Laos	SEACAP – RRSR (Rural Road Surfacing Research)	TRL/OTB/Intech Assoc. (J Cook, J Rolt, R Petts)	140+	Digital
5	Botswana	Calcrete in Road Bases in the Kalahari Region of Southern Africa	P A K Greening, J Rolt (TRL)	8	Hard copy
6	Botswana	The Nata Base Course Experiment	Botswana Road Dept, CSIR, F Netterberg	8	PDF
7	Botswana	The Jwaneng Sand/Asphalt Experiment	Botswana Road Dept, CSIR, F Netterberg	23	PDF
8	Zimbabwe	Secondary and Feeder Roads Development Programme Phase 1 - Gravel	U Brudefors, G, Sibanda, DSR, SweRoad.	27	Hard copy and Digital
9	Zimbabwe	Secondary and Feeder Roads Development Programme Phase 1 Sealed	U Brudefors, G, Sibanda, DSR, SweRoad.	15	Hard copy and digital
10	Ethiopia	Performance Criteria and Life-Cycle Costing for LV and Labour-based Unpaved Roads	K Mukura, P A K Greening, G Morosiuk, R Bennett (TRL with ILO)	24	Digital
11	Ghana	Engineering Standards for unpaved roads	K Mukura, P A K Greening, G Morosiuk) (TRL with ILO).	24	Digital
12	Mozambique			24	Digital
13	Zimbabwe			31	Digital
14	Lesotho			23	Digital
15	Uganda	Increased Application of Labour-based methods for LVRs	K Mukura, P A K Greening, G Morosiuk) TRL with ILO	8	Digital
16	Botswana	Botswana Pavement Monitoring Sections	CPP, InfraAfrica, Haas Consult, P Page-Green, CSIR.	23	Digital
17	Mozambique	Back Analysis of Previously Constructed Low Volume Rural Roads in Mozambique	K Mukura, J Rolt, F Dangare, A Otto (TRL)	24	Digital
18	Jamaica	The Performance of a Full Scale Road Pavement Design Experiment in Jamaica.	J Rolt, H Smith, C Jones (TRL)	8	Hard copy

19	Zambia, Zimbabwe	Performances of Chemically Stabilised Roadbases: Results and Recommendations from Studies in Southern Africa	C S Gourley and P A K Greening (TRL)	31	Digital
20	Zimbabwe	Secondary and Feeder Roads Development Programme Phase 2 - Gravel	U Brudefors, G Sibanda, DSR, Sweroads	21	Hard copy and digital
21	Zimbabwe	Secondary and Feeder Roads Development Programme Phase 2 - Sealed	U Brudefors, G Sibanda, DSR, Sweroads	34	Hard copy and digital
22	Botswana	Monitoring of Sealed Low Traffic Roads in Botswana	C Overby and Botswana Roads Dept.	27	Digital
23	Botswana	Monitoring of Sealed Low Traffic Roads in Botswana	C Overby and Botswana Roads Dept.	19	Digital

9 Preliminary Gap Analysis

The process of identifying gaps is essentially part of the continuing process of planning the phases of the project. A methodology needs to be developed that will make this a routine activity in the future, therefore this chapter is concerned with the development of such a method. The first step is to define the type of 'gap' that we are concerned with.

9.1 Data Gaps Identified in the Database Projects

The current database is based on the data which was entered from 23 priority projects. A review of these data indicated a number of critical issues that are discussed in the following sections and summarised in Table 9-1 and 9-2.

9.1.1 Gap Type 1

The initial task was to examine the data critically and to identify aspects that limit the range of analyses that can be carried out. These have been called 'gaps' in the existing database and it is hoped that most, if not all, of these gaps can be filled.

The number and type of analyses that could be undertaken with the database is potentially large and diverse. It is almost impossible to anticipate everything that a researcher might want to study about LVSRs and therefore it is impossible to cater for all possible analyses. Indeed, to do so would require every possible variable to be identified and included.

Therefore an important task was to identify a *basic* set of variables that will *always* be required in order to be able to analyse road performance data with a view to improving and extending specifications. It is the presence or absence of items in this basic set that define the gaps of this type that need to be filled. Table 9-1, for each project, includes about 50 variables that comprise the basic set.

The period of monitoring is classified as follows:

1. BA - simple back analysis based on one survey
2. STPP – Short term pavement performance (0-10 years)
3. MTPP – medium term pavement performance (10-15 years)
4. LTPP – Long term pavement performance (15-20 years)

It will be noted from Table 9-2 that of the 14 sealed road projects, only 4 are classed as true LTPPs and 3 are essentially back analysis projects with only one survey. The other seven are either STPPs or MTPPs (some projects contain a range of monitoring periods).

The database also contains 9 projects concerned with unsealed roads. These do not usually contain the same 'gaps' as those for sealed roads and the basic set of variables is slightly smaller.

The Table can now be completed for each project in the database and data gaps identified.

Table 9-1 Basic Data Set for Sealed Roads

1	Country	
2	Project Title	
3	Author(s)	
4	Type of study (BA, STPP, MTPP, LTPP)	
5	Sealed or Gravel	
6	Summary	
7	Number of roads	
8	Number of test sections	
9	Total traffic (mesa):)	
10	Age of road	
11	Year of re-construction/reseal	
12	Duration of monitoring period	
13	Dates of condition surveys	
14	Total traffic (mesa)	
15	Composition of traffic (% heavy trucks) Direction 1	
16	Direction 2	
17	Rainfall (mm/year)	
18	Climate factor N or Thornthwaite	
	Surfacing Material Properties	
19	Type	
20	Thickness	
21	Strength	
	Roadbase properties	
22	Type	
23	Thickness	
24	Strength wet	
25	In situ strength	
	Sub-base properties	
26	Type	
27	Thickness	
28	Strength wet	
29	In situ strength	
	Subgrade properties	
30	Type	
31	Thickness	
32	Strength wet	
33	In situ strength	
	Construction Details	

34	Carriageway width	
35	Shoulder sealed or not	
36	Shoulder width	
37	Gradient	
38	Crossfall	
39	Crown height above drain invert	
40	Drain depth	
	Deterioration Parameters	
41	Are all chainages recorded?	
42	Cracking	
43	Roughness	
44	Rut depth (mm)	
45	Rut depth range (10 and 90 percentiles)	
46	Deflections (wet season)	
47	Deflections (dry season)	
48	Moisture profiles across road	
	Test methods	
49		

A similar Table has been developed for unpaved roads but with slightly different variables.

9.1.2 Gap Type 2

The amount of data currently included in the database, despite the size and scope of the projects, is only a small part of the data that should be available and therefore a second form of 'gap' are gaps in the range of the data currently included. For example, more extreme climatic conditions, different types of roadbuilding materials and so on. Many gaps of this type can be filled by identifying sources of suitable data, obtaining the data and adding to the database. This is part of Phase 2, hence a full gap analysis cannot be completed until later. However, a running record of the characteristics of the projects as they are entered into the database is essentially a 'live' 'contents' analysis. Since the range of conditions required is essentially known, then so are the remaining gaps.

9.1.3 Gap Type 3

Finally there will be some conditions/materials for which no data currently exists. Identifying these is very useful, but obtaining data on these topics requires active research. The scale and scope of such research cannot be defined at this stage, but the topics will provide a starting point for future research activities, some of which may form part of Phase 3 in collaboration with research centres in the region.

9.1.4 Defining Road 'Life' and Performance

The performance of a road cannot be defined in terms of traffic carrying capacity or time, or indeed anything else, unless the road has deteriorated to a measurable extent sufficient for its effective 'life' to be defined. This does not require complete failure, only a performance percentile related to reliability; 5% of the road length having reached a defined failure criterion is probably the smallest measurable level. However, to prove that a road has performed adequately it is necessary for it to have deteriorated to this level (or more) after 12 or 15 years and after carrying sufficient traffic. If these two conditions are not met then it is not possible to say much about defining more appropriate specifications. Only if failure has occurred can a deduction about acceptable or unacceptable specifications be made. However, if it has not failed or deteriorated after 12-15 years we can certainly say that its

performance is acceptable, even though we cannot determine if the design is conservative and, if so, by how much.

Any failures before 10 years are considered very premature. This is incomplete information that is useful for helping to define inappropriate specifications, but not for defining suitable ones very accurately.

9.1.5 Pavement Loading

Traffic growth is usually exponential, or nearly so, hence the traffic loading for which a road was designed is approached much more rapidly towards the end of the design life period than at any other time (see Figure 9-1). For example, at a 5% growth rate, 33% of the total cumulative traffic loading occurs in the last 5 years, compared with only 18% in the first 5 years. Therefore, it is only towards the latter years of the design life that it is expected that traffic induced deterioration will be manifest. Without observing and measuring this it will not be possible to deduce anything about improved specifications. Therefore a realistic target for monitoring needs to exceed 10 years and preferably 12 years, hence any monitoring period that does not exceed 10 years is technically inadequate.

However, this data gap can be filled for several of the projects because a further site visit to collect performance data should provide evidence of performance over a much longer time span. The risk is that the roads may not have performed well enough and may have been rehabilitated or received major maintenance. However this should not pose a problem because maintenance and rehabilitation data (if rehabilitation was required) should also be available, so the dates will be known. Since nobody does such major repairs unless the road has failed, knowledge of its 'life' is also available. It is therefore recommended that further surveys be carried out on these projects to turn them into LTPPs.

It can also be valuable to revisit some of the 'one-time-only' back-analysis projects. Considerable data are already available about the materials used and the structural designs. After several more years, surveying again those that were performing well during the original research should provide some valuable new data for relatively little effort, especially if some of those sites are now showing differential performance.

Table 9-12 Summary of Current Sealed Road Project in the Database

#	Author(s)	Work Title	Age of road(s)/ Section(s) at termination of monitoring (Years)	Traffic carried up to termination of monitoring or to date (MESA)	Span of continuous monitoring period (Years)	Comments/Remarks
1	Gourley and Greening	Performance of Low Volume Sealed Roads: Results and Recommendations from Studies in Southern Africa	<5 (Zimbabwe Sections) 5-20 (Botswana and Malawi Sections)	Zimbabwe: all 14 sites <0.1 Malawi: 4 sites 0.7-1.0, 7 sites <0.7 Botswana: all 7 sites <0.3	One off/Back analysis	Zimbabwe traffic loading is low. Traffic loading covers all low, medium and high (very few sites (4) in the high traffic category. The report indicated that base CBR of 80 could be relaxed if more sites in the high traffic loading category were investigated.
2	Paige-Green	The Evaluation of Marginal Base Course Materials in Low Volume Roads	>10	<0.1 (9 sites) 0.3-0.5 (2 sites)	One off Back analysis	Low to medium traffic loading (very few sites in medium traffic)
4	Cook	SEACAP	To be added	<0.04 for most sites 0.52*	<5 STPP/MTPP	Traffic loading is low Not Africa Region
5	Greening and Rolt	Calcrete In Roadbases In The Kalahari Region	15	0.45	(LTPP)	Defines specifications for using calcretes (broken down into 4 classes)
6	Netterberg	Nata Calcrete Base Course Experiment	10+	0.5	10 LTPP	Only one road and one set of in-service conditions investigated. Trial sections very short (100m). Data are useful in evaluating performance of calcrete bases.
7	Netterberg	Kanye-Jwaneng: Sand Asphalt and Calcrete Base Course Experiment	13	0.16	7 LTPP	Traffic is very low
9	Brudefors and Sibanda	SFRDP	2-16	<0.1	3 STPP	Traffic loading is very low
17	Rolt, Mukura, Dangare, Otto	Back Analysis of Previously Constructed Low Volume Rural Roads in Mozambique	10-40	0.3-2.7	One off Back analysis	Data is useful in determining upper limit of specifications in the Mozambique conditions.
18	Rolt	Road Pavement Design Experiment in Jamaica	4	1.3-4.3	4 STPP	These are high volume roads but the data is useful in determining upper limits of specifications. Pavement: 50mm AC, Limestone base (CTB and neat), subbase and subgrade.

19	C S Gourley and P A K Greening	Performance of Chemically Stabilised Roadbases in Zambia and Zimbabwe			One off back analysis	
21	DSR, SweRoad Report,	SFRDP Sealed Phase 2 (Zimbabwe)			STPP	
22	Charles Overby	Monitoring of Sealed Low Traffic Roads (Oodi-Modipane Road, Selebi Phikwe-Mmadinare Road, Sebina-Tutume road)	11	<0.2	8 STPP/MTPP	Traffic is very low
23	Charles Overby	Monitoring of Sealed Low Traffic Roads (Sehitwa-Tsau road)	11	0.19	8 MTPP	Traffic is very low

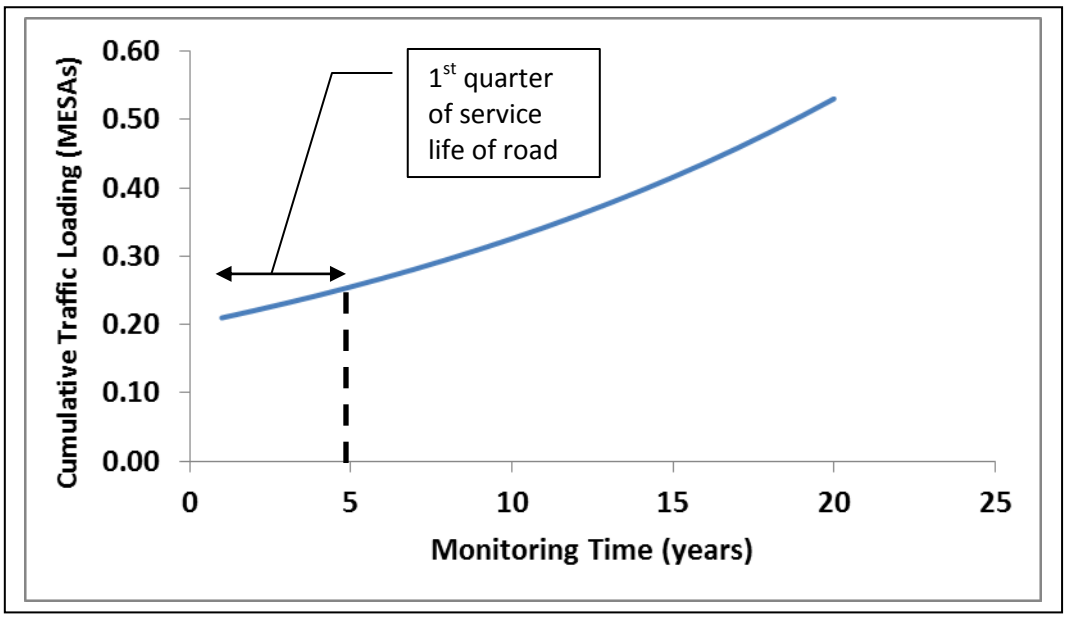


Figure 9-1 Illustrating the Importance of Traffic in the Later Years of a Road's Design Life when Growth has Significantly Increased the level of Annual Traffic

10 The Database and User Manual

The Low Volume Roads (LVR) database holds data from a wide variety of scientific research on LVRs in one place. Users can input and access data online or analyse and review data externally by creating exportable reports.

10.1 Attributes of the Database

The database has been under continuous development since data have been available for input from September 2016. The database is now 'live' for all team members and the expert pool for testing. Initial feedback is very favourable and minor improvements have been made following the stakeholder workshop, held in Dar es Salaam in April 2017, and also following detailed testing.

The user manual is accessed from the 'help' button on the database home screen.

The database structure is designed to be very flexible and accept an unlimited amount of data types. This will allow for a wide variety of data sources to be held by the database both presently and in the future. This is achieved by using separate tables to store data types and using relationships to link stored data to its data type. This approach allows for new data types to be added without having to alter the database architecture to add a new field.

The front end of the database is portrayed through a website interface. This was chosen as it allows the database to run at one central location. All users will view the same version of the database and it requires no software installation on the client computer. All that is required to access the database is an internet connection and web browser. A further advantage of this approach is that updates will be rolled out to all users simultaneously.

The database requires a user account to use. There are four user access levels which provide different level of privileges ranging from read only to full edit and delete ability. The majority of users will be read only; fewer with input ability and even fewer with edit and delete abilities.

Reports can be exported from the database by all users. This function is controlled by 6 filters to narrow data selection. The filters adjust dynamically in a downwards direction through SQL queries to show only options available with the current selection. The filters create a dynamic SQL query that returns the desired results to a table. This table can then be exported to either Excel or CSV format. This will allow for further analysis on a wide variety of data to take place.

Users with the appropriate authorisation level can add, edit or delete data from the database. There are multiple validation checks carried out before data is accepted to ensure quality is high. This includes each data type having an expected format (e.g. text, numerical) attached to it. This means when new data is entered against a data type it must match the expected format to be successfully entered. As an additional safety precaution, deleted data is not removed from the database. Each data has an active flag which is switched to inactive on deletion, but can be reinstated easily if needed.

10.2 Feedback from the Tanzania Stakeholder Workshop

A stakeholder workshop was held in Tanzania from the 4th to the 6th of April 2017. The following is a summary of the feedback from stakeholders.

10.2.1 Feedback on the Database

1. The LVR database is fully functional and the stakeholders were comfortable navigating and extracting data after a demonstration workshop.
2. There were AfCAP partner countries willing to contribute data to the population of the database, including DRC, Kenya, Ghana, Uganda, etc.
    (i) Uganda is currently aggregating research data and information of past research work and these would be available for the LVR database.

(ii) There is also a possible source of information from Nigeria on 'Engineering Properties of Subgrade Soils'.

(iii) DRC has data dating back decades which could be explored.

(iv) InfraAfrica has data from Malawi which can be included in the database.

3. The ongoing performance monitoring projects under AfCAP are a good source of data for the database.
4. In some cases obtaining data would require some form of permission to ensure compliance with intellectual property rights and copyright.
5. Sources of data to be included in the database and this would be vital for future reference.
6. It was suggested that mapping visualisation or GPS information should also be included in the database where possible.
7. Some of the comments relating to the use of the database include the following:

(i) There is need for capability in the architecture of the database to do a named search.

(ii) It was hard to keep track of the searches in the various layers of data and it would be good if the database could do the tracking and have a window which shows the information to the user.

(iii) There is need to specify the table which is required during querying and exportation of data from the database. There is also need to include right click to obtain additional information which should be in the background.

(iv) There should be capability to sort the data in alphabetical or other logical order.

(v) Basic data which will more commonly be required by users should be included in the database e.g. Atterberg limits should include LL, PL and PI not only LL or PI and LL only.

(vi) There is need for source code i.e. where the materials which were tested or investigated came from.

(vii) There is need to set up standard queries to assist the users and/or flexibility in the report design templates.

(viii) Creating a bulk upload tool for data.

The following updates to the website have been made since the workshop:

1. Amended some of text labels based on feedback from experts and users,
2. Allowing reviewers to more easily locate and access attachments,
3. Update to layout of reports page,
4. Including a record for user data downloads in the audit log,
5. Ability to delete user accounts from database,
6. Allowing Administrators to reset passwords,
7. Adding Terms and Conditions for use of downloaded data,
8. Checking functionality on Android devices.

Some of the more comprehensive updates (e.g. including GIS functionality, creating a bulk upload data tool, creating custom report templates) should be reviewed in Phase 2 to understand the effort required and if they should be incorporated into the website.

10.2.2 Feedback on the Gap Analysis

The following key issues were raised:

1. There is a need to get data on durability of surfacings in different situations, as this is a major gap.
2. The impact of tyre pressure on the performance of LVRs is largely unknown; this is important.
3. The significance of a road maintenance strategy or regime on the performance of LVRs is also largely unknown and maintenance data should be included in the database.
4. As-built data is important in evaluating the performance of LVRs and such data should be included in the database.
5. Swell information is also lacking in most projects; it is important to collect such information for the database.

Item 1 is a key deterioration parameter and is included in several of the projects in the database. Some of these issues are basically concerned with information that can probably only be obtained from new research, a research review or untapped project sources because the data will not be available from the projects already included. If such projects exist and can be identified and are of satisfactory quality, they will certainly be added to the database in Phase 2. Other Items are examples of information that is undoubtedly useful for some types of analysis. These topics can be added to the basic data set in order to encourage researchers to include them in their studies, but it is not something that can be made mandatory. Such data can always be added to any new project if the researcher wishes to do so. As stated above, there are many aspects of road performance that a database user might want to study and so there may be particular items of data that are not usually available that may prevent the particular study from being possible, but this project can only recommend a basic data set and cannot control what is actually done by the researchers themselves.

11 Proposed Approach for Phase 2 and 3

11.1 Rationale

Phase 2 of this project is a continuation of work started in Phase 1. While good progress was achieved during Phase 1, much data remains to be identified, procured, evaluated and added to the database, and, with this, more data and knowledge gaps may be filled. Thus Phase 2 will predominantly cover the identification and review of more data sources for prioritisation, and once approved, the data from these sources will be added to the database. The database will remain as a live repository for the foreseeable future.

Researchers using the database will notice data gaps, hence at a certain level gap analysis will be a continuous process. However, when substantial data have been entered during Phase 2 a comprehensive gap analysis will be carried out and a listing of gaps prepared. The gaps will then be reviewed to assess how they can be filled. There are several ways that this can be done, differentiated primarily by the scale of the work required. This will entail identifying:

1) Research already carried out and published that can be added to the database.

2) Additional data that can be readily obtained to enhance existing projects. Simply extending the period of performance monitoring is likely to be the most common method. It is important to recognise that additional data collection should include both failed or failing sections and also sections exhibiting good long term performance.
3) Research projects that could be included in the ReCAP programme.

The gaps will need to be prioritised based on peer review and technical assessment.

The dissemination of all the information and opportunities for research using the database shall be the key outputs of Phase 3, described in detail below.

11.2 Review of the Terms of Reference

The initial ToR described three phases:

Phase 1

1) Identification of a pool of experts with knowledge of historic data that will be critical to the population of the database. A pool of six (6) experts should be assumed.
2) Conduct an extensive desk review (in consultation with the pool of experts) of previous relevant research work done in Sub-Saharan Africa and elsewhere in order to identify and highlight knowledge gaps and further inform the fieldwork component of the assignment.
3) Design the framework for an appropriate database to collate and manage LVSR performance, materials and design. The structure of this database should be compatible with other similar repositories in other countries or regions (for example the SEACAP RRSR database)
4) Populate the database with data-sets on relevant sections that have previously been investigated to capture and manage the data. Specialist inputs from individuals and organisations involved in historic investigations will be required during this phase to populate the database.
5) Gap analysis to identify the data sets to be collected in Phase 2 and define procedures for collecting and managing this data in formats suitable for statistical analysis and inclusion in the database. These data sets should include but not limited to:
    a) Section location (GIS coordinates)
    b) Traffic counts
    c) Road geometry (carriageway width, shoulders, gradient)
    d) Visual survey of potholes, cracking, rutting, drainage)
    e) Rut depth measurements
    f) Roughness
    g) DCP measurements, where appropriate
    h) Deflection measurements
    i) In-situ densities and moisture content
    j) Classification of road pavement materials (laboratory testing)
    k) Specialised testing of pavement materials as required
    l) Analysis of the surfacing seals (binder and aggregate properties)
    m) Indicative costs.
6) Identify and recommend geographic areas to be included in phase 2. The final selection must reflect, as far as possible, the regional extremes of climatic factors, terrain, soils, traffic, and road agency capacity. The selection of study areas should also include a wide range of surfacing types, on existing LVSRs built prior to the start of AFCAP in 2008. It is expected that at least four different AFCAP countries will

participate in the study. The selection of countries is subject to approval by the Client.

7) Identify and recommend appropriate road sections within each selected geographical area for detailed study. It is expected that a total of 30 road sections will be included in the study. The selected sections should include a range of existing road condition (good to poor).
8) Establish collaboration agreements with the appropriate road agency/authority in each of the selected study areas with assistance from and approval by the AFCAP PMU.
9) Prepare a detailed methodology and budget for the implementation of phases 2 and 3 of the project for presentation and review at a stakeholder workshop leading to a final report for phase 1 for approval during the interim project review.
10) Prepare a scientific paper for publication in an approved scientific/engineering journal of high international standing.

Table 11-1 Summary of Phase 1

Item	Comments
1	Completed
2	Completed
3	Completed
4	Completed. • While the original ToR focussed on the LVSRs, data on unpaved roads was also obtained and entered into the database, hence the database was developed for all LVRs (i.e. paved and unpaved). • Acquisition and processing of the data proved to be a challenge more than was previously envisaged. Most of the data were not in electronic format and digitising such data was time consuming.
5	A basic set of variables has been defined that is similar, but not identical, to that listed in the ToR. In particular, very few existing studies include items (a) and (m). Where data is missing (gaps), filling some of them for completed projects may be impossible. However, one of the most important gaps is often a result of project duration and therefore revisiting some of the project roads and obtaining additional condition data after a further period of time ought to be valuable for some projects.
6	Four countries have been proposed and informal contacts established with local participants. Final selection requires country visits which will take place early in Phase 2.
7	The scope of this item has been reduced during project discussions. Full back analysis studies are not now contemplated. The field work will essentially comprise adding longer term performance data to existing projects.
8	Initial informal contact has been made.
9	Completed.
10	Postponed at this stage.

Phase 2

1) Establish research teams in each of the research areas with capability to collect reliable data in a consistent format; it is expected that these teams will be constituted and managed by the successful bidder and comprise personnel from

local organisations including road authority research units, materials testing laboratories (private and government), universities and consultants.

2) Collect all relevant existing data on the road sections including design and construction details, maintenance interventions, historical traffic counts, rainfall and other relevant road environment data; and ensure the consistency and quality of the data collected.
3) Collect new data on the selected sections in the dry and wet seasons (where appropriate).
4) Populate the database with raw data and make it available through the ReCAP web site.
5) Undertake an initial review of the data to ensure data quality and consistency of format.
6) Analyse the data to draw conclusions relevant to the design and maintenance of pavements and seals for LVSRs.
7) Review the identified design tools and catalogues and make recommendations for any modifications based on the analysis of the project data.
8) Review existing guidelines for the selection of surfacing seals and make recommendations on revisions to existing guidelines that would incorporate the full range of key performance factors observed under the study.

Phase 3

1) Conduct a comprehensive knowledge exchange and dissemination programme that targets key stakeholders and is aimed at ensuring outcome uptake and embedment. Succinct and clear summaries of project outcomes should be prepared aimed at a range of levels from central ministry to practising engineers at district or similar level.
2) Conduct a two day workshop in each of the participating countries to discuss the findings of the study and to achieve consensus from participants on the recommendations. Participation in the workshops must include local technical experts from the government and private sector, as well as representatives of AFCAP member countries not included in the study and invited international experts who were not part of the study team.
3) Ensure that the responsibility for the ongoing management and population of the database is vested in an appropriate Sub-Saharan regional organisation. This will include the development and scoping of a suitable training programme in association with that organisation. Funding of the training will be outside the scope of this project.
4) Present papers summarising the findings and recommendations to at least two relevant international conferences.
5) Prepare at least one technical paper for publication in an approved scientific/engineering journal of high international standing.

11.3 Modifications to Phase 2

As a result of the execution of Phase 1 and the issues that arose, modifications and additions to Phases 2 and 3 are proposed:

1. Phase 2 shall predominantly involve:

   (i) The identification of data sources, acquisition of the data and information from AfCAP and SEACAP partner countries and beyond.

(ii) Training and capacity building of the research entities (RRCs et al) so that they can undertake appropriate field work to populate the database.

(iii) Develop an exit strategy for ensuring that the future of the database is sustainable. A suitable host institution is required and agreement needs to be reached as early as possible.

(iv) Further population of the database and any additional or continual improvements of its architecture.

(v) A more detailed gap analysis.

(vi) Recommendations for Phase 3.

(vii) Reporting.

2. Phase 3 shall involve:

(i) Fieldwork – this will be discussed and agreed depending on the outcome of Phase 2. The fieldwork will however be targeted at filling specific gaps in the data and knowledge.

(ii) Further population of the database with data and information from the field and laboratory investigations.

(iii) Analysis – the depth of analysis shall be subject to availability of resources.

(iv) Dissemination – the outputs of the project shall be disseminated to practitioners and decision makers through different platforms such as technical papers published in journals, web-based platforms such as the ReCAP website, presentation in international workshops, etc.

More details are provided in the proposed methodology below. For costing purposes it is assumed that there will be field work under Phase 3 but more effort is required in populating the database under Phase 2. However, should it become clear that the data are not as forthcoming as is currently envisaged and that it would be beneficial to collect data through fieldwork, a review will be made and fieldwork may be initiated under Phase 2.

11.4 Methodological Approach

It is evident from the scope of the project that both Phase 2 and Phase 3 are predominantly collaborative undertakings which will involve the participation of several parties in order to ensure success. In addition, obtaining the desired outputs requires high level research expertise – analysing complex data correctly is not a simple exercise.

The approach in delivering this project will therefore include the following:

1. Coordination – the success of the project depends on effective coordination of all the parties who will be involved in the project. The participation of local RRCs and road authorities is vital for obtaining data from existing sources, conducting field surveys (and laboratory investigations if necessary), reviewing outputs by experts, etc. Collaborative agreements are necessary to achieve this.
2. Awareness – awareness among participating parties of the benefits of the project, and future ownership of the outputs is necessary in order to ensure buy-in.
3. In-depth review of previous work – this is important for all research but in the case of the continuation of research it is particularly important to understand the achievements and problems which were encountered during the execution of the

project under Phase 1 because the problems may not be fully resolved and adjustments may need to be made.

4. Training and capacity building - one of the key objectives of the project is training and capacity building. The approach shall include formal training in seminars and one-to-one training on the use of the database. It is important that the knowledge of how to carry out field and laboratory investigations to the required research standard and the associated quality assurance is imparted to the research centres and road authorities in order for them to be able to partake in Phase 2 and 3 activities such as populating the LVR database and to continue with the investigations to the same standard after the project is completed.
5. Knowledge exchange - this project requires knowledge exchange as well as knowledge transfer because some of the information required will be supplied by local practitioners who have accumulated local experience over many years. On the other hand the project team will bring the necessary research experience to the project.
6. Development of new knowledge – This is in line with the mandate to fill both data and knowledge gaps.
7. Dissemination – the outputs at interim and final levels will be disseminated through the web-based database, on the live ReCAP website, scheduled workshops and distribution of reports among a variety of options.
8. Local ownership – this is one of the key indicators of success in such an undertaking. This will include local ownership of the database, the research outputs and the processes. To achieve this, the project team will work together with all parties who will be involved in the project, especially with whomsoever finally agrees to take responsibility for managing the database in the future, so that they are part to the delivery of the project and hence will take ownership of the outputs.
9. Preparation of a scientific paper for journal publication – this is one of the key outputs and will help to develop the confidence required for future use of the database and the recommendations and information which will be contained in the research report. Ideally this paper will contain an example of a detailed analysis of road performance using data from more than one source in the database to demonstrate the power of such a concentration of data but it is currently too early to identify a specific project.

11.5 Proposed Phase 2 Methodology

The project will be delivered through the tasks described in Section 11.5.1.

11.5.1 Population of the database

Task 1: Preparation of updated schedule of activities and launch meeting

An updated schedule of activities shall be prepared to reflect the key activities and the timing of deliverables. A launch meeting involving the project team and ReCAP PMU will be held to finalise the key strategies, key activities and outputs including any modifications to the proposed methodology including the final selection of other existing data sources and countries which will participate in any investigations.

Task 2: Consultation with entities with potential data sources

During the first workshop held in Phase 1 approximately 70 projects were identified. Out of these 23 have been processed and data from these projects have been entered into the database. Only a few of the remaining projects have been rejected. The other remaining projects shall be considered and consultations made with entities and individuals who may have access to the data in order to verify its status and to obtain it if it is deemed appropriate and available for open access.

Consultations will also be made with AfCAP in order to be able to obtain data which is being collected on ongoing monitoring projects. These will be among the first data sets to be collected under Phase 2. Firstly, contacts and liaisons will be made through AfCAP to obtain information on the nature of the data which is being obtained from these projects. A draft format will be developed preferably in excel and this will be accompanied by a questionnaire which will provide the necessary information on the data required from them. The draft format is necessary to standardise data compilation from the different AfCAP countries for ease of entry into the LVR database.

Task 3: Review of the preliminary gap analysis

The preliminary gap analysis will also be reviewed in the light of the discussions, strategies and agreements arrived at during the launch meeting to refine the research work to be undertaken. Key gaps (Types 1 and 2, described above) will be addressed to make the database more complete. This includes:

1. The age of the roads. More than 80% of the projects involve very short monitoring periods i.e. up to five years. Only one involved 11 years of monitoring. It is important to deal with this gap in the data and to fill it.
2. Defining the minimum data requirements. The task is to identify a basic set of variables that will always be required if road performance data is to be analysed with a view to improving and extending specifications. It is the presence or absence of items in this basic set that defines the gaps of this type that need to be filled. A draft has already been prepared, but one or two additional items can be added after debate amongst the project team.
3. The review will also identify other data that are thought to be available but are currently missing; this will help in the development of strategies to obtain such data. This does not guarantee that such gaps can be filled quickly but to be aware of the gaps can help when collaborating with potential data providers and may often help to identify supplementary data that may be of use.
4. Identifying gaps in knowledge and in the database will be a continuous process that will feed into populating the database but also identify potential research projects for the future.

Task 4: Training and capacity building

Phase 2 of the project presents an opportunity for building knowledge and capacity of the intended users of the database. The main tasks of Phase 2 include data collection, collation and entry into the database. The participation of the RRCs, road authorities particularly their research departments will play a major role in delivering the project activities stated above. There are also individual researchers who may have access to data and may be willing to participate in the processes.

It is important to ensure that these entities and individuals are properly trained and are able to navigate and enter data into the database. While TRL takes the overall responsibility of populating the database the participation of the RRCs and other entities in the process will ensure hands-on training. The training shall be tailor-made to develop capacity in AfCAP countries and the intended host of the LVR database to partake in the Phase 2 and 3, including the post project period after the database is officially handed over. The training shall be both technical and operational. Seminars and workshops shall be held at regional level in the three regions i.e. West Africa, East Africa and Southern Africa. It is proposed to hold the training workshops in Ghana, Uganda and Mozambique. It is anticipated that at least two participants will be selected to attend the training from each RRC and AfCAP countries in each Region. It is expected that each workshop will last two days.

The training will include:

1. Data collection and processing - this will include the identification of data sources, verification of the quality of the data, collation and general organisation of the data into the formats which are compatible with the database.
2. Architecture and functions of the database – this will include training on the parameters which are covered in the database and the different layers of data and information. This will also include navigation through the database and querying mechanisms.
3. Data entry – it is important to monitor and supervise data entry into the database in order to maintain the required oversight and credibility of the database going forward. There will be limited rights for editing data in the database but all participants will be trained on how to create data fields, data sets and enter the data.
4. Generation of reports and data exportation – most if not all who may be interested in the LVR data will have full rights to access and extract data from the database hence there will be no restrictions in this area. Training shall be carried out in this through a hands-on practical approach.

In addition, plans and actions need to be put into place so that the database project is sustainable in the future. This will mean that responsibility for future training will need to be passed to others.

Task 5: Collection of data and reports for quality review

The associated reports and data from the projects identified in Tasks 2 and 3 shall be collected. A thorough review shall be carried out to ensure that the data is appropriate for inclusion in the database. This process is necessary in order to eliminate any obvious typing errors and to flag up any data which may be questionable, so that future users of the database may be made aware of the review that was carried out during the development of the database.

The intended purpose of each study has a bearing on the nature of the data that was collected and this information needs to be understood and documented. The assumptions and presumptions, including hypotheses taken into account, also need to be captured. To achieve this abstracts will be prepared as was done for many of the projects in Phase 1, specifying among other information; test methods and standards used, statistical significance and accomplishments or results of the study. However, the draft summary sheets prepared in Phase 1 require improvement and completion.

It is not feasible to guarantee the quality of data prepared by other entities and individuals, but checks for obvious outliers and any clearly erroneous data shall be made. However, if a data value is within the likely range of values it is difficult to determine whether it is correct or erroneous, hence such data shall be entered as presented in the reports and maintained as such in the database. Users of the database will gain considerable knowledge of any projects that they are using, therefore if users suspect that any data is unreliable they should inform the database manager. Such a feedback loop is important to help safeguard the reliability of the data.

The collection of existing data shall include the following:

1. Compilation of reports and data which were identified during the meeting of the pool of experts that was held in South Africa. This shall be followed by a quality rating process and prioritisation of the data for entry into the database.
2. Collection of data from the ongoing AfCAP monitoring projects. These data should be readily available for entry into the database. However, liaison shall be made with AfCAP and the team leaders of these projects to submit the data in a standard format, which will make it easier for entry of the data into the database.
3. Additional sources shall be identified and the relevant reports and data shall be collected and processed, as described above.

Task 6: Populating the LVR database

Data from the projects which will have passed the quality tests and approved shall be entered into the database. Criteria for assessing data sources was developed during the course of Phase 1 and will be further refined at the outset of Phase 2. The criteria will include accreditation of the originators of the data, reputation of entities and individuals who produced the data, general consistency and statistical significance, among others.

Data entry will involve the participation of RRCs and other key data providers. These will have undergone training and capacity building (Task 4) as part of the required capacity building process for local ownership by the intended Regional host and nuclei RRCs. This will also build the necessary experience for population of the database in the future. The data will be checked for errors that occur during entry.

Task 7: Data analysis

Once the database has been populated the team shall carryout a review of the database, involving the exportation of the data to Excel to assess data sets individually in order to determine the coverage of the range of performance parameters and causative factors. A preliminary analysis of the key deterioration and performance parameters shall be carried out to determine trends. Such a preliminary analysis is essentially part of a more detailed gap analysis.

It is rare for monitoring to be carried out for more than five years (and even rarer for 10 years). Hence, regardless of the volume of data that will be gathered, it is not anticipated that many projects will meet the criteria for LTPPs. This is already evident from the projects which have already been entered into the database. For this reason a comprehensive back-analysis of roads which are older than 10 years will be necessary, but on a limited number of sites. This involves performance investigations on LVRs, which are old enough for the data to be used to define the life cycle of LVRs. The ToR states that approximately 30 sites shall be selected in four or five countries in Sub Saharan Africa. In fact it will be more beneficial to

revisit the sites that were monitored and investigated in the projects in the database, if they still exist (e.g. the Gourley/Greening Study, the Netterberg study and the SFRDP study), (See item 5 in Table 11.1). Investigations of the related sites will convert some of these key projects from STPPs into LTPP thus providing the required long-term evidence of performance.

Task 8: Detailed data gap analysis

Once the database has been populated with data from the sources identified above, a further gap analysis will be carried out. Indeed, it is anticipated that all potential and actual data sources could have missing information and therefore gap analyses should continue to be a feature of reviewing the database so that such gaps can be identified as early as possible and, if possible, filled (see Section 11.1).

Task 9: Project Review

A detailed project review shall be carried out to determine and prioritise the critical data and knowledge gaps which need to be filled to make the project viable in the long term and to provide the parameters for developing recommendations for LVR specifications and standards.

Task 10: Development of methodology for Phase 3

Although a tentative methodology for Phase 3 is provided in Section 11.6 of this report, the actual scope of Phase 3 will depend on the results of the detailed gap analysis (Task 8). This will involve specifically targeted field and laboratory investigations where appropriate. The methodology will also include further population of the database, development of recommendations for LVR specifications and standards, and dissemination of the findings.

Task 11: Reporting

1. Quarterly progress reports – these will provide information on the progress and challenges faced during the reporting period.
2. Workshop reports – these will provide details of the 3 regional training workshops proceedings and outputs.
3. Presentation of the final updated database with substantial amount of data and related abstracts.
4. Final report for Phase 2

The conclusions and recommendations developed as a result of work carried out in Phase 2 will lead to Phase 3 of the project.

11.5.2 Proposed Milestones for Phase 2

Table 11-2 shows the proposed milestones for Phase 2.

Table 11-2 Phased Milestones

	Reporting and Milestones	**Months**
1	Inception Report	N+1
2	Capacity Building and Training Workshops Report	N+3
4	Populated Database	N+9
5	Final Report for Phase 2	N+12

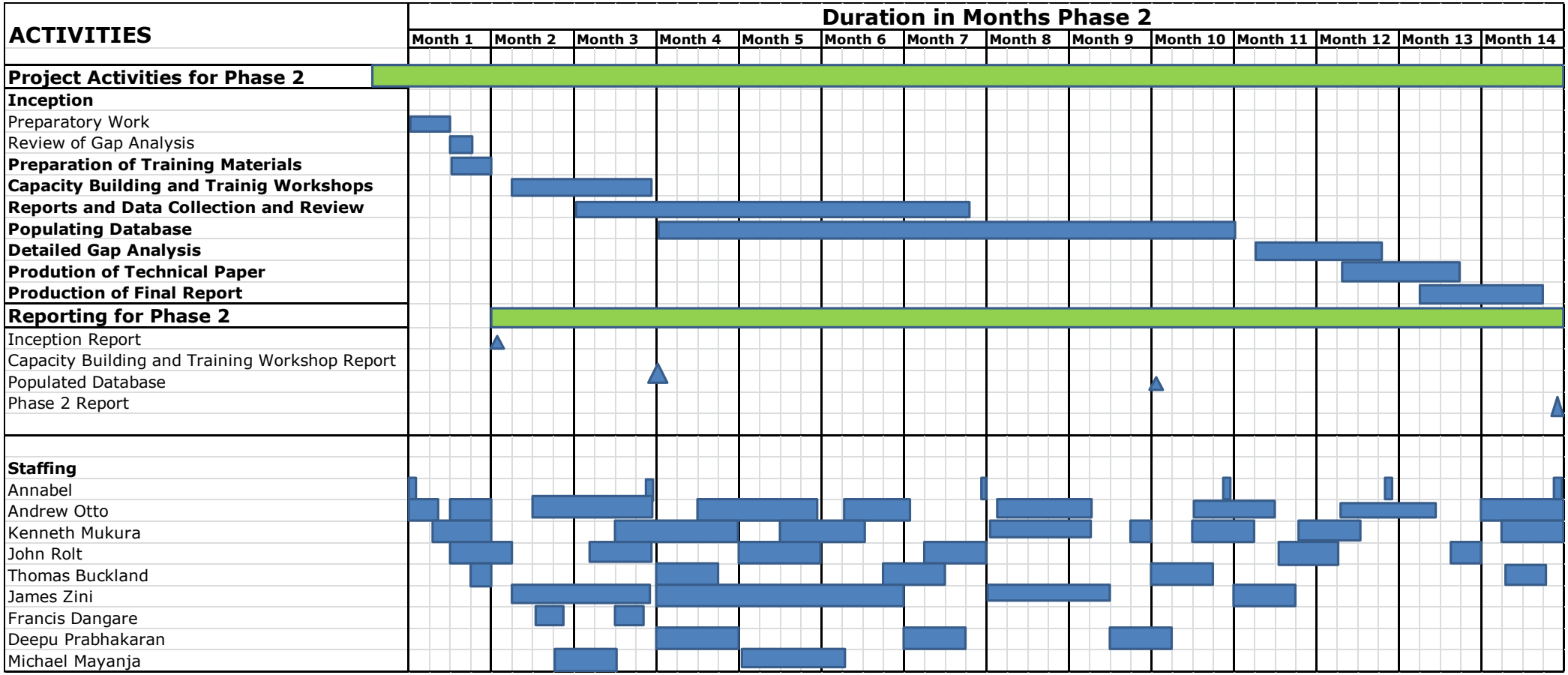
11.5.3 Staff inputs for Phase 2

Table 11-3 shows the staff inputs required to undertake Phase 2 of this assignment. The activity schedule is shown in Figure 11-1. In agreement with ReCAP, we shall transfer Team Leadership of the project from John Rolt to Andrew Otto for Phases 2 and 3 of the project. Dr Rolt will continue to be involved in the project at a senior technical level, and shall provide mentoring and capacity building to Andrew, who himself has over 15 years' experience in low volume road engineering and materials research. In addition, we propose the use of field engineers, namely Michael Mayanja, Deepu Prabhakaran and Francis Dangare to enhance the project team, particularly during any proposed field investigations conducted in Phase 3. Modifications to the project resources will strengthen the competencies of key personnel in the delivery of ReCAP projects going forward, and will be closely supervised by the Project Manager and Technical Reviewer.

Table 11-3 Staff Inputs for Phase 2

Staff	Post	Total Staff Inputs (Days)	Total Staff Inputs for Ph2	Staff Inputs for Phase 2 (DAYS)									
				Preparatory work	Review of gap analysis	Preparation of training materials	Training workshops	Reports/data collection and review	Populating LVR database	Preliminary data analysis	Detailed gap analysis	Technical Paper	Final Report
Annabel Bradbury	**Project Manager**	**14**	**8**	1	0	1	1	2	0	0	1	0	2
Andrew Otto	**Team Leader**	**220**	**172**	6	7	10	25	52	30	10	10	10	12
Kenneth Mukura	**LVRs Expert**	**165**	**131**	2	5	10	20	38	15	10	10	10	11
John Rolt	**Senior Researcher**	**80**	**65**	1	4	5	5	15	5	5	10	5	10
Thomas Buckland	**Data Management Specialist**	**35**	**30**	0		5	10	0	10	0	0	0	5
James Zihni	**Data Management**	**90**	**78**	0		10	20	0	40	0	3	0	5
Francis Dangare	**Field Engineer**	**42**	**10**	0	0	0	10		0	0	0	0	0
Deepu Prabhakaran	**Field Engineer**	**70**	**50**	0	0	10	20	10	10	0	0	0	0
Michael Mayanja	**Field Engineer**	**88**	**42**	0	0	5	10	12	10	5	0	0	0

Figure 11-1 Activity Schedule for Phase 2



11.6 Proposed Methodology for Phase 3

This section covers the approach and methodology which TRL will employ in delivering Phase 3 of the project. TRL will deliver the projects through the tasks described in Section 11.4.1.

11.6.1 Field surveys

The scope of any field investigations will depend on the data that are collected from existing data sources, quality approved and entered into the database and on how many of the perceived gaps can be adequately covered. This is the purpose of the continuing gap analysis stated above. *There will be no need to collect further data through field surveys if such gaps are to be adequately covered in the database.*

The first priority is to collect road condition data that will successfully convert STPP and MTPP data into LTPP data by extending the monitoring period so that pavement 'life' can be defined. Associated with this is the need to make sure that for all projects for which 'life' can be defined the rest of the basic data set is also complete. Depending on what is missing and an estimate of the work required to fill that gap, decisions will be made as to which projects are worthy of such additional field work.

The field surveys and investigations will therefore be specifically targeted research e.g. one involving conversion of STPP and MTPP data into LTPP data that can be fully analysed.

Task 1: Visiting selected countries and selecting candidate roads and test sites

For costing purposes it is assumed that four countries will be selected. Several potential candidate countries were contacted during Phase 1 of the project, all of whom showed great interest to be partners and to collaborate on the project. These countries included Mozambique, Uganda, Ghana, Kenya, Zimbabwe, Zambia and Tanzania. SEACAP data will also be considered because some sections are over 10 years old.

During the site visits the project team will coordinate with the local staff in order to gather local knowledge and also obtain assistance in the selection of candidate LVRs for the field investigations, based on the Phase 2 gap analysis exercise.

Particular attention should be given to the main data and knowledge gaps that have been selected for study based on outputs described above. However, the common conclusions in many of the studies are that the investigations should focus on the performance of LVSRs under different conditions. The basic process of data collection, material testing and performance analysis is therefore common to most of the studies although the details will differ. Both good and bad performing sections shall be included in the study. During the initial site visits vital information about the candidate roads shall be obtained so that the sites selected for the study are those with the greatest potential for providing good data that can be analysed with confidence. This will also include tentative section demarcations, information on the prevailing conditions, and insights into the perceived performance from the local road authorities. In addition, photographs of the different roads and sections shall be taken for further analysis.

Task 2: Analysis of the candidate roads and sections, prioritisation and final selection of candidate countries, roads and test sections.

After the initial field visits an analysis will be carried out to select the roads most likely to yield good data bearing in mind that this process will highlight both candidate roads and, therefore, candidate countries. This will be carried out based primarily on the scientific

requirements of the studies themselves but other factors shall also be considered including the geographical coverage, capacity of the candidate countries to facilitate and participate in the investigations (and contribute in cash or kind), the availability of reasonable laboratory capacities to do the testing, and other criteria to be decided.

Task 3: Formulation of memoranda of understanding

After finalising the selection the terms of reference will be prepared for the country components of the project stipulating the responsibilities of the participating authorities so that there is clear understanding of the objectives and mandates of the parties involved. With this TRL shall seek collaboration with the selected countries, and where necessary, ReCAP shall establish memoranda of understanding which will commit various local parties to the collaborative research.

Task 4: Mobilisation

The field surveys will be conducted in collaboration with the local road authorities and RRCs where they exist. The local laboratories will play a leading role in both the field work and any laboratory testing. The research may involve the following categories of activities:

1. Mobilisation of personnel and equipment – It is important to mobilise appropriate equipment for the field surveys but it is also important to bear in mind that the primary task is to fill the identified gaps of Type 1 and much of this is likely to be surface condition measurements that require very little equipment. Secondment of personnel from the RRCs and road authorities, particularly the laboratories, will be required to carry out the field work together with the project team.
2. Transport – There will be the need for transport to take personnel to and from sites and also to transport any samples that need to be sent to the laboratories.
3. Both government and private laboratories shall be mobilised to carry out tests on the samples of pavements and surfacings.

Task 5: Field and laboratory investigations

The field investigations will include some or all of the following key tests/measurements:

1. Condition surveys. These include the observation and measurement of surface defects such as cracking, potholes and patching, geotechnical movements, general deformation, rutting, texture, edge break, etc.
2. It is recognised that the performance of surfacings is very variable and is a cause for concern. Contractor and designer errors need to be identified and rectified so that the 'life' of surfacings can be increased to maximise the whole life benefits.
3. In-situ strength surveys, material sampling and destructive tests. These tests and surveys include deflection tests (lightweight deflectometer (LWD) or falling weight deflectometer (FWD), and DCP measurements.

   Transportation of samples to laboratories – It is anticipated that most of the tests will be carried out in-country. However, it is also anticipated that there will be some specialised tests which may need to be carried out outside the country, most likely in the UK. Such tests may possibly include Brookfield viscosity and gas chromatography tests on surfacings.

The laboratory investigations are expected to include but not be limited to the following:

1. Tests on bases, subbases and subgrades – grading, Atterberg limits, CBR, laboratory DN where possible, proctor tests.
2. Tests on surfacings – binder content, binder ageing, viscosity, softening point, and other specialised tests on binders. Tests on aggregate strength and other material properties such as mineralogy grading and shape.
3. Test on stabilisation – cement, lime and bitumen content (for emulsion treated based).
4. Comparison of key test methods such as BS, AASHTO, ASTM, and TMH only on key test parameters.

Task 6: Analysis

All field and laboratory tests results shall be compiled and recorded in spreadsheets which conform to the database requirements. Inputting data shall form an aspect of capacity building and it is anticipated that the participating staff will carry out a significant amount of the work. Analysis of the data shall be carried out primarily by the TRL team but in a knowledge transfer format so that capacity building covers the range of all the activities associated with the project.

Task 7: Updating the Database

Relevant data and results of the analysis will be entered into the LVR database.

Task 8: Training/Capacity

Whilst the local teams will already have various skills, this research project will require skills and knowledge that covers a relatively wide range. Some of these will be acquired from on-the-job training during the project itself and some, initially, from class room lectures and practical exercises. These training sessions will be designed to be flexible and to be provided at an appropriate time so that the participants will have an immediate experience using their new knowledge.

Task 9: Preparation of the Final Report

The report will cover details on the research proceedings, results and outputs of Phase 2. The report will also give details of the data collected and included in the database. The report will also provide guidance on how the data can be used and any precautions which should be considered in using the data.

Task 10: Dissemination

The outputs of the research shall be disseminated to the stakeholders with the following objectives:

1. To develop awareness of the outputs and their importance to the provision of LVRs.
2. To transfer ownership of the outputs to the intended beneficiaries of the research.
3. To develop a platform for the hosting the database regionally e.g. by ARTRef perhaps or a national research laboratory.
4. To obtain feedback from the stakeholders on any additional improvements.

Several methods of dissemination shall be employed including but not limited to the following:

i. Presentation in forums such as the T2 and other international conferences.

ii. Use of media and other similar platforms.

iii. Publication of websites including the ReCAP website in order to reach the wider audience.

Task 11: Training

It is important to carry out training on the use of the database. This will eventually and necessarily include methods of analysis and basic research methods and will require a very different approach to that used for training on entering and editing data. At this stage it is not possible to set out a plan for this but it is likely to involve collaboration with a good local University and the RRCs. The training will need to cover the following:

1. Training is required for potential users to be able to use the database at the basic level. This involves understanding what the data are for, how to assess, enter, edit and retrieve data through the database reporting procedures and also generate reports.
2. More detailed training is required for those who will manage the database on a day to day basis. This is a critical requirement for its future sustainability and further development.
3. The most comprehensive training is required for those who aspire to analyse data and to develop improved standards and specifications. Long-term collaboration and partnership with a University and a well-established research organisation is probably required.

Task 12: Preparation of scientific paper

A scientific paper will be prepared for publication in a journal. The primary objective will be to publicise the database but it may be necessary to use an analysis of one or more live research projects in order to do so. The paper will be published in a journal that has recognised reviewer quality. The objective is to reach a wider audience, develop international awareness and confidence in LVR technology.

Task 13: Final Report for Phase 3

A final report will be prepared on Phase 3 detailing the outputs and outcomes of the assignment, the coverage and recommendations on downstream matters which should be considered by the client and the beneficiaries.

11.7 Proposed Milestones for Phase 3

Table 11-4 shows the proposed milestones for Phase 3.

Table 11-4 Milestones for Phase 3

	Milestones	**Schedule**
1	Inception Report	N+16
2	Fieldwork Report	N+18
3	Final Report and scientific paper	N+19

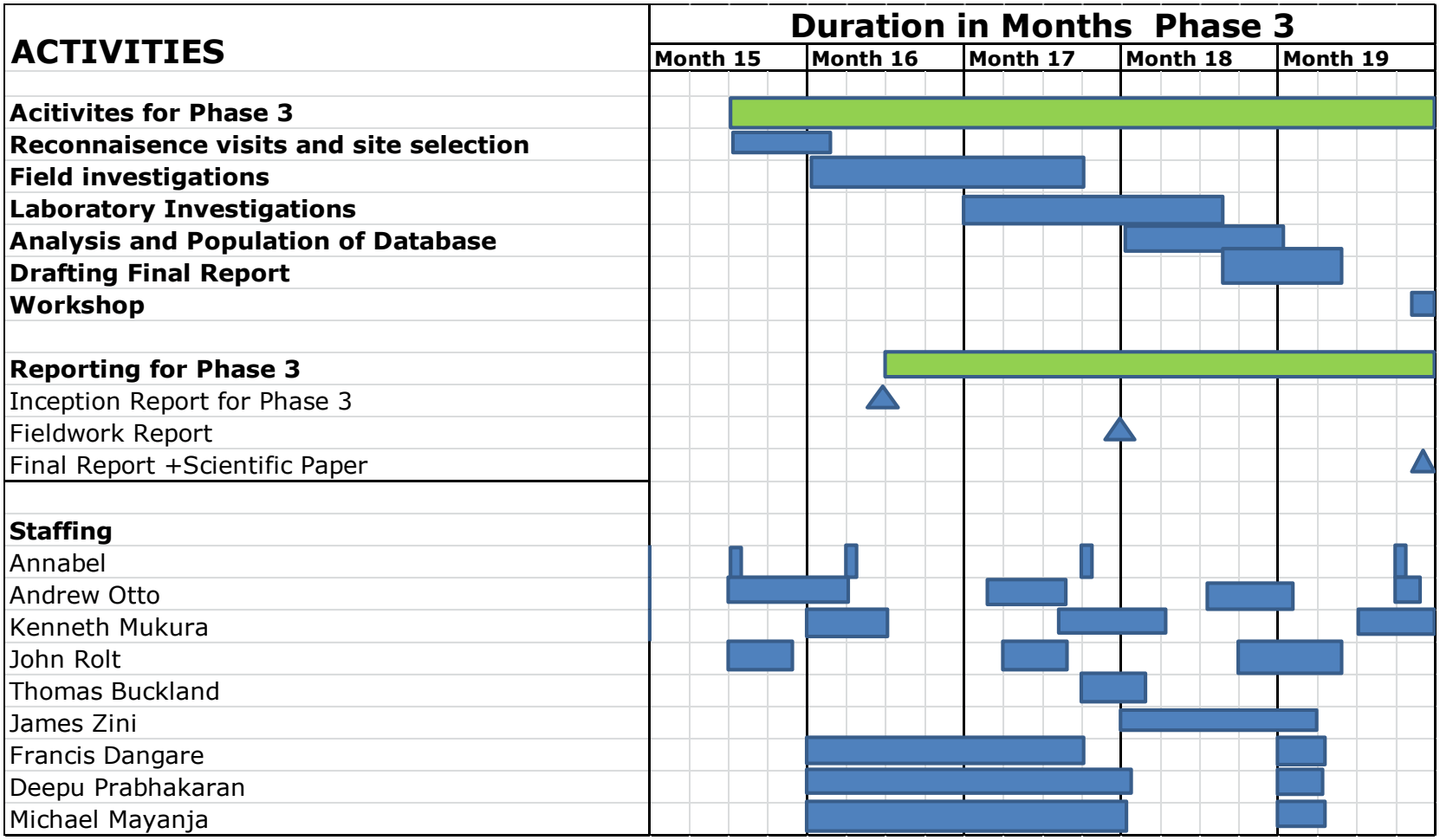
11.8 Staff input for Phase 3

Table 11-5 shows the staff inputs for Phase 3.

Table 11-5 Staff inputs for Phase 3

Staff	Post	Staff Inputs for Phase 3 (DAYS)								
		Field work and Dissemination								
		Total Staff Inputs for Ph3	Reconnaisance visits	Field Work	Lab testing	Analysis	Populating database	Scientific Paper	Dissemination	Reporting (incl Final Report
Annabel Bradbury	**Project Manager**	**6**	2	1	1					2
Andrew Otto	**Team Leader**	**48**	8	10	5	5	5	5	5	5
Kenneth Mukura	**LVRs Expert**	**34**	0	10	5	5	0	4	5	5
John Rolt	**Senior Researcher**	**15**	0	0	2	3	0	4	2	4
Thomas Buckland	**Data Management Specialist**	**5**	0	0	0		3	0	0	2
James Zihni	**Data Management**	**12**	0	0	0		10	0	0	2
Francis Dangare	**Field Engineer**	**32**	10	20	2	0	0	0	0	0
Deepu Prabhakaran	**Field Engineer**	**20**	5	15	0	0	0	0	0	0
Michael Mayanja	**Field Engineer**	**46**	5	20	15	0	0	0	0	6

Figure 11-2 Activity Schedule for Phase 2



12 Lessons Learned and Recommendations

The effectiveness of knowledge exchange, good collaboration, problem solving and basic project efficiency is enhanced through personal meetings rather than electronic communication. This project has underlined this lesson. A considerable amount of 'brainstorming' was required to not only identify but to solve a number of problems for which consensus were required. The workshops for the expert pool were an ideal way to accomplish this and it was perhaps fortunate that members of the pool could manage their time so well that each workshop was fully attended (with one exception from the expert representing West Africa who could not attend due to administrative reasons).

The project also highlighted the difficulty of accessing data that were not held in electronic form or could not easily be translated into electronic form. Research reports where data is all included in tabular form in appendices ought to be the standard or recommended format for all research that is of sufficient quality to be publishable. It was surprising how often data were not accessible and underlined the need for this project to rectify this situation for the future.

The project also underlined another problem that researchers have always been aware of namely that preparing one's own data files to be easily useable by someone else is not a trivial or even a straightforward task. Of necessity and time limitations, the project team have concentrated on obtaining the data sets and getting the data into the database. Problems of data manipulation will become apparent when using the data and will need to be addressed in Phases 2 and 3.

13 Next Steps

The following steps should be taken in order to progress the project to its successful completion, and it is proposed that the African Road and Transport Research Forum (ARTReF) take responsibility for ownership and hosting of the LVR database.

1. ARTReF should be invited to take steps to acquire the infrastructure necessary to host the database which should be accomplished before the end of Phase 2. This is because the database will be handed over at this stage to whosoever has agreed to host the database.
2. Phase 3 provides a good opportunity for the project team to carry out investigations during both the wet and dry season and this can only happen if the methodology for Phase 2 and 3 is speedily approved.
3. The pool of experts - though not specifically mentioned in the ToR with regards to their need during the delivery of Phase 2 and 3, it may be necessary for considered reconstituting at the outset of Phase 2 but this shall be decided by the ReCAP PMU.

14 Conclusions and Recommendations

The objective of Phase 1 of the assignment was to collect and collate data from previous research and mainstream road research works carried out on LVRs with the aim of creating a repository for such data and information. Another key objective was to develop a user friendly database for LVRs which would capture the majority of relevant data from LVR projects and research work including performance monitoring. The ultimate aim is to improve standards and specifications for the Sub-Saharan Africa region and elsewhere.

With the help of the pool of experts the project team collected and collated data from several high ranking projects and reports. The team also developed a web-based database which has been tested and is fully functional although it will be improved further in Phase 2.

The database has been populated with the LVR data. More data will be entered in due course and this includes the data that will be collected from site and laboratory investigations to be carried out in up to four countries in the region.

Major challenges were encountered in retrieving old data from non-digital sources and this was compounded by the gaps in the datasets. These gaps will be largely filled during Phase 2 of the project.

This project is something of a landmark in low volume road research. The Low Volume Roads Database will be the first repository of its kind, containing data about LVR sections on roads in Sub-Saharan Africa and South East Asia that was collected over a number of decades, and including aspects of their design, construction and maintenance that have influenced their in-service performance. The database will enable engineers and researchers to add new data collected from LVSR monitoring and use it to identify key factors associated with good or poor performance. Lessons learned from the database can then be used by recipient countries to update existing specifications or develop new documents to improve the quality of future LVSR design, construction and maintenance.

References

Brudefors, U, and G Sibanda (1995). *Secondary and feeder road development programme: Phase 1*. SIDA, Sweroad. Government Ministry of Transport and Energy, Department of State Roads, Harare, Zimbabwe.

Brudefors, U, and G Sibanda (1999). *Secondary and feeder road development programme: Phase 2.* SIDA, Sweroad. Government Ministry of Roads and Energy Department of State Roads, Harare: Zimbabwe.

Cook J.R (2009). *The rural road surfacing research (RRSR) database*: DfID, SEACAP 27. TRL, Crowthorne, UK.

Gourley C. S. and P A K Greening (1999). *Performances of low-volume sealed roads; results and recommendations from studies in southern Africa.* DfID KAR R6020. Report PR/OSC/167/99. TRL, Crowthorne, UK.

Gourley C. S. and P A K Greening (1999). *Performances of chemically stabilised roadbases: results and recommendations from studies in southern Africa*. DfID KAR R6020. TRL Report PR/OSC/168/99. Crowthorne, TRL, UK.

Greening, P A K and J Rolt (1997). *Calcrete in roadbases in the Kalahari region of southern Africa.* In Transport Research Laboratory Annual Review 1996. Transport Research Laboratory, Crowthorne, U.K.

Intech and TRL (2005). *SEACAP 1 Final Report* (3 vols). Report for MoT, Vietnam. TRL, Crowthorne, UK.

Lionjanga, A V, T Toole and D Newill (1987). *The development of specifications for the use of low-grade calcretes in lightly trafficked roads in Botswana.* Transportation Research Record 1106, Vol 1, pp 281-304. National Research Council, Washington, DC.

Mukura, K, P A K Greening, G Morosiuk) (2005). *Increased Application of Labour-Based Methods through Appropriate Engineering Standards.*Transport Research Laboratory, Crowthorne, U.K.

Netterberg, F (1989). *The Jwaneng sand asphalt experiment: performance up to 1986*. Ministry of Works and Communications Roads Department, Botswana and Division of Roads and Transport Technology, CSIR, Pretoria, RSA.

Netterberg, F (1990). *The Nata calcrete base course experiment: performance after 10 Years.* Report Number DPVT/C 124.1. Division of Roads and Transport Technology, CSIR, Pretoria, RSA.

Netterberg F and M I Pinard (1991*). Derivation of interim performance-related specifications for coarsely graded plastic calcrete basecourse gravels*. Proc of the 10th Annual Conference for Africa on Soil Mechanics and Foundation Engineering. Maseru, Lesotho.

Netterberg, F, D Newill, D, and B Obika (1993). *Kanye - Jwaneng road: panel inspection of Jwaneng sand-asphalt and calcrete base course experiment*. Frank Netterberg, Pretoria, South Africa.

Overby, C (1990). *Monitoring of low volume sealed roads in Botswana 1982-1989: Oodi-Modipane road, Selebi Phikwe-Mmadinare road, Sebina-Tutume road*. Report Number 1476. Norwegian Road Research Laboratory, Oslo, Norway.

Overby, C (1990). *Monitoring of sealed low volume traffic roads in Botswana 1980 - 1989: Sehitwa-Tsau*. Report Number 1478. Norwegian Road Research Laboratory, Oslo, Norway.

Paige-Green, P (1989). *The influence of geotechnical properties on the performance of gravel wearing course materials*. PhD Thesis, University of Pretoria, RSA.

Paige-Green, P (1994). *Recommendations on the use of marginal base course materials in low volume roads in South Africa.* Research Report, RR 91/201, CSIR, Pretoria, RSA.

Paige-Green, P (1999). *Materials for and construction of sealed low volume roads*. Proc 7th International Conference on Low Volume Roads, Baton Rouge, May 1999, Vol 2, pp10-15.

Rolt, J, S G Williams, C R Jones and H R Smith (1987). Performance of a full scale pavement design experiment in Jamaica. Transportation Research Record 1117. Transportation Research Board, Washington DC.

Rolt, J, K Mukura, F Dangare, A Otto (2013). *Back Analysis of Previously Constructed Low Volume Rural Roads in Mozambique*. DfID AFCAP Project MOZ/001, CPR1612. Transport Research Laboratory, Crowthorne, U.K.

TRL (2013). Back Analysis of Previously Constructed low Volume Roads in Mozambique – Final Report. TRL Report CPR 1612. Wokingham: TRL Limited

World Bank (2016). *World Development Indicators 2016*. Washington D. C.: World Bank.

Annex A. Summary of Desk Study Review

A.1. Data Review

During the period whilst the experts were being recruited and contracts agreed, the team began a review of data sources. TRL's own data sources were accessed through the TRL library and Information Centre, but the review also included many international studies. The review at this stage consisted of filtering out all the documents that contain data as opposed to the many documents that are very useful in themselves but do not contain data that can be added to a database and analysed further (i.e. manuals, guidelines, specifications and the like). The 257 documents comprising the comprehensive information source list in the *Low Volume Rural Road Surfacing and Pavements – A Guide to Good Practice by J R Cook, R C Petts and J Rolt* and another 80 documents were reviewed. The resulting list, which is not complete at this stage, is shown in Annex E. Some of the data sources were reviewed in more detail to identify potential problems and some preliminary solutions proposed.

The main issues that form an integral part of the review include, but are not limited to, the following:

1. Determination of the full set of parameters which need to be considered in the study.
2. Identification of sources of information which are likely to yield credible information and data which can be used for more detailed analyses for the development of guidelines and specifications for LVRs.
3. Collection and compilation of reports that provide data sets involving previous performance studies of LVRs and classifying the data sources as either 'back-analysis projects or long term pavement performance studies (LTPPs) because the contents and therefore the data structure are rather different. The data sets should contain details of:
    a. Structural Design. It is one of the most important aspects of the project to determine appropriate pavement structures for LVRs for different levels of traffic loading and environments.
    b. Road building materials including non-conventional materials.
    c. The geometrics design and drainage provision have a very strong influence on road performance.
    d. Traffic is a primary causative factor in pavement performance. Limits for traffic for low volume roads have been derived, mainly through consensus. The project provides an opportunity for these limits to be derived scientifically and statistically.
    e. Environmental factors, primarily rainfall, ground moisture. These data should be available in the study reports but not always. However, information may be obtained from ongoing projects including ReCAP projects in the area concerned.
    f. Poor construction is, all too frequently, the main cause of much of the deterioration and premature failures experienced on low volume roads. It is anticipated that many projects will include such data but, if not, it is also possible to obtain such data at a later date through

tests such in-situ density tests and DCP measurements and through sampling and laboratory testing. As part of the desk study, reports with these data will be noted for detailed review.

g. Poor maintenance. All roads require maintenance, some more than others. Therefore one of the biggest challenges faced by engineers when analysing road performance data is to determine how much deterioration is a result of the lack of the maintenance that could reasonably be expected. If possible it is desirable to quantify maintenance in some way to capture this effect.

There are also other data sets covered in the report which have been considered as part of the desk study, and the significance of their influence on the performance of LVRs will be ascertained in due course.

At this stage the desk study report is not exhaustive because more information will be considered as more documents and data are assessed and limited analysis is carried out with a view to segregating data and information which is either irrelevant or inaccurate and therefore cannot be used to populate the database. The meeting of key experts provided considerably more data sources, as described in Section 6 and Annex B.

The review of additional international data sources was one of the tasks to be undertaken by the key experts at the meeting on 26th-27th of September, and is described in Chapter 6.

A.2. Summary of Reviews – Preliminary Conclusions

A.2.1 Types of reports

There are many studies and many reports, both published and unpublished, that are accessible. Their usefulness covers a wide range and it is vital to classify them in such a way that the time of the project team is spent in the most productive manner. A robust classification system is required. As a first proposal, the following classifications illustrate the initial problem of accessing the data in a way that allows it to be entered into a database as easily as possible

Class A1 Data are in digital format. This is the easiest format but even recent data is not necessarily available in digital format.

Class A2 The data are tabulated in printed reports in a word processing format that allows almost instant translation to spreadsheets. A trial with a study that produced about 30 full page tabulations of the various types of data required about one man-day of effort to convert to spreadsheet format.

Class B Data available in non-electronic hard copy format that requires scanning to convert to electronic format. This should be relatively straightforward with modern character recognition programs for example, but is likely to require considerably more time for each document?

Class C Data may be available in digital format but may be too old to be accessed. Technology 'drift' has made old data storage systems obsolete.

Class D1 The data are comprehensive and of high quality but the published documents only record the data in the form of graphs and model equations, the original data being unavailable. Such reports are often very comprehensive in terms of the quantity of data

but the data have already been fully analysed as far as the authors are concerned. The data are likely to be extremely valuable but accessing the basic data is a problem that may prove difficult to solve. A good example is the data set emanating from the studies that led to the HDM series of models and published in the mid 1980's from studies completed in 1981.

Class D2 Similar to Class D1 but the reports do not contain sufficient analysis for definitive models to be derived. The graphs within the reports are designed for illustration purposes, not for close numerical analysis. They can contain a great deal of data but it will be difficult to extract.

Most reports contain a mixture of data presentation methods. The easiest to use are those reports that include fully comprehensive data tables, usually as appendices.

A.2.2 Types of studies

There are a wide range of studies including factorial research studies ranging from monitoring performance from newly built to ultimate failure. The range includes performance studies of existing roads, accelerated loading studies, laboratory investigations, and road failure investigations. The first task is to understand the research study itself in order to ensure that the data are stored properly to prevent future errors.

Many studies are based on specific issues rather than general road performance, for example, comparisons of the performance of different surfacings. The data from such targeted studies may not be so easily amalgamated in a database to provide a wider range of data for a more comprehensive analysis but it is important to do so – missing data may be a problem.

A.3 Quality of Research Studies and Selection for Inclusion in the Database

Data quality is one of the most important characteristics of the data that must be evaluated for each source. Final selection of data to be entered into the database will depend on this evaluation. It is salutary to realise that these days at least 70% of papers submitted for publication to recognised research journals are rejected at review stage because some aspect of 'quality' is inadequate. Quality is judged in many ways for journal publication. In this project the important 'quality' indicators will be different. Potential problems with data and its analysis are discussed briefly and a ranking scheme is proposed in Chapter 7 that helps to eliminate unreliable and inappropriate data from inclusion. However, comprehensively judging data sets is not the role of the compilers of the database. Such detailed review as may be necessary is the responsibility of the users of the database and forms part of their analysis role. This section is therefore primarily an awareness raising section that may be considered as a summary of the issues considered when reviewing data sets.

A.3.1 Data Range and Quantity

As part of the classification system to value each research study, the key variables in the study and their range needs to be identified. Data sets should include any studies where a basic minimum range and quantity of the key variables have been measured. This is not restricted to research studies. For example, investigations of existing roads for upgrading usually include analysis of performance, hence rehabilitation studies are potentially a source of good information. The minimum acceptable range and composition of each data set needs to be defined.

A recent analysis of a comprehensive research study revealed over 150 measured variables (excluding time series repetitions) for each road link. Many simply confirmed that a specification was met and probably had no bearing on the results of the analysis, but these data are essential for the database.

A.3.2 Variables used

A key problem with amalgamating data from different studies is concerned with the variables (factors) that have been measured and recorded and the measurement system used. Obviously many variables can be converted from one system to another (metric to Imperial, for example) but the problem is considerably more complicated than that. It may be that some similar studies that could benefit enormously from amalgamation will simply not lend themselves to amalgamation for one reason or another. In classifying different studies this problem needs to be addressed in the database design.

A.3.3 Data reduction

Published data should not consist of absolutely raw field data or data that have been more than partially analysed. There is an ideal level that researchers generally recognise but there are potential problems. For example, laboratory data sheets are usually worthless at the level of analysis that is envisaged but can often highlight inadequacies in measurements and therefore can be a pointer to data quality. Again, this is a feature that needs to be included in the classification of research studies and which could easily disqualify a study from consideration for inclusion in the database.

A.3.4 Statistical Problems

The most serious problems with data are concerned with statistical issues. They include sample size, identifying the most important variables, design of the experimental 'matrix' to include an adequate range of the variables, adequate control points, duplicate sections, dealing with missing cells in the experimental matrix, and statistical bias amongst others. In practice it is almost impossible to apply ideal statistical design for the kind of engineering studies that are being considered in this project. The researchers' skills in identifying any serious deficiencies and coping with them is a key measure of the quality of the research. In particular, errors can arise by accident or through inexperience. For example, statistical bias is part of a potential statistical problem and is fairly common in this area of research. The need for random samples is always emphasised in all statistical text books but the magnitude of its effect is not widely appreciated. Examining the properties of only long-term pavement survivors is a clear case of studying a very biased sample.

A.3.5 Cause and effect – false correlations

This is also a statistical issue. In many cases correlation does not mean causation. An example is the relatively common response to the question 'Why did this road fail early?' The answer may be simply that the specifications for some aspect of the design and construction were not met or, commonly, that the traffic exceeded the design value, but the problem may not be quite so straightforward. There are many examples of roads that did not fail even though one or more of the specifications were not met. Thus analysis of road performance is often complex and this adds considerably to the problem of judging the quality of the research. However this is mainly a problem for the database users provided that the data that is included in the database passes the criteria that form the core of our ranking scheme.

A.3.6 Precision of the measurements

The natural variability of tests such as Atterberg limits, CBRs etc. is sometimes a problem especially in contractual situations. A specification showing the acceptable ranges or, better still, averages/means and percentiles helps to solve this problem. This is also tied into the problem that only a few percent of a road needs to fail for the whole road to be of insufficient standard, thus average values of key variables are generally quite useless unless the average is highly correlated with the lowest percentile – usually a very unlikely situation.

A.3.7 The interactive effect of some material properties

Engineers try to cope with this (e.g. by combining PI with the percentage of fine material, i.e. PP and PM) but properties that do not cause a monotonic change in performance are rarely identified or used in practical performance analysis. A good example is permeability. Permeable may be good, impermeable may also be good, but in between there are likely to be problems.

A.4 Summary

The main point here is that the time spent by the average reviewer of reports for publication is often not sufficient to identify the possible problems with the research. During the first phase of this project it is not intended that detailed problems associated with the data itself and its analysis will be addressed. This is the role of the users of the database. However there is no reason why helpful information concerning how the data were judged as suitable for inclusion in the database should not be included in the user's manual.

Annex B. Summary of the First Workshop

Venue: CSIR, Pretoria, South Africa

Date: 26th and 27th September 2016

Present:

	Name	Organisation	Role	Contact
1	Les Sampson	ReCAP	PMU/Chairperson	Les.Sampson@cardno.uk.com
2	Nkululeko Leta	ReCAP	PMU	nkululeko.leta@cardno.uk.com
3	Mike Pinard	InfraAfrica	Pool of Experts	mipinard@global.bw
4	Phil Page Green	Private Consultant	Pool of Experts	paigegreenconsult@gmail.com
5	Tony Greening	Private Consultant	Pool of Experts	tonyk.greening@sky.com
6	Gamalihle Sibanda	Private Consultant	Pool of Experts	gamasibanda@gmail.com
7	Frank Netterberg	Private Consultant	Pool of Experts	fnetterberg@absamail.co.za
9	Benoit Verhaeghe	CSIR	Host	bverhaeg@csir.co.za
10	John Rolt	TRL	Team Leader	jrolt@trl.co.uk
11	Kenneth Mukura	TRL	LVRs Expert	kmukura@trl.co.uk

Apologies:

Andrew Otto – Senior Research

Adekunle Olowosulu – Private Consultant – Pool of Experts (West Africa)

Tom Buckland – TRL- Data Specialist (Database)

Michael Mayanja – TRL – Data Specialist/Researcher (Database)

Agenda:

1. Personal Introductions
2. Introduction to RECAP
3. Introduction to the project and workshop
4. Classification of research reports and data sources to identify the best material for inclusion in the database. How to evaluate:
   (i) Data range
   (ii) Data quality
   (iii) Data reliability
   (iv) Statistical validity
5. Our responsibility for data 'quality'.
6. Format for providing the database specialist with data.
7. Role of the pool of experts
8. Next steps

Summary

Items/Issues	Deliberations	Comments
1 Welcome by Chairperson		
	The Chairperson welcomed all participants	

<table>
<tr><td></td><td>to the workshop and thanked all for making time to attend and contribute to the project.</td><td></td></tr>
<tr><td>2 Brief by the Chairperson</td><td></td><td></td></tr>
<tr><td rowspan="2"></td><td>The Chairperson introduced the project and emphasised its importance for ReCAP.
i. A great deal of data has been collected and there is a need to capture these data for use now and also for future generations.
ii. It is understood by the Client that the project is difficult and a pool of experts is needed.
iii. The project provides an opportunity to bring all the experts on low volume roads together.
iv. The database which will be produced will be a repository for research data for ARTREF and research work for the upcoming Road Research Centres.
v. The Draft Review Report produced by TRL will be finalised based on the outputs of the workshop.
vi. John Rolt was requested to make a presentation and highlight all the issues which needed to be discussed.</td><td>The participants agreed that the project was complex but it is important to work with what is available.</td></tr>
<tr><td colspan="2">CSIR Data.
Benoit Verhaeghe confirmed that data from CSIR are available but, when moving to the current building, documents in hard copies were stacked in boxes and not in any particular order so finding any reports would require significant effort.</td></tr>
<tr><td>3. Presentation by John Rolt</td><td colspan="2">Details</td></tr>
<tr><td></td><td colspan="2">The presentation outlined the project and introduced the issues arising from the preliminary review of data sources outlined in Chapter 4 and 5 of the Draft Review Report already forwarded to the expert pool:
i. There is a great deal of information about reducing the costs of roads and making them more reliable that has been developed through research studies carried out principally by specialist research institutions, consultants, and academic institutions
ii. The project involves the collection of available data on the performance of low volume roads and its inclusion in a database designed for this purpose. This will make it possible for more comprehensive analyses to be carried out enabling the effects of the full range of factors which influence the performance of LVRs to be quantified.
iii. The project consists of 3 Phases. The key outputs of Phase 1 include:
• Recruitment of a pool of experts to help with the sourcing of data and review of documents.
• Creation of a suitable database.
• Knowledge gap analysis which may lead to further research under Phase 2.
• Partial analysis of data.
• Proposed methodology for carrying out Phase 2.
The following progress has been achieved:</td></tr>
</table>

	i. The pool of experts has been recruited. ii. A preliminary (sample) list of data sources from TRL has been assembled. iii. A preliminary (sample) list of International data sources has been assembled. iv. Some of the data sources have been reviewed in detail, some potential problems have been identified and some preliminary solutions proposed.
4 Initial Discussions and Actions	i. The list of data sources now needs to be completed with sources of data available to the pool of experts. ii. The data sources which should be used for the project should cover key issues, subject areas and topics and should have a geographical balance. iii. 40 examples of data sources were initially identified at the meeting (listed in Annex E). iv. A Pilot Phase is required with a limited number of good data sources (class A – Chapter 5) which will be used to develop the architecture of the database, identify problems and develop solutions. v. A selection of data sources was made for the Pilot stage, initially comprising 15 data sources. Annex E. vi. Summary spreadsheets are being compiled and now a classification scheme needs to be developed. This will evolve from the pilot study. vii. The architecture of existing databases should be reviewed. Examples include: • Bill Paterson's HDM4 Database. (Phil has the Excel version of the database but it is 25 years old) • SEACAP Database (Jasper Cook has a copy). John R is scheduled to meet Dr Cook for this purpose on 30th September
5 Detailed discussions Part 1	Concerned with problems already identified in the draft Review Report and new issues raised at the workshop.
Reviewing, Evaluating, Prioritising and Selecting Data Sources	The selection and prioritisation of data sources is an inherently difficult and time consuming exercise. It requires a good assessment of several aspects including *scientific quality*, *amount of data*, *range and scope*, and *ease of preparation for entry into the database*. It is necessary to develop a marking/ranking scheme that takes account of all the characteristics listed here in order to prioritise the data sources. This is complex because each report is different and has different data sets. Also the ranking scheme should cover unpaved and paved collectively or separately depending on which way is more appropriate. The methodology will evolve during the pilot phase.
Identifying difficulties of 'manipulation' of the data sources.	• The first step is an efficient evaluation system that will quickly identify the level of staff input required for each data source. This will depend on the type and scale of the problems. • The pilot study will provide the experience to develop a methodology for this task. • There will be anomalies which may be difficult to resolve unless the authors of the reports are available to explain. This will be a big challenge especially regarding old reports where the authors are no longer accessible. • Ultimately 100 reports are thought to be a realistic target.
Using Data Sources	• Data that is already in digital format should provide the least problems. • Digitising hard data into Excel format is done by scanning (optical character recognition (OCR) software) and can be time consuming because of the need for thorough checking to correct errors. • Old data may only be in obsolete electronic formats and may not be recoverable. • Other data formats are discussed briefly in Chapter 5.

Data Quality	There are very many data sources but only scientifically 'sound' ones will be entered into the database. Initially the reliability of data sources largely depends on the credibility and reputation of the authors but care should be taken to scrutinise the data and a more quantifiable classification scheme will be developed during the pilot phase. Good statistical practices are essential for good science. The complication is that there are many variables and many possible sources of error in analysis. The reviewers will need to be very vigilant.	
Data Compatibility and Test Methods	Compatibility between variables has to be obtained if data sources are to be combined and analysed together. A prime example is road deterioration parameters. Authors use variables that differ substantially but comparisons and combined analysis can only be done if the variables can be related to each other. • The problem is compounded by the use of a variety of different test methods and standards. • It is important for the database users to find or develop correlations between test methods so that data from different sources can be correlated or reduced to the same standards, but how can this be done? • It is also important that the significance of the differences in test methods and the magnitude of differences in the test results are known because some will not be significant. • This is an important problem but how can it be resolved? Should the user's manual be used to provide expert help? • The general view was that provided the data sources explain the variables used and how they were measured then it is the responsibility of the users of the database to resolve compatibility issues.	
Responsibility for data	The level of responsibility over the quality of the data which will form the database could be an issue in the future when users start accessing the database. How much responsibility could or should TRL and ReCAP have? It was decided that there would be no responsibility on the part of TRL and ReCAP but efforts should be made to check the data so that whatever goes into the database is as accurate as it would be if a journal were to publish it. A disclaimer will be required.	
Scope of Data	There is need to make sure that the data sources have enough coverage of parameters therefore an assessment of what is covered in each one is a good idea but somewhat time consuming. A research matrix can be used for this. However, the parameters are very many. An example was shown to the participants on the magnitude of the set of parameters which was over 150 and yet the set was incomplete. Identifying gaps may be difficult. General Classification of data sources. a. Report type - general, specific, targeted, laboratory only etc. b. Data range and quantity. c. Reliability –What limits do we set? d. Variables used and conversion (both test method issues and variable definitions) e. Data reduction – how much has been done and can we trust it? How? f. The most serious problems are arguably statistical in nature – omitted variables, bias, and false correlations (cause and effect issues), interactive effects, two valued (not changing monotonically) plus more. g. Age – reports from a period covering 4 decades.	
User manual	Gathering ideas for the user manual should be .a continuous process	
6 Discussions Part 2		
a. Parameters for LVRs	The parameters for LVRs should be properly defined. This will affect the selection of the reports.	For defining a LVR it was concluded that loading in terms of Equivalent Standard Axles (ESAs) should be the main parameter and traffic volume

		is not necessarily important.
b. User manual and guide for the database	The preparation of the user manual for the database is one of the key outputs of the project and it is important to review any such manuals which may be available.	It was suggested that Phil Page Green, Dave Jones and Jasper Cook could be consulted on this matter for information and guidance.
c. Nature of the database	The database will be large but that is the nature of many databases. They are designed to handle this. The following suggestions were made about the nature of the database: i. May need to separate LTPP and Back Analysis Projects ii. May need to capture the models and test methods. iii. There may be a need to enter information which qualifies the data e.g. TRL/Kleyn equation for DCP-CBR relationship. iv. There will be a need for data on preconstruction, design and construction where possible.	These requirements were generally accepted. The test data should be accompanied by the test methods unless good correlations are available.
d Accessing information in the database	Easy accessibility of information from the database is a major factor. There were detailed discussions on the various options.	It was concluded that the database should be web-based and multi-layered. Accessing information or data sets would be through queries and key words.
7 The Way Forward		
Providing data sources for TRL	Members of the pool of experts were requested to supply TRL with reports and documents asap.	Some of the reports were transferred to TRL electronically from the pool of experts. Other information and reports will be sent electronically by email or in Hard Copies (Mike Pinard will send reports from Botswana by courier) but these will need to be returned.
Rolling out the database	It was suggested that initially TRL should populate the database and then roll it out.	TRL will populate the database. TRL may need to liaise with Client should the estimated time to do this be too constrained.
Inclusion of data from current ReCAP projects	There is a lot of data being collected from many ReCAP projects including the monitoring of trial sections that will need to be captured in the database but much of this will necessarily take place at a future date when it becomes available.	There is need to standardise data collection to ensure synergies in the data format.
Expertise required in populating the database	A question was asked on the level of expertise that is required for populating the database.	Considerable expertise is required for sorting out the data and solving the problems raised in this review and in the workshop. Once this has been done properly (often quite difficult) there is no need for special expertise in converting existing data to digital format and entering it in the database.
Compatibility of the	It was suggested that there is need to	John Rolt is to meet with Jasper

database to others.	ensure compatibility with other existing databases such as the SEACAP LVR database.	Cook on the 30th of September 2016 and one of the key areas of discussion will be the SEACAP database.
Information within countries	There is a lot of information within countries from research and rehabilitation projects including ReCAP research which will need to be accessed.	TRL will need to liaise with Leta particularly on information which can be obtained from AFCAP Countries.
Information from West Africa (Nigeria and Ghana)	West Africa was not represented in the Workshop. However, a key expert, Dr Adekunle Olowosulu from Nigeria has been secured for the pool of experts and he has indicated that he has information and data from West Africa. Also Dr. Osei Bonsu from Ghana should be a good source.	TRL will request these and other sources from West Africa to provide LVR data.
Finalising the Desk Study Report	The Chairperson recognised that a lot of work had been accomplished by TRL but this had not been reflected properly in the Desk Study Report.	TRL was requested to finalise the Desk Study Report, provide more detail in the report and submit by the 5th of October 2016.

The expert team also debated other issues that are recorded here.

Other technical matters	Details	Conclusions/Recommendations
a. Subgrade strength criteria – Fatigue failure theory	There was a question about whether subgrade stress/strain relationships apply to LVRs. Are the stress and strains not mostly below the threshold which is required to effect fatigue failure of the subgrade layers? The background to this issue is that little or no fatigue related subgrade failure has been observed on LVRs	It was concluded that this area needed further investigation but indications are that the subgrade stress/strain relationships are not appropriate in the design of LVRs except such roads which are in special circumstances such as logging or quarry roads.
b. 4th power law	There are schools of thought that believe the exponent in the equation should be less than 4.5 for LVRs - 3 and 2 have been suggested. Some studies on this were sited. It was assumed that the exponent of 4.5 leads to overdesign.	There was no concrete conclusion on this issue. The exponent is an indirect measure of the damaging factor of an axle load in comparison to that of a standard axle of 80kN and is therefore not a fundamental unit of deterioration. Also, a higher exponent leads to low ESA's if the majority of the loading is less than 80kN. This needs to be explored further.
c. Geometric Design standards vs traffic volumes	The background to this was to try and save on construction and maintenance costs by reducing the widths for LVRs. The frequently-used current limit of a maximum AADT of 300 is too low and could be much higher. An example was given of a road in UK with a width of approximately 6m carrying AADT of 14,000 (but a long and perfectly straight road with extremely good sight distances and no large trucks	It was concluded that road width should be influenced by traffic mix. Where non-motorised traffic or motor cycles are significant, then the road width should be accommodating but, in general 5.5m may suffice.

	because alternative routes exist). Thus 'functionality' is a key aspect.	
d. Carbonation of cement-stabilised materials	Carbonation occurs and this is the general agreement. However, there are cases where carbonation occurs and the strength of the layer does not decrease significantly enough to result in failure. The original message was that carbonation was detrimental to road performance. Examples of research carried out by Frank Netterberg were cited.	It was concluded that further deliberations and research were required to determine circumstances where carbonation would have adverse effects.
Closure	**Details**	**Conclusions and recommendations**
Closing Remarks of the Chairperson	The Chairperson thanked those present for making time to come and participate in this important workshop and that, as the Chairman and Client he was satisfied with the proceedings and the outcomes of the workshop. There being no further issues to discuss he closed the meeting at 1100hrs on the second day (27th September 2016).	It was agreed by the participants and the Chairperson that workshops of this nature were very important and should be held more often. The Client would consider additional workshops of this nature for this project.

Annex C. Summary of the Second Workshop

Venue: CSIR, Pretoria, South Africa; Date: 6th February 2017

Purpose: To review the database and suggest further data sources and identify potential knowledge gaps consideration in Phase 2.

Present:

	Name	Organisation	Role	Contact
1	Les Sampson	ReCAP	PMU/Chairperson	Les.Sampson@cardno.uk.com
	Jasper Cook	ReCAP	PMU	jaspercook@cardno.uk.com
2	Nkululeko Leta	ReCAP	PMU	nkululeko.leta@cardno.uk.com
3	Mike Pinard	InfraAfrica	Pool of Experts	mipinard@global.bw
4	Phil Page Green	Private Consultant	Pool of Experts	paigegreenconsult@gmail.com
5	Tony Greening	Private Consultant	Pool of Experts	tonyk.greening@sky.com
6	Gamalihle Sibanda	Private Consultant	Pool of Experts	gamasibanda@gmail.com
7	Frank Netterberg	FN	Pool of Experts	fnetterberg@absamail.co.za
9	Rob Geddes	CDS	LVR Performance Evaluation	rgeddes@cdsafrica.com
	Alexander van Dostenrijk	Independent Software Developer	Software Expert	alexander@independent-software.com
	Adele van der Merwe	CSIR	LVR Performance Evaluation	audmerwe@csir.co.za
	Joseph A Boateng	CSIR	LVR Performance Evaluation	Janachi.boateng@csir.co.za
	Martin Mgangira	Independent Researcher	LVR Performance Evaluation	mmgangira@csir.co.za
10	John Rolt	TRL	Team Leader	jrolt@trl.co.uk
11	Kenneth Mukura	TRL	LVRs Expert	kmukura@trl.co.uk
	Tom Buckland	TRL	Software Developer	tbuckland@trl.co.uk

Apologies:

1. Andrew Otto – Senior Research
2. Adekunle Olowosulu – Private Consultant – Pool of Experts (West Africa)
3. Tony Greening – TRL- Pool of Experts
4. Michael Mayanja – TRL – Data Specialist/Researcher (Database)

Proceedings of the Workshop

Items/Issues	Details	Deliberations/Resolutions
Workshop Opening		
Welcome by Chairperson – Les Sampson	The Chairperson welcomed all participants to the workshop and thanked all for making time to attend and contribute to the project.	
Brief by the Chairperson	The Chairperson indicated that two members of the pool of experts, Tony	A key question was raised regarding the purpose of the database particularly what

	Greening and Adekunle Olowosulu could not be present. It was also felt that some of the ongoing LVR monitoring projects would contributed significantly to the population of the database and it was decided to invite key members involved in these projects to participate in the meeting. The Chairperson gave some opening remarks covering a recap of what transpired during the first meeting and objectives for the second meeting. First meeting objectives: i. He mentioned that the first meeting was aimed at determining key sources of data of which 13 such sources were identified and provided to the consultant. ii. The development of the architecture of the database was another key output and different levels of data sets were developed in a hierarchical manner i.e. country, project, sites, data sets of key parameters and raw data. iii. Guidance on drafting the database and the user manual. iv. Guidance on the population of the database and trials on its functionality. The Chairperson mentioned that the above items had been executed by the project team and a draft database and user manual were available. He hoped that the participants had had time to work with the database. The database had been populated and approximately 9 projects had been covered. More data was still to be entered. Objectives of the second meeting: i. The first objective was to go through the draft database and comment on its architecture and data input and output functions and suggest improvements. ii. The second objective was to determine gaps in the database and knowledge of LVRs in general; this will form the basis for formulation of tasks and outputs for Phase 2 of the project. After deliberations he asked John Rolt to address the meeting on the status of the project and key expectations of the meeting.	the database was going to be used for and by whom. It was mentioned that the database is a repository of data on LVRs and the first of its kind. A lot of work had been carried out over many years but it was all in different reports mostly in hard copies and was most likely never going to be accessed in the future. The database would keep the data available for future generations. The database is not expected to have analytical functionalities but should allow extraction of the data to excel, for example, where analysis may be carried out in detail. The main user will be researchers and others in the road sector who may want to develop their own standards or specifications or manuals or for academic purposes by lecturers and students. It was highlighted that analysis would be complex and required good knowledge and experience to be able to manipulate the data properly. It was also highlighted that capacity building on the use of the database would be a key element of the Phases 2 and 3 of the project. It was agreed that the data being collected as part of the AFCAP monitoring projects and the databases being produced in the countries should be compatible with the main regional database. The chairperson and the participants came to the conclusion that the project was complex but invaluable at the same time. It was indicated that there would be a breakpoint at the end of March 2017 and the project will proceed into Phase 2.

Presentation by Dr John Rolt	Details	Deliberations/recommendations
a. Project Status	John made a presentation covering the following aspects: i. The data were from different sources and produced for different purposes. This will make it potentially difficult to combine some of the data sets for more extensive analysis. One of the main purposes of the database is to be able to combine the data for analysis in the future and compatibility is therefore a major challenge in this regard. ii. All are familiar with the complexities faced in populating the database. - Some of the data are in spreadsheets and relatively easy to include in the database. - Hardcopy data where the key information is in tabular form are easily scanned to convert to electronic format but key information is often only mentioned in the text and requires careful searching to identify this. - Graphical information was almost impossible to convert to digital numeric format. No method has been found to date to simplify this sufficiently for regular use. This has meant that several projects could not be entered into the database at this stage. - Three additional projects were selected to substitute for those that were not suitable iii. So far 9 projects had been entered into the database iv. The team were requested to check their particular projects in the database for completeness and accuracy in interpretation. v. Additional data are needed. The pool of experts was requested to supply additional data sources if at all possible. After the deliberations the Chairperson requested for a presentation on the database which was carried out by Tom Buckland.	The following issues were raised and deliberated on. There is need to prioritise on the missing data and information so that more data can be entered before the end of Phase 1. There are databases being produced in Tanzania and Mozambique and there is need to collect similar data and send such data for entry into the regional database – liaison is required amongst the different teams. There is need to standardise the test methods for the performance monitoring exercises in different countries so that the data can be used in populating the regional database. Phil has prepared research protocols and these should be shared with the consultant and other monitoring project teams. The database must include the test methods in order to assist the analysis. These are mainly materials test methods which tend to produce different results depending on which standard is used e.g. AASHTO, BS, TMH, etc. Phase 2 includes rolling out of the database. There is need to manage expectations because potential users will have a very wide range of requirements and therefore expectations. For example, it should be clear that the database will not design a road for the user. Managing expectations so as not to disappoint or mislead is vital for success and sustainability. There is need for a brief summary for each data set for the benefit of the user – the providers of the projects and data were requested to prepare such summaries. There is need for hyper-links to the reports from where the data were obtained. In future there will be need to prepare worked examples on how to process the data. An appropriate level of competency will be required to be able to edit the database and process the data. Capacity building is key to the successful application of the database.
Presentation of database by Tom Buckland	**Details**	**Conclusions and resolutions**

	a. Architecture of the database b. Data population	
Gap Analysis by John Rolt	**Details**	**Conclusions and resolutions**
a. Project Data	The following Gaps in the Database were highlighted. i. Data which has not been supplied to TRL from the first experts meeting. ii. Much of the data from Botswana was largely in graphical form and in hard copy reports. It would be good to include these data if available in tables. iii. HDM data are not yet available. Data on unpaved roads has been supplied by Phil and will be entered into the database. iv. Data which are being collected from AfCAP monitoring project are not captured in the database and have not been supplied to the project team yet. v. The Hoopstad project has data dating back 30 years and the report should be available on the AfCAP website. vi. Juanang BG4 Botswana data could also be included. vii. Road design studies particularly for rehabilitation may be included e.g. the Malawi study with DCP, traffic, rut depth, etc. viii. Maintenance data should be included in the database when and where available. ix. Cambodia data may also be relevant and Jasper will look into it. x. Botswana data on NATA project can be used but it is in hard copies.	The population of the database is and will remain a continuous process and at this stage additional projects shall be added. The participants involved in the pool of experts and others present were requested to supply the data for the stated projects (which they have). It was agreed to pursue the World Bank HDM data particularly because the WB are working on the data and carrying out further analysis hence recent outputs could be available. Leta was tasked to be the liaison person to coordinate the harmonisation of the AFCAP projects, receive data and supply information to the project team and pool of experts. Maintenance is key to the performance of LVRs. However, this is not forthcoming in the available reports. In future maintenance and its impact will need to be quantified and recorded. It was noted that the Kenya project K402 is still a pipeline project so no data are available yet.
b. Knowledge gaps	The following potential knowledge gaps were identified. For details see Annex D i. *Self-cementation of calcretes and laterites.* ii. *Performance of grey sands in pavement layers*. iii. *The sand guideline Laterite*. iv. *Drainage.* v. *Alternative surfacing.* vi. *Stabilisation*. vii. *Emulsion stabilisation*. viii. *Environment*. ix. *The impact of pavement moisture* x. *Terrain*. xi. *Soft subgrad*e	The list of knowledge gaps was not exhaustive. Participants were asked to consider how these gaps could be closed through back analysis of existing sections under Phase 2 and the following issues were raised: There are many variables affecting road performance and the number of sites required in a statistically robust experimental design is therefore very large. This is, of course, one of the key reasons that the projects in the database should be capable of being combined where possible to provide a much better statistical base for analysis. However priorities need to be set

	xii. *Investigation of soils with high mica content*. xiii. *Use of salty or sea water in the construction of LVRs* xiv. *Traffic loading*.	because the task is large. A systematic approach is needed to choose priority projects. Important data from ongoing AFCAP research studies may provide useful data but the timescale for extensive performance data to be available may be too long. This aspect of AfCAP projects needs to be addressed when selecting new projects for the database. Furthermore it must be made clear precisely why particular studies have high priority. 'Re-inventing wheels' must be avoided and chasing problems that researchers have been trying to solve for many years but have failed to do so must be considered very carefully given the relatively small scale of the research element included in the ToR for the next phase of this project. The suggestion from the consultant was that 30 sites are not likely to be adequate for anything but the simplest comparisons but such sites have the other vital necessity, namely training and capacity building. The meeting resolved that the consultant would review the inputs in the database and the knowledge gaps and come up with a costed proposal and programme for Phase 2. It was also noted that the sites do not necessarily have to be selected in AfCAP countries as long as there is technical justification for their selection and prioritisation.
c. Additional Projects	Notification was made by the Client that it was envisaged from the beginning of Phase 1 that the Regional Sands and Laterite Projects which were started under AfCAP Phase 1 and could not be completed would be added in the Regional Back Analysis Project.	It was resolved that the consultant should consider including these additional projects in the proposal for Phase 2.
Way Forward	**Details**	**Conclusions/Recommendations**
a. Pool of Experts	To provide summary guide for their reports or the reports which they provided; not more than a page long and preferably half a page. To provide additional data and/or reports. To attend the workshop slated for the beginning of April 2017.	
b. Client	To hold a meeting with TRL around 20th or 21st February 2017 Jasper to meet with Tom to discuss SEACAP data. To attend the workshop in the first week	

	of April 2017.	
c. TRL	To improve the architecture of the data base to provide all key parameters and also allow for an option of adding new data fields. To provide a more structured database and provide breakdown or lower tier items for terms which have been presented in global terms such as materials (surfacing aggregate, laterites, calcretes, etc) or strength (soaked CBR, in-situ CBR, UCS, etc.) To populate the database and continue the evaluation process. To carry out a more detailed gap analysis and propose a matrix for Phase 2 to close key gaps. To prepare a methodology and a costed proposal for Phase 2. Conduct a workshop in the first week of April 2017. To prepare the final report with recommendations for Phases 2 and 3.	There will be a break at the end of March 2017. Visits to potential candidate countries, roads and sites would not be carried out under Phase 1. The technical paper and training will no longer be part of Phase 1 but Phases 2 and 3.
Closure	**Details**	**Conclusions and recommendations**
Closing Remarks of the Chairperson	The Chairperson thanked the participants for making time to come and participate in this important meeting. He also requested for feedback from the participants with regard to the meeting, discussion points and presentations. There being no further issues to discuss he closed the meeting at 1500hrs (6th of February 2017).	The participants indicated that the meeting was useful and they now had a better understanding of the issues and the database. They said database was simple, user friendly and functioned well and it will be much better when suggestions made during the meeting.

Annex D. Research Projects in the Database

	Country	Project/Report	Authors	No. of sections	
1	Botswana, Malawi, Zimbabwe	Performance of Low Volume Sealed Roads: Results and Recommendations from Studies in Southern Africa	C Gourley, P A K Greening (TRL)	55	The performance of roads with natural gravel roadbases were studied and new design charts produced. The main conclusions and recommendations were: • The minimum standard of 80% soaked CBR for natural gravel roadbases is inappropriately high. New specifications are recommended depending on traffic, materials and climate. • Field/optimum moisture content ratios ranged between 0.5 to 0.7 in the driest areas to between 1.0 to 1.2 in the wettest areas. • Alternative (wider) grading envelopes were recommended. • Many sections had been subjected to a high degree of overloading but deformation (rutting) was low. New limits for PI were recommended. • A minimum crown height of 0.75 metre is recommended. Sealed shoulders provide a structural and maintenance benefit and should be considered even on low volume roads.
2	RSA	LVR Performance Study (Paved)	P Paige Green (CSIR)	54	A factorial design based on climate and materials. Roads with either marginal quality natural gravel bases or thin structures. Seal types were a random variable.
3	RSA and Namibia	LVR Performance Study (Unpaved)	P Paige Green (CSIR)	110	A factorial design covering 6 natural gravel wearing course materials (acid and basis crystalline, arenaceous, argillaceous, pedocrete and high silica), 4 climate zones (N< 2, 2-5, 5-10, > 10) and two traffic categories < and > 100 vpd).

4	Vietnam, Cambodia, Laos	**SEACAP – RRSR (Rural Road Surfacing Research)**	J Cook, J Rolt, R Petts (TRL/OTB/Intech Assoc.)	140_+	The RRST studies contained two main phases of trial construction between 2004 and 2006. 107 representative sections of between 80 m to 200 m length were selected for ongoing performance and whole-life-cost monitoring. Key aspects of the two phases are as follows: The RRST-I programme concentrated on four roads in the Mekong Delta and the Central Coastal area. Short lengths (100-200 m) of different pavement options were constructed on each trial road. Each trial road had, in addition, short lengths (100m) of control sections of unsealed road or penetration macadam sealed road. The RRST-II programme was undertaken in a wider set of physical environments in the Northern Highlands, Central Highlands and the Red River Delta as an extension of the RRST-I programme. It involved much longer lengths of trial and control section, from 500 m to more than 2 km. The SEACAP 1 project included initial as-built condition surveys and some initial condition monitoring up to March 2007. The SEACAP 27 project was an extension of SEACAP 1 and was concerned primarily with the continued collection and analysis of pavement performance information from the RRST I and RRST II trial road sections. Mid-term pavement monitoring provides information on early performance and deterioration and is vital if the reasons for deterioration are to be recognised and understood. A total of 12.67 km are included in the monitoring programme with section lengths of between 90 m and 200 m.

5	Botswana	**Calcrete in Road Bases in the Kalahari Region of Southern Africa**	P A K Greening, J Rolt (TRL)	8	This principal objectives were to: • evaluate the performance of four different calcretes used as road bases in a pavement designed to carry 0.5 million equivalent standard axles over a 20 year period. • establish guideline specifications for the use of calcretes in road bases. • assess the use of Kalahari sand as a sub-base material. • estimate the cost savings that can be achieved by using the calcretes. • measure and evaluate the impact on road performance of compacting materials at moisture contents less than the optimum value. A preliminary part of the programme was the location and mapping of calcareous deposits in the southern Kalahari and an investigation of their engineering properties. Four types of calcrete were used as road bases in a full-scale road trial constructed near Jwaneng as part of the Lobatse-Jwaneng road. A regular monitoring programme was carried out to measure the performance of the test sections over a period of nearly 15 years. In carrying out the analysis, a number of subsidiary outputs have been produced. For example, the applicability of the fourth power axle load/pavement damage law has been examined and relationships have been developed between road deterioration and traffic.
6	Botswana	**The Nata Base Course Experiment**	F Netterberg (Botswana Road Dept, CSIR).	8	5 sections of mostly substandard untreated, calcrete base courses under a 6.7 m wide double surface treatment (6.7mm on 13.2 mm chippings, and 60% cationic emulsion) with gravel shoulders was constructed on the road between Francistown and Nata in 1977 with 3 control sections of similar material modified with 3 or 3.5 % of hydrated lime. Average annual rainfall was 417 mm. Monitoring was carried out every 2 or 3 years. After 10 years all the sections remained in a satisfactory to good condition after carrying a cumulative traffic of at least 0.5 mesas. It is concluded that the PI of similar coarsely graded (GM >2.0) calcrete base course can be relaxed from 6 to a maximum of 15. The minimum laboratory soaked CBR at 98%, MAASHO compaction can also be relaxed from 80 to 60.

7	Botswana	**The Jwaneng Sand/Asphalt Experiment**	F Netterberg (Botswana Road Dept, CSIR).	23	The study consisted of 23 sections constructed in 1979. The main purpose was to evaluate alternative base materials and thicknesses for roads in the Kalahari. Average annual rainfall was 464 mm. Carriageway width was 6.7 m. Sections 1 to 12 had Kalahari sand-asphalt bases; sections 13 to 23 had calcrete bases. Surfacings were double seals, sand seals and unsurfaced. The calcrete bases had soaked CBRs between 60-120% at 100% MAASHO. Monitoring was done over a period spanning 13 years.
8	Zimbabwe	Secondary and Feeder Roads Development Programme Phase 1 - Gravel	U Brudefors, G Sibanda, (DSR, Sweroads).	27	The Secondary and Feeder Road Development Programme (SFRDP) was established to promote the technical development of secondary and feeder roads in. The study was conducted between 1986 and 1995 and comprised 27 gravel road sections. Rainfall varied from 274 to 783 mm/yr and traffic varied from 30 to 107 ADT with heavy trucks between 33 and 55%. . Common maintenance practices (light and heaving grading) were carried out on the sections.
9	Zimbabwe	Secondary and Feeder Roads Development Programme Phase 1 - Sealed	U Brudefors, G Sibanda, (DSR, Sweroads).	15	The Secondary and Feeder Road Development Programme (SFRDP) was established to promote the technical development of secondary and feeder roads in. The study was conducted between 1986 and 1995 and comprised 15 road sections.
10	Ethiopia	Performance Criteria and Life-Cycle Costing for LV and Labour-based Unpaved Roads	K Mukura, P A K Greening, G Morosiuk, R Bennett (TRL with ILO)	24	The main component of the study was to investigation the performance of different types and qualities of wearing course materials. The independent variables were rainfall, terrain, gradients, and traffic. The project was carried out in 6 countries The intention was to cover the geographical and physiological distribution of the Region. The study included cross-sectional surveys from verge to verge with measurements of cross-sectional levels taken at every 20 m.. Roughness measurements were carried out every 6 months using the MERLIN and data
11	Ghana	Engineering Standards for Low Volume Unpaved Roads.	K Mukura, P A K Greening, G Morosiuk (TRL with ILO)	24	
12	Mozambique			24	
13	Zimbabwe			31	
14	Lesotho			23	

15	Uganda	Increased Application of Labour-Based methods for LVRs	K Mukura, P A K Greening, G Morosiuk (TRL with ILO)	8	were collected and analysed to determine the rate of progression of deterioration. Materials were tested for quality including plasticity, grading and CBR. Rainfall ranged from <200mm to high (>1000mm). The range of AADT was from. 1-10 to 200. The plasticity PIs ranged from non-plastic (NP) to highly plastic (>20). The gradient ranged from flat (0 %) to high (15%). Grading is represented in the form of grading modulus, GM. Both BS and AASHTO test methods were used. The types of wearing course materials included laterites, sands, quartzitic, decomposed granite and calcrete gravels among others. The outputs included trends for deterioration, the determination of the environmental component of gravel loss and correlations between rate of gravel loss mm/100 AADT/yr, traffic and material properties. Also, a life cycle costing model was developed including a Life-Cycle Costing Calculator.
16	Botswana	Botswana Pavement Monitoring Sections	CPP, InfraAfrica, Haas Consult, P Page Green, CSIR	23	The objectives were to: • Determine calibration factors for the correct prediction of pavement deterioration in any future year by examining different types of pavements under various traffic loading, construction, specifications and environmental conditions; • Provide accurate deterioration models to facilitate a more appropriate and cost-effective maintenance strategy, thereby optimising the use of allocated funds; • Provide data required for the upgrading of the Botswana Road Design Manual). The performance monitoring produced results that mostly showed more variation than actual changes, to the point that no continuous deterioration patterns were evident. It was clear that materials conventionally regarded as marginal or sub-standard according to existing standards, can perform very well in roads carrying in excess of 3 million standard axles. Many of the successful base courses were constructed from materials of G6 quality, and other conditions being favourable, it appears that more use should be made of such materials in the appropriate situations.

17	Mozambique	**Back Analysis of Previously Constructed Low Volume Rural Roads in Mozambique**	J Rolt, K Mukura, F Dangare, A Otto (TRL).	24	The main objective was to investigate the performance of existing low volume sealed roads taking into account the types of surfacings, the materials used for the construction of bases, sub-bases and subgrade, the age of the roads, cumulative traffic loading, and the physiological factors of climate and terrain. The study also included the measurement of the drainage factors of crown height and distance of drain invert from the shoulder. The test sections were 300m in length and the tests included detailed condition surveys, roughness measurements, rut depth measurements, deflection measurements using a light weight deflectometer, DCP tests, trial pits, materials sampling and laboratory tests. The range of traffic was up to 870 AADT and the cumulative traffic loading was up to 2.7mesa though most of the roads had traffic loading not exceeding 1mesa. The CBRs of the base courses were in the range 30 to 60. The PIs were in the range NP to 19. Crown height was varied. Overloading was encountered but not wide spread. The tests carried out on the bituminous surfacings included penetration, viscosity, melting point. Cement and lime content tests were also carried out. The results of the investigations and analysis of the data showed the following: 1. The pavements were substantial in terms of overall thickness as measured by the DCP. While the actual measured thicknesses of the bases were commensurate with low volume roads (LVRs) design (150mm+/-) the structural contribution of the subgrade in terms of the CBR values was high and equivalent to that of the subbase. This was a result of long term consolidation under traffic action. The traffic loading capacity of these pavements was much higher than is expected of LVRs, some in excess of 6 MESAs. 2. There was no significant structural failure on the test sections even though, a. Some of the bases were very weak and highly plastic b. Traffic loading was high (0.3 – 2.7 mesa). 3. Most of the samples of bitumen extracted from surfacing samples were very hard with penetration ranging from 1 to 5dmm. This showed bitumen which had exceeded its service life and had become brittle. Bitumen samples obtained from Otta seals had penetration values of close to 10dmm and those from hot sand asphalt ranged from 18 to 35dmm. The ages of the bitumen were relatively low (4-7 years). 4. The fresh bitumen from Mozambique had a penetration value of 58 instead of 80 – 100dmm. No volatiles were found in the fresh samples when the gas spectrograph mass spectrometry (GSMS) tests were carried

18	Jamaica	The Performance of a Full Scale Road Pavement Design Experiment in Jamaica.	J Rolt, H Smith, C Jones (TRL)	8	Nine experimental sections, each 91m long and separated by transitions of 30m, were constructed on the May Pen bypass. The following aspects of performance were studied. (i) The relative performance of different thicknesses of good quality marly limestone roadbases. (ii) A comparison between the performance of a poor quality marly limestone stabilised with cement and a good quality unstabilised limestone of the same thickness. (iii) A comparison between a full depth pavement of river shingle mechanically stabilised with fine-graded limestone and the same thickness of conventional pavement comprising a good quality limestone roadbase and a lower quality sub-base. (iv) Comparisons between conventional designs using different qualities of roadbase and sub-base. Correlations between CBR and UCS and also between the strength coefficients of stabilised and unstabilised materials were developed for use in structural number computation and, hence pavement structural design. A new relationship was developed for calculating the structural coefficient in terms of UCS which should be more appropriate for stabilised granular materials. The difference in traffic loading in the two directions enabled the pavement damages law relating different axle loads to be examined and improved.
19	Zambia, Zimbabwe	**Performances of Chemically Stabilised Roadbases: Results and Recommendations from Studies in Southern Africa**	C S Gourley and P A K Greening (TRL)	31	23 test sections on roads in Zambia, 8 in Zimbabwe with chemically stabilised roadbases. The objectives of the study were: a) Establish reasons for the disparate performance of chemically stabilised roadbases in the region. b) Provide guidelines for the chemical stabilisation of granular materials based on performance data.

20	Zimbabwe	Secondary and Feeder Roads Development Programme Phase 2 - Gravel	U Brudefors, G Sibanda, DSR, Sweroads.	21	21 unsealed sections of low volume road were selected for detailed monitoring. The gravel wearing courses included laterite, quartz, basalt and calcrete materials. The analysis indicated that for an ADT of 30 the optimal grading frequency was one grading per year for light grading and once every two years for heavy grading. For an ADT of 60, the optimal grading frequency was estimated to be double this. An analysis of total transport costs showed that heavy grading was preferable to light grading, the costs being between 6% and 13% lower for heavy grading. Gravel layer thicknesses ranged from 85-161 mm.. Rainfall at locations of the study roads ranged from 425-1415 mm. The economic evaluation also indicated that it is optimal to upgrade gravel roads once traffic volumes exceed 70 ADT.
21	Zimbabwe	Secondary and Feeder Roads Development Programme Phase 2 - Sealed	U Brudefors, G Sibanda, DSR, Sweroads.	34	34 sealed sections of low volume road were selected for detailed monitoring during Phase 2. The experimental trials included narrow mats, Otta seals and single and double seals. An analysis of total transport costs showed that for traffic levels below 300 ADT it is more economic to design for lower cross section and crown height. For traffic levels above 1000 ADT, it is economic to reduce the risk of economic disturbance by increasing the height of cross section and crown height. The soaked CBR of the roadbases at 98% MDD ranged from 35-220%, the thickness range was 90-200 mm, plasticity index from non-plastic to 12. For the sub-base, the CBR range was 14-240%, thickness range was 85-200 mm, plasticity index from non-plastic to 7. Rainfall at locations of the study roads ranged from 425-1415 mm

22	Botswana	Monitoring of Sealed Low Traffic Roads in Botswana	C Overby and Botswana Roads Dept.	27	Sehitwa – Tsau Road 1980 – 1989 The study consists of 6 sections constructed in 1980 on the 45 km road from Sehitwa – Tsau villages. The sections are each 200 m long. The principal materials used in the base and sub-base were calcified sand and powder calcrete. The subgrade was Kalahari sand of CBR 17-42% @ 95% MDD Mod. AASHO. The CBR of the calcified sand was 28-61% @ 95% MDD Mod. AASHO. The same calcified sand for the base had CBR of 38-79 @ 98% MDD Mod. AASHO. The stabilised material had CBR of 228-248 @ 98% MDD Mod. AASHO. Section 4 and Section 5 had bases constructed from 3% lime stabilised calcified sand. On average for all the sections, the sub-base was 10 cm and the base was 15 cm thick. The top of the base was armoured using 19-26 mm stone. The surfacing consisted of Single Otta Seal (quartz/silica aggregate) topped with a Sand Seal using Kalahari sand. An adhesion agent was used on the Otta Seal. The road was 5.4 m wide with 5.0 m wide sealed surface. The camber was 4%. In 1982, a seventh section was incorporated into the study. By the end of the monitoring period in 1989, the sections had carried about 188,000 ESA combined for both lanes due to channelization resulting from the narrow width. Very few defects were observed. The mean annual rainfall was 430 mm, and the area is classed as semi-arid. Deflection was measured using a Benkelman beam by the rebound method and a truck axle load of 6350 kg.

23	Botswana	Monitoring of Sealed Low Traffic Roads in Botswana	C Overby and Botswana Roads Dept.	19	Oodi-Modipane Road, Selebi Phikwe- Mmadinare Road, Sebina-Tutume Road 1982-1989. The selected sections are generally 1000 m long. From Oodi-Modipane Road, 12 sections were selected; from Selebi Phikwe- Mmadinare Road, 2 sections were selected; and from Sebina-Tutume Road, 5 sections were selected. Materials generally used were decomposed granite (soaked CBR at Field Density of 15-118% and plasticity NP-16), calcrete (soaked CBR at Field Density of 16-67% and plasticity 10-14), and laterite (soaked CBR at Field Density of 16-57% and plasticity 7-9). Base thicknesses were in the range 10-15 cm. Several types of surfacing were used: Surface Dressing + Sand Seal, Sand Seal, Otta Seal, in single and double layers. Binders used were bitumen and tar. By the end of the monitoring period in 1989, the traffic carried per lane for the roads were 200,000 ESA for Oodi-Modipane Road, 671,000 ESA for Selebi Phikwe- Mmadinare Road, and 377,000 ESA for Sebina-Tutume. The main defects at the end of the period was surface cracking with the Sand Seal constructed with tar having the highest amount of cracks. The annual rainfall was 380-500 mm, and the area is classed as semi-arid. Deflection was measured using a Benkelman beam by the rebound method and a truck axle load of 6350 kg.

Annex E. Knowledge Gaps

Introduction

During the discussions about 'knowledge gaps' that this project may be able to fill, the problem of knowledge gaps in general were discussed. A summary of these discussions is included in this Appendix. The range of 'knowledge gaps' is as follows:

E-1 Missing data from the projects entered into the database.

A basic set of data has been defined that is essential for any meaningful performance analysis. Data sets from previous projects may be incomplete in that all the information required to carry out any specific type of analysis may not be present. These types of 'gap' are to be filled, if possible, during this project.

E-2 Different Conditions

Data concerning information about the performance of LVSRs under conditions and situations that are not covered by the projects included in the database during Phase 1. Thus identifying these gaps leads immediately to a search for additional research projects that were not included in the original sample but which can be added during Phase 2.

E-3 Lack of Experience

Knowledge gaps that stem from a lack of experience with particular materials and their performance in road structures. Such gaps will help with the selection of future research projects should the 'gap' be large or important enough.

E-4 Knowledge gaps that stem from inexperience in the actual construction methods or techniques.

Pavement performance depends on many technical factors that are reasonably well understood but construction quality and the ability of contractors are critical and factoring these into the design and construction process in a quantifiable way is difficult. Hence a wide range of different performances can be expected from nominally identical designs. The solution depends on human rather than technical factors but a scoring scheme that helps to quantify this issue linked to how such risk factors can be used in the design process is an achievable and worthwhile goal.

Gaps of this kind may simply be of local importance because, by definition, the knowledge probably already exists. However, there is a serious danger that methods might be rejected because an initial trial by an inexperienced contractor has not worked well. A good solution to a problem can be sabotaged and never tried again if trials of it are unsuccessful because of a lack of the appropriate skills within the engineering community. Thus good demonstrations, training and general capacity building are an essential component in the filling of 'knowledge gaps' to create sustainable solutions.

E-5 Long-standing and largely fundamental knowledge gaps

Long-standing and largely fundamental knowledge gaps that research has been attempting to resolve for many years. There are several examples of this type of gap but they lie outside the scope of this project.

Collectively they can be summed up as a general lack of a useable and reliable theoretical approach to pavement design. This includes a number of key problems that are discussed in several of the recent manuals. For example:

1. Developing a reliable method of defining the critical stresses or strains at subgrade level (the current range of criteria do not depend on the 'strength' properties of the subgrade and the published values range across 4 orders of magnitude on the traffic scale),
2. Developing models that can predict the performance of asphalt materials with greater accuracy for different situations. The 'healing' time between applications of load is critical but at present cannot be taken into account. Top down cracking is widespread but not predictable in any useful way,
3. In general, developing a useable theoretical design method that deals with all the unreliable and over-simplifications of current theoretical methods.

E-6 Knowledge Gaps Identified by the Expert Group

In terms of this project the knowledge gaps that are of high priority are those currently missing from the database but which are likely to be filled through a wider and more comprehensive search amongst the research community, published research studies and studies that are known to have been successful but not published at the present time. In other words there is potentially valuable data to be obtained and analysed.

However, it is not surprising that a group of experts would concentrate on the 'big picture' and the most fundamental problems of pavement engineering when asked to identify knowledge gaps. Many of these might form part of a future research programme but would be beyond the scope of this project. Nevertheless it is worthwhile including such 'gaps' in this report for future reference.

lists these studies.

Table E-14-1 Knowledge Gaps Identified by the Project Team

Knowledge Gap	Notes
Based on existing projects	
LVR roadbase specifications	Relaxing of specifications
Subgrade strength for design	Comparison of different methods of developing design charts, resolving differences of opinion and reconciling methods.
Knowledge Gaps based on new projects	
Performance of alternative surfacings	Insufficient data especially concerning contractors abilities and subsequent performance
Surfacings for steep terrain	Always difficult
Drainage quality indicators	Current methods are too general
Stabilisation	More needs to be done
Emulsion stabilisation	More needs to be done
Soft subgrades	More needs to be done
Investigation of soils with high mica content	More needs to be done
Salty or sea water in the construction of LVRs	More needs to be done
Road width and vehicle channelling	Important where roadbase specifications are relaxed
Contribution to research into climate resilience	Included in other ReCAP projects

E-6.1 LVR roadbase specifications and structural designs

Over the past 5 years, a number of low-volume roads manuals have been written individually for Ethiopia, Kenya, Tanzania, Mozambique and Uganda. In the design catalogues the base layer strength for traffic class between 0.5 and 1.0 MESA is CBR 80% (soaked) for subgrade classes S2, S3, and S4 in regions of Weinert's N less than 4. However it is very rare to find natural gravels that have 4-day soaked CBR values as high as 80% minimum. To find a material of these characteristics often requires chemical stabilisation of a natural gravel or the use of crushed stone, or blasted and crushed rock which is also referred to as crusher run. Furthermore, all of the manuals recommend relatively stringent plasticity and CBR requirements for bases in the traffic category 0.5 to 1.0 MESA but the study states that, as more data become available, it is possible that the standards set in the guideline could be relaxed further.

Most road research projects have a time limit. This means that it is often not possible to obtain valuable long-term road performance information that would help to confirm or improve conclusions concerning both specifications and design methods. Several of the research projects already entered into the database are of such an age that such long-term performance information may be reliable and could be obtained by revisiting and testing the trial sites. A preliminary assessment is required before formulating a detailed plan.

The manuals also include the option of using the DCP-DN method of design that does not put so much importance on some of the traditional specifications and uses the DN value obtained with the DCP instead of CBR for specifying material strength. The relaxation of specifications for LVRs in this method is greater than in the traditional method and therefore a study designed to reconcile the

differences is required. This should focus on characterising pavement layer materials in roads that have so far successfully carried traffic to this level, especially roads built with natural gravel bases.

E-6.2 Performance of alternative surfacings

The performance of the surfacings on LVSRs is very variable (penetration macadam, emulsion based Otta seals or graded aggregates, single Otta seals with sand or slurry capping, etc). Hence, selecting the most cost effective surfacing for different situations is very uncertain and inaccurate. This problem is well worth investigating. There is an upcoming AfCAP project in Ghana which could feed such data into Phase 2. Some sites in Uganda and surfacings in Zimbabwe are performing well and could be included in such a study.

E-6.3 Surfacings for steep terrain

Terrain is an important factor in the performance of LVRs. A project in Ghana to investigate the performance of different surfacings on steep slopes should provide useful information for improving designs in hilly areas.

E-6.4 Drainage quality indicator

Drainage is a key parameter in the development and performance of LVRs. A simple 'drainage quality' indicator was developed in a previous study using crown height and distance of invert of side drains (H_{min} and D_{min}) but not tested extensively. Such an indicator would be valuable for defining the likely subgrade support to improve subgrade assessment for structural design purposes.

E-6.5 Stabilisation

It is important to determine where and when stabilisation is really necessary for LVRs. Sites in Mozambique with both stabilised and neat sand could be considered for back-analysis.

E-6.6 Emulsion stabilisation

Emulsion stabilisation is a good alternative to cement stabilisation. Sorowe-Orapa site could be back-analysed for this purpose.

E-6.7 Soft subgrade

This is a critical design factor and should be investigated so that performance data can be obtained for the modification of specifications. This includes TE treatments (treatment for expansive soils) which have worked well in Zimbabwe and have not been successful in some countries.

E-6.7 Investigation of soils with high mica content

Such soils cannot be compacted easily and there are good examples in Zimbabwe and Malawi.

E-6.8 Use of salt water in the construction of LVRs

Where alternative options are too costly – there are examples in South Africa, Botswana and Namibia.

E-6.9 Vehicle channelling

One of the problems with LVRs is the question of how much relaxation of traditional specifications can be permitted. The concern is that some LVRs will be trafficked only by relatively light vehicles but others may carry some quite heavy ones. The road damage power law is essentially concerned, or developed, based on subgrade deterioration. The usual specifications for the upper layers of pavement are designed to eliminate failure in those layers provided good engineering principles are used in the overall design. However, if specifications are relaxed the risk of roadbase (or sub-base) failure increases especially if heavy vehicles use the road. This risk increases dramatically if the road

is narrow and vehicle channelling is concentrated in a narrow wheelpath. This effect is not generally serious at subgrade level because the stress at that level is spread sufficiently but near to the surface of the road the concentration of high stresses resulting from channelling and heavy wheel loads can cause failures in weaker roadbases. Heavy vehicle simulator (HVS) testing has shown that concentrating the wheelpaths can be equivalent to increasing the traffic by up to an order of magnitude. A correction factor linked to roadbase specifications is required that depends on road width, traffic level and the proportion of heavy vehicles in the traffic stream. An approximate table already exists for the channelling effect but more research is required to improve the correction. Again, information in the database may help but it is thought that it is unlikely to be detailed enough.

This problem is closely associated with the form of pavement damage law that is suitable for LVRs. Such a project could be considered in future.

E-6.10 Contribution to research into climate resilience

Mitigating the effects of climate change falls mainly into the drainage/hydrology area of road design and construction but structural design will have a part to play. Current research projects looking at climate resilience are developing adaptation methods that will need to be studied through trials. Until such studies have been completed it is not possible to propose suitable trials, but such trials could possibly be combined with the studies being proposed here.