The Uptake of Existing LVRR Research Output in S E Asia to Deliver Affordable and Sustainable Rural Transport Infrastructure

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Abstract

Low Volume Rural Road (LVRR) surfacing and paving trials construction was carried out between 2001 and 2012 in Vietnam, Cambodia and Laos under various initiatives; including EngKaR[3] & SEACAP[4]. A range of materials and surface/paving types were trialled in various environmental and climatic conditions. There is a considerable amount of un-analysed cost and performance data for a range of low cost surfacing types that is unique and could benefit the design and construction of low volume rural roads in the region and elsewhere. Analysis of this data could lead to guidance and significant cost savings in the provision of affordable and sustainable access to rural and poor communities in whole-life-cost orientated asset management.

This Paper describes the background research carried out under SEACAP and other initiatives, the current status of the surfacing research data. It presents the rationale for the compilation, analysis, dissemination and embedment of the surfacing and paving research knowledge in the region and elsewhere.

Key words

SEACAP, LVRR, surfacing, paving, trials, performance, review, Cambodia, Lao PDR, Vietnam

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1 Introduction

The Asian Community Access Partnership (AsCAP) is a programme of research and knowledge dissemination funded by the UK government through the Department for International Development (DFID). AsCAP is promoting safe and sustainable rural access in selected countries in Asia through research and knowledge sharing between participating countries and the wider community. AsCAP commenced on the 1st August 2014 with the management contracted by DFID to Cardno UK.

This paper is concerned with the assessment and potential application of substantial investments in Low Volume Rural Road (LVRR) surfacing research and paving trials by DFID, World Bank, ADB and the partner road agencies in Vietnam, Cambodia and Laos. The research (2001-2012) was largely funded by DFID under the South East Asia Community Access Programme (SEACAP: 2004-2009) with significant contributions by preceding DFID programmes, with major support from the World Bank Rural Transport Programmes in Vietnam (2001-2012 and the ADB Roads Programme in Laos (2004-2007). All of the trials focussed on the use of local resources, particularly materials, and the optimisation of whole-life-costs of the transport infrastructure assets.

A study initiated by AsCAP has been completed on an assessment of the current status and content of surfacing trials undertaken in S E Asia, and the Vietnam Rural Road Surfacing Research (RRSR) database in particular, to assess the value in utilising it as a data resource for increased dissemination and uptake in AsCAP and possible AfCAP[5] countries. The subsidiary knowledge bases in Laos and Cambodia have also been assessed. This work has been carried out by Intech Associates under contract to Cardno as the Project managers of AsCAP and the overarching Research for Community Access Partnership (ReCAP).

This paper focuses on key aspects of this study with respect to its potential uptake by other ReCAP initiatives in Asia and sub-Saharan Africa.

2 Background

2.1 Overview

One of the aims of the ASCAP initiative, is to build on the programme of high quality research initially established under the South East Asian Community Programme (SEACAP, 2004-2009) and a first phase of AfCAP (2008-2014) and take this forward in a sustainable manner so that the results of the research are adopted in practice and influence future rural transport policy.

The current AsCAP Steering Committee has recognised the potential usefulness of the SEACAP research and basic data in terms of contributing to the current AsCAP programme. In this context the significant amounts of data on Low Volume Rural Road (LVRR) performance collected and analysed under SEACAP is seen as being particularly relevant.

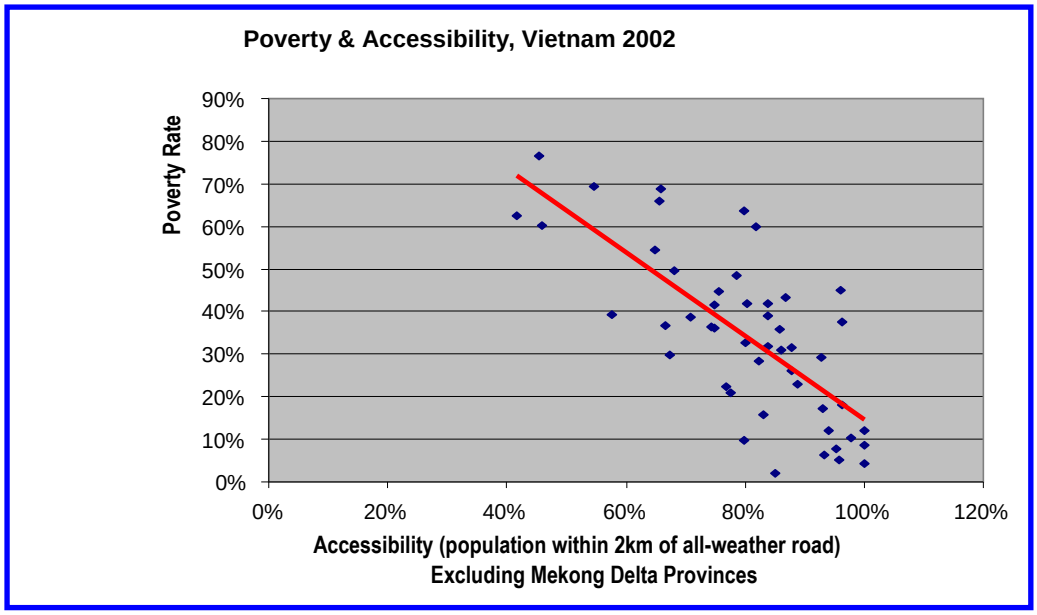
2.2 The Rationale for LVRR Research

The key driver for this research is the relationship between poverty incidence and access to an all-weather road; in most circumstances in the region earth and gravel roads cannot be categorised as ‘all weather’. It is now an accepted reality that rural development and poverty alleviation are significantly hampered if rural communities are denied suitable road access for their economic and

5 Africa Community Access Partnership.

social needs. There is an established link between poor access and poverty incidence (e.g. Figure 2.1 from the SEACAP 1 Final Report).

Figure 2.1: The link between poverty incidence and all season access.



Source: Vietnam 2002 Living Standards Survey

There is a range of alternative low-cost surfacings which are already proven and used in various locations around the world. Many of these options optimise the use of local materials and other available resources. They could have superior durability and whole life cost attributes, compared to unpaved, and certainly un-maintained, surfaces. Unfortunately, many national standards and specifications do not recognise these surface options and therefore they cannot be specified or used under normal contract arrangements.

Many of the options can use labour-based approaches, and can generate up to 1,500 worker-days per km during construction. The local communities (particularly the poor and otherwise un- or under-employed) would benefit considerably from their adoption in terms of productive work creation, empowerment of groups that currently are severely disadvantaged, and local enterprise creation. These advantages are in addition to the economic benefits to the poor communities through provision of improved infrastructure that would otherwise not be provided, and tackling poverty through creation of increased social and economic opportunities in the communities. Appropriate use of the various surfacing options would depend on local circumstances.

There is also considerable potential to use the alternative surfacings on short particular problem sections such as through villages, on weak subgrades and hill sections. This is effectively a 'spot improvement', 'Environmentally Optimised Design – EOD', or basic access approach, for situations when resources are particularly constrained. Considering the wide range of circumstances and factors, which usually vary along a road route, it is often appropriate to specify different surfaces and paving thicknesses for sections of different characteristics.

A particular constraint is that the alternative surfacing techniques are often not properly documented and accessible; decision makers are usually not aware of the options, potential, requirements, appropriate specifications, cost and benefits.

The DFID funded Systematic Review of technology selection for low-volume rural roads in low-income countries (Burrow et al, 2015) made an important Policy and Practice recommendation:

'To appreciate the very different resource environment in LICs/LMICs, which is characterised by the scarcity and high cost of finance/capital for the private sector, low labour costs, the availability of usable non-standard materials, typical overdependence on imported materials, skills and equipment, and a weaker institutional support framework. This necessitates the development of more sustainable and local resource-based technologies, such as those identified in this review, and operationally effective asset management systems.'

There is therefore an urgent need to document the extensive local-resource-based SEACAP surfacing trials experiences and develop usable guidelines to enable road authorities to be informed of, review, adapt and mainstream the range of alternative, affordable, robust and sustainable surfacings suitable for their physical and operational environment.

2.3 Climate Impact and Climate Resilience

The climatic environment in S E Asia, with its variability and frequency of extreme weather events, makes AsCAP and former SEACAP partner countries highly susceptible to climate impacts. At the same time, it is increasingly acknowledged that rural transport infrastructure is particularly vulnerable to climate threats and associated impacts. The risks arising from these impacts are considerably increased when the likelihood of increasing climate threats from future climate change is taken into account. There is therefore an increasing focus on identifying and applying cost-effective approaches to increasing the climate resilience of rural roads that takes into account the local road environments and the constrained budgets within which most road authorities have to work.

There is wide range of possible interventions required to make roads more climate resilient (Table 2.1). It is important to note that improved surfacing is only one of a number of potential interventions. There has nevertheless, recently been an appreciation that the SEACAP surfacing trials, and the Vietnam RRSR trials in particular, are a valuable source of information on the climate resilience of surfacing options.

Table 2.1 Engineering Climate Resilience Options

Ref.	Adaptation Option	Comment
1	Pavement sealing	Pavement sealing particularly recommended for steep gradients (>8-10%).
2	Additional or enlarged culverts/drifts	Additional, enlarged or improved existing cross culverts/drifts considered essential to improve overall road drainage.
3	Side drainage.	Additional side drains and associated turn-outs. Scour checks where necessary, Lined drains required on erodible soils with gradients >6%.
4	Raised embankments	Raising of earth embankments where the alignments are low and are being impacted by flooding and/or the weakening of the pavement by saturation.
5	Culvert or bridge abutment protection.	Gabion, concrete, masonry or bioengineering protection where erosion of abutments is identified as a significant risk.
6	River/stream erosion protection	Gabion, concrete, masonry or bioengineering protection where erosion of the alignment by rivers or streams is identified as a significant risk.
7	Cut and fill slope protection	Gabion, concrete, masonry or bioengineering protection where erosion or deterioration of existing earthwork slopes is identified as a significant risk.
8	Re-alignment	Re-alignments where an identified climate impact hazard and consequent engineering risk may be most cost-effectively overcome by avoidance.
9	River/stream crossing	Existing fords or low level bridges might be replaced by climate resilient structures such as vented fords, or submergible multiple culverts.

3 The SEACAP Surfacing and Paving Trials

3.1 General

Towards the end of the 1990s the challenges of providing and sustaining gravel surfaces for LVRR were becoming apparent in a number of emerging economies. There was increasing recognition that gravel surfacing was not always the best solution for rural roads, and in S E Asia, a series of surfacing trials were initiated in Cambodia in 2001 and extended to Vietnam (2003) and Laos (2006) with DFID support. The initial research focused on the performance of various bituminous and non-bituminous surfaces in comparison to unsealed gravel options (Petts, 2007). Subsequently, particularly in Vietnam, their role in providing a more climate resilient rural infrastructure took a more prominent role. In general, this work has concentrated on a range of pavements to establish the best performance within a range of physical and socio-economic environments. The bulk of the research was undertaken between 2003 and 2010 in Vietnam where three phases of trial road selection, design and construction were undertaken as the Vietnam Rural Road Surfacing Trial (RRST) programme, under joint DFID-World Bank funding in cooperation with the Ministry of Transport (Petts & Cook, 2006, and Cook, 2012).

In Cambodia SEACAP took over the rehabilitation and monitoring of 10 short sections of pavement and surfacing options on a rural road at Puok in Siem Reap province constructed under the DFID funded EngKaR programme (Gleeson, 2003). In Lao SEACAP funded the design, construction and some limited monitoring of 26km of LVR trials, constructed under ADB funding, consisting of eight options within one northern hill region (Roughton, 2008).

The combination of all three phases of the RRST programme together with the Cambodian and Laos trials mean that there is wide coverage of typical rural road environments found within the region, Table 3.1.

Table 3.1 SEACAP, ADB and World Bank Bituminous Surfacing Trials in S E Asia

Region	**Trial Terrain**	**No. of Bituminous Trials Sections per Geographical Unit**							
Vietnam		DBSTe	DBST	PMac	SSe	DSe	S/SBSTe	OTTA	OTTA2
Mekong Delta	Flat deltaic			4	2		2		
South Central Coast	Flat coastal			4	2		2		
North Central Coast	Flat coastal-small hills	7	11						
Central Highlands	Rolling hills	9	3	2			4		
Red River Delta	Flat coastal-deltaic	7	18		4				
North East	Rolling hills	10	6						
Lao PDR									
North West	Rolling hills				1	1		1	1
Cambodia									
Central	Flat inland plain	1		4	1				

Key

DBST: Double Bituminous Surface Treatment (chip seal). e: Emulsion. PMac: Penetration Macadam. SS: Sand Seal. DS: Double Sand Seal. S/SBST: Sand Seal on Single Bituminous Surface Treatment. OTTA: Otta Seal. Otta2: Double Otta Seal.

3.2 Trials Constructed

The complete range of SEACAP trialled options comprised a combination bituminous seals, block or stone surfacing and concrete slabs of various types. Sections composed of local standard unsealed option were constructed along with these options as a control on the performance and cost data sets, Table 3.2.

Table 3.2 Complete Range of SECAP Trialled Options

Trial Options	Cambodia	Vietnam			Lao
	Puok	RRST-I	RRST-II	RRST-III	Bokeo
SEALS					
Double emulsion chip seal - DBSTe			**2006**	**2011**	
Double bitumen chip seal - DBST	**2002**		**2006**	**2011**	
Emulsion sand seal over single chip seal - S/SBSTe		**2005**			
Single emulsion sand seal - SSe	**2005**	**2005**	**2006**		
Double emulsion sand seal - DSe					**2006**
Otta Seal - OTTA					**2006**
Double Otta Seal - OTTA2					**2006**
UNSEALED SURFACES					
Gravel Wearing Course	**2002**	**2005**	**2006**		**2006**
Water-Bound Macadam (WBM)		**2005**	**2006**		
Hand Packed Stone	**2002**				**2006**
Engineered Natural Surface					**2006**
SEALED BASES & SUB-BASES					
Water-Bound Macadam (WBM)	**2002**	**2005**	**2006**	**2011**	**2006**
Dry-Bound Macadam (DBM)		**2005**	**2006**	**2011**	
Emulsion Stabilised Sand		**2006**			
Cement Stabilised Sand		**2005**		**2011**	
Lime Stabilised Clay Soil		**2005**		**2011**	
Graded Crushed Stone				**2011**	
Natural Sand		**2005**			
Sand-Aggregate Mix	**2002**				
Natural Gravel	**2002**	**2005**	**2006**	**2011**	
BLOCK SURFACES					
Stone Setts/Cobble Stone	**2002**	**2005**	**2006**		**2006**
Fired Clay Brick		**2005**	**2006**	**2011**	
Concrete Brick		**2005**	**2006**	**2011**	**2006**
CONCRETE					
Steel Reinforced		**2005**	**2006**		
Bamboo Reinforced	**2002**	**2005**	**2006**		**2006**
Non-Reinforced			**2006**	**2011**	
Cast in Situ Blocks (Hysen Cells)					**2006**

Notes: 2005 etc. Year of original construction **Puok Trials upgraded in 2005 under SEACAP**

3.3 Trials Monitoring and Database: Vietnam

Under the three phases of RRST a total of 156 km of trial roads have been constructed within a range of road environments in 16 provinces, from which a representative 123 sections of between 80m to 200m in length have been selected for ongoing performance monitoring,

Table 3.3 The RRST monitoring programme, Vietnam

Trial Phases	Provinces	Trial road completed	Monitoring times									
			SEACAP I				SEACAP 27			RT3	RT3 AF	
Monitoring survey round			AS built	I	II	III	IV	V	VI	VII	As built	I
RRST-I	Hue	May-05	Jun-05	Jan-06	Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Jul-10		
	Tien Giang	May-05	Jul-05	Jan-06	Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Jul-10		
	Dong Thap	Jul-05	Jul-05	Jan-06	Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Jul-10		
	Monitoring survey round				As built	I	II	III	IV	V		
	Da Nang	Jun-06			Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Jul-10		
RRST-II	Tuyen Quang	May-06			Jul-06	Mar-07	Jan-08	May-08	Jan-09	Jul-10		
	Ha Tinh	Jun-06			Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Jul-10		
	Quang Binh	Jun-06			Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Jul-10		
	Ninh Binh	May-06			Jul-06	Mar-07	Dec-07	May-08	Jan-09	Jul-10		
	Hung Yen	Jun-06			Jul-06	Mar-07	Dec-07	May-08	Jan-09	Jun-10		
	Gia lai	Jun-06			Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Aug-10		
	Dak Lak	Jun-06			Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Aug-10		
	Dak Nong	Jun-06			Jul-06	Mar-07	Jan-08	Jun-08	Jan-09	Aug-10		
RRST-III	Cao Bang	Mar-12									Mar-12	Sep-12
	Thai Nguyen	Mar-12									Mar-12	Sep-12
	Thai Binh	Apr-12									Apr-12	Aug-12
	Thanh Hoa	Apr-12									Apr-12	Sep-12

The monitoring of the completed RRST trial pavements involved the systematic collection of the following data:

- Visual condition: using numeric coded sheets.
- Roughness: using low cost simple apparatus (MERLIN[6]).
- Strength: using Structural Number correlations derived from simple in situ tests (DCP[7]).
- Gravel loss (where appropriate): cross-sectional leveling.
- Traffic: 12 hour traffic counts (3 or 6 day).
- Photographic records.

The condition monitoring of the Vietnamese trials has resulted in the assembly of significant amounts of data on the performance of a wide variety of pavement and surfacing types over a 6-7 year period. The RRST database was developed as a means of managing and analysing this wide range of data on rural road surfaces and pavements in Vietnam. The database includes information on:

- Trial pavement designs.
- Construction costs.
- As built condition.
- Change of condition with time.
- Traffic.
- Physical and climatic environments

The RRST information is being held principally in the Rural Road Surfacing Research (RRSR) database whose structure was set-up in 2009 under the SEACAP 27 project. The updated database is currently held by OTB Engineering Ltd, who were the principal consultants in the latter stages of the project (see Chapter 6, below).

6 MERLIN: **M**achine for **E**valuating **R**oughness using **L**ow-cost **In**strumentation

7 DCP: **D**ynamic **C**one **P**enetrometer

3.4 Trials History: Cambodia

The construction of Pouk Low Cost Surfacing (LCS) Trials in Siem Reap Province, Cambodia was completed in September 2002 under a cooperation agreement between Intech Associates and ILO Upstream Project, utilising DFID funding provided under the EngKaR programme. The work was carried out under the authority of Ministry of Rural Development (MRD) and in cooperation with the Ministry of Public Works and Transport (MPW&T), Cambodia using local resource based approaches utilising two local contractors with the aim of demonstrating techniques that maximise the use of local labour, materials and enterprises.

An objective was to trial more sustainable rural road surfacing alternatives to problematic gravel/laterite, in view of the widespread scarcity of good gravel materials in Cambodia, long gravel haul distances, high rates of gravel losses from road surfaces and problems of funding and achieving maintenance of gravel roads. An initial monitoring of the surfacing trials was undertaken in April-May 2003, all trials road sections were found to be in good condition. Subsequently in 2003, a sand deposit was discovered close to the road trial site and an unauthorised commercial extraction operation was commenced to exploit the sand to supply many of the buildings and hotels being constructed in Siem Reap; the large provincial town nearby. Large 3-axle trucks with extended bodies were used with excessive (and illegal) axle loading to haul along the trial road; well beyond the rural road design criteria used for the trials site.

Despite warnings as to the consequences, the heavily overloaded trucks continued to carry sand through the LCS trials. In August 2003 during the routine monitoring visit, the first signs of failure appeared. By October 2003 the damage was already extensive and Intech carried out the first investigations of the pavement distress and causes.

In January 2004, a SEACAP funded Intech Associates technical team visited the trial site to carry out a full survey. It was found that 80% of one section and 20% of another had become severely damaged and some of the other sections were also showing signs of distress. A rehabilitation and repair proposal was submitted to DFID and approved as “SEACAP-8 Cambodia Low Cost Surfacing Phase II”. The rehabilitation and repair of Phase II was completed in late July 2005. Monitoring of the trial continued until March 2006 with a regular visit programme of every 2 months. It was necessary to carry out deterrent measures to prevent the large trucks from continuing to use the route. Deterrent measures are still in place today to prevent passage by anything larger than a small truck.

3.5 Trials History: Laos

SEACAP 17 aimed at identifying cost- effective methods of improving all-season access to the rural poor through low-cost, local resource-based improvement of problematic lengths of road, resulting in effective and sustainable rural access roads in Lao PDR.

The project was implemented to carry out research on a group of rural access roads in Houay Xai district of Lao PDR in conjunction with the Asian Development Bank (ADB), which funded the associated Northern Economic Corridor Project (NEC) Route No 3 (R3). The project required close collaboration between the Ministry of Public Works and Transport, ADB, SEACAP and the Consultant.

The construction of 12 trials sections and associated seven gravel control sections was completed in August 2007. This was followed by an initial as–built condition survey which was also intended to provide the base-level data for a future condition monitoring programme. A first monitoring survey was carried out by OtB Engineering and LTEC. The trials monitoring survey which followed-on from an initial training period, was completed during February and March 2009. A total of 2.75km of trial sections in 24 lengths on seven trial roads were surveyed.

Table 3.4 – Laos Trial roads, characteristics and lengths.

Roads					Monitored Lengths		
New Ref	Old Ref	From	To	Pavement Type	Start (km)	End (km)	Length (m)
1011	1-1	B.Phi Mon Sine	B.Chom Keo	Gravel	0+600	0+700	100
1013	1-3	B.Chan Sa Vang	B.Si Pho Sai	Gravel	1+270	1+370	100
102	2	B.Nam Phou Kang	B.Nam Sa Mok Neua	Gravel	0+450	0+550	100
				Packed Stone	0+700	0+800	100
				Packed Stone	0+940	1+040	100
1032	3-2	B.Bolek	B.Nam Tong Neua	Single Otta Seal	0+150	0+250	100
				Double Otta Seal	0+415	0+515	100
				Engineered Nat. Surface	0+800	0+900	100
				Mortared Stone	1+200	1+300	100
				Mortared Stone	1+300	1+400	100
				Gravel	1+520	1+720	200
1033	3-3	B.Nam Tin	B.Phou Vane Kao	Gravel	1+650	1+750	100
105	5	Gam Mining	B.Houay Sala	Paving Blocks	0+950	1+050	100
				Paving Blocks	1+250	1+350	100
				Bamboo Concrete (125mm)	2+000	2+100	100
				Bamboo Concrete (150mm)	2+350	2+450	100
				Geocells (75mm)	2+800	2+900	100
				Geocells (100mm)	2+950	3+050	100
				Geocells	3+050	3+125	75
				Gravel	3+175	3+275	100
				Gravel	4+550	4+650	100
108	8	B.Chom Chouk	B.Nam Kham Neua	Sand Seal	1+800	1+900	100
				Sand Seal	2+000	2+100	100
				Gravel	2+225	2+325	100
						Total	2,475

The following data sets were collected.

- Visual survey - using standard numeric based coded sheets;
- Cross sections – using standard levelling techniques;
- In Situ pavement layer strength – using Dynamic Cone Penetrometer (DCP);
- IRI Roughness - MERLIN;
- Pavement structure stiffness - Mini Falling Weight Deflectometer (FWD); and,
- Rut depth – using dipped measurements from a straight edge.

A further monitoring exercise was carried out by Roughton International in 2012 (Roughton, 2013).

4 Data Analysis

4.1 Performance

To simplify the condition assessment of the RRST roads assessment two indices were set up; the Road Condition Deterioration Index (RCDI) and the Deterioration Extent Index (DEI). The Calculation of a Road Condition Deterioration Index (RCDI) for each trial section, which is based on key indicators, allows assessment of the **level** of deterioration on a percentage basis, whilst the calculation of the Deterioration Extent Index allows assessment of the **extent** of deterioration for each trial section by summing all 5m blocks of the trial length of road showing any deterioration with respect to the key indicators.

Table 4.1 lists the key factors for the calculation of specific indices for each trial road group.

Table 4.1 Key Performance Indicators

Trial Group	Indicative Factors
Concrete	Joint condition Crack extent Surface condition Potholes
Bituminous seals	Crack extent Ruts Potholes
Blocks	Block condition Joint Condition Ruts Potholes
Control Group	
Unsealed	Erosion Ruts Potholes

The Road Condition Deterioration Index of a trial section is the ratio of Road Condition Deterioration (RCD) and maximum Road Condition Deterioration (RCD_{max}). This index shows the level of deterioration on each trial section for the features mentioned above. These indices were aimed for use in establishing the level of maintenance requirement as well as providing a starting point for the calculation of the whole life cost. In general terms it was considered that RCDs of around 10% should trigger routine level maintenance; 25% indicated a periodic requirement and anything greater that 50% would probably necessitate rehabilitation.

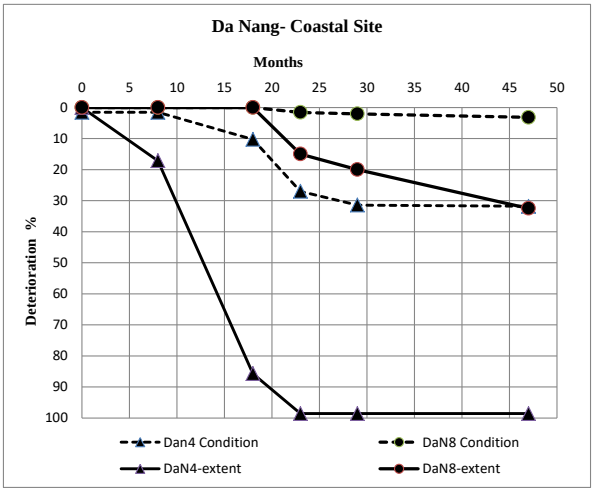
They can also be used to establish relationships between the performance of the trial surfacing options within a series of road environment in Vietnam. These simplified indices can be used at provincial or district level to monitor maintenance requirement.

Individual Condition Deterioration Indices (CDIs) for individual factors can also be established. For example, in the case of the concrete slabs, assessing an individual CDI for slab seals has proved to be a necessary step.

The Road Condition Deterioration Index (RCDI) can be calculated for the series of condition surveys over a number of years and the comparative deterioration of pavements can be plotted versus time or traffic (esa[8]). Individual Condition Deterioration Indices (CDIs) for separate factors can be examined to identify the most significant deterioration modes. The combination of RCDI and DEI allows a rapid assessment for maintenance of deterioration, seriousness, and extent; for example. Figure 4.1 presents an example of plots of RCDI and DEI over time for one particular trial section in Da Nang Province.

8 equivalent standard axle (80kN)

Figure 4.1 Typical RCDI and DEI Plots with Time



In Laos, the surfacing trials monitoring exercise carried out in 2009 made the following conclusions regarding viable alternatives to natural gravel surfacing:

> The interim survey of trial road conditions has raised some important issues regarding the selection and maintenance of LVRR pavement and surfacing options in Lao, namely:
>
> 1. The unsealed block option with sand joints is not likely to be a sustainable option unless regular maintenance is undertaken on the joints. Mortared joints or some form of water resistant bitumen-sand mix are likely to be more sustainable options. More stringent compliance with block strength specifications may be required in future use of this option;
> 2. The hand packed stone and mortared stone options have not been successful. Indications are that problems during construction may have contributed to their current deteriorating condition;
> 3. The sand sealed option is showing signs of serious deterioration and without immediate maintenance this could escalate rapidly;
> 4. The geocell options are performing well, although the deterioration of the surface screed and joint areas should be monitored for indication of any more serious consequential defects; and,
> 5. The concrete options require ongoing maintenance to the inter-slab seals, otherwise only occasion localised cracking is evident.

There is now a need for a final monitoring survey of these sites if uptake in terms of sustainable and cost-beneficial application of the various options are to be achieved from the initial investments in this surfacing trials programme.

There have been no formal investigations of the performance of the Puok trials in Cambodia since the last Intech monitoring surveys under SEACAP 8 in 2006. However, the recent scoping study visit under this assignment found most of the trial sections to be in reasonable condition considering age since construction and lack of maintenance. Refer to Chapter 7 for a current assessment.

4.2 Whole-Life Costs

A simple Cost Model was developed under the RRST SEACAP 1 project which considered only the costs associated with the road agency; that is construction and maintenance costs. The aim was to facilitate the assessment of Whole Life Asset Costs for the options trialled. Construction costs and Norms were developed for Phases I and II of the trials that were reviewed and refined for proposed future use on rural road works from the experiences on the trials construction and feedback from the contractors and supervisors. The model was developed in terms of Whole Life Road Assets; that is excluding vehicle operating costs (VOCs) due to the difficulties at that time obtaining truly representative VOCs for Vietnam.

The cost model was designed with the intention that a later edition would be able to accommodate an optional VOC sub-model. The model introduces a menu of appropriate rural road pavements with the road /asset/ agency whole life cost details (construction and maintenance costs) of each option, suggesting the most appropriate options for each defined local road environment.
The essential inputs for the model are

- Sub-grade geological and hydrological conditions:
- Types of soil,
- Strength
- Flood regime

- Road alignment longitudinal gradient,
- Terrain (mountainous, midland, plain etc.), related to region,
- Annual rainfall, related to region,
- Material sources and haulage distances to the site.
- Traffic volume
- Axle load regime
- Costs associated with the above

And outputs are:
- Construction cost of the selected option per km (with defined surface width),
- Maintenance cost per km in terms of present cost,
- Maintenance cost per km in terms of NPV.
- Whole Life Asset Costs for the road agency

The model was designed based on MS-EXCEL spreadsheets in order to provide rural road authorities and design consultants with a supportive tool for their road surface and pavement selection process. The model introduced a menu of appropriate rural road pavements with the whole life cost details (construction and maintenance costs) of each option, suggesting the most appropriate options for each defined local road environment. The initial menu was based on the early research findings of the RRGAP, and RRST-1 and RRST-II trials.

The Cost Model was complete to a functional state and could be used to analyse a range of options based on the RRST trials experiences. Further work was intended to fully develop the model to encompass all surfacing options for all possible environments encountered in Vietnam. The maintenance relationships were tentative only and needed to be refined in the light of the planned RRST long term monitoring data capture. The development of a VOC cost sub-model was also recommended to achieve a total transport whole life cost model capability.

It was expected that the further work on the model would have followed with later phases of SEACAP. This did not occur and hence the model requires further development work; nevertheless, the basic cost-norm data and initial model framework exists. Together with the accumulated performance data, this provides an ideal low-cost base from which to undertake additional whole-life cost and cost-benefit analyses on a range of sealed and unsealed LVRR options within a series of low volume rural road environments that could be of significant use to AsCAP and AfCAP partner countries.

5 Uptake Potential

5.1 AfCAP Back Analysis Project

TRL is undertaking a DFID funded research project for the Research for Community Access Partnership (ReCAP) to Develop Guidelines and Specifications for Low Volume Sealed Roads (LVSRs) through Back Analysis: RAF2069A - Development of Guidelines and Specifications for Low Volume Sealed Roads through Back Analysis.

The aim of Phase 1 of the project is to provide a consolidated knowledge base related to the performance of LVSRs especially where non-conventional materials and designs have been used and to capture the data in a web based database. The database will provide a repository for information related to roads that have been 'back analysed' over the past four decades in Sub-Saharan Africa, and will provide:

1. A valuable source of information for use in current and future research projects involved in the development of guidelines and specifications for LVSRs,
2. The identification of gaps for further investigation in Phase 2 of the project,
3. An information management tool for consolidation of relevant LVSR performance data generated by emerging African research centres in future.

Phase 1 of Back Analysis runs until end Feb 2017, with an option for an additional 64 weeks for Phase 2 and 3.

The intention is to develop an accessible database for researchers to lodge and analyse data on surfacing performance. There are obvious synergies between this project and the proposed follow up to this SEACAP Trials Scoping Study.

5.2 AsCAP Uptake Potential

The wide range of surfacing types and climatic environments encompassed by the Vietnam trials make the potential application of the derived knowledge applicable in many other regions. This paper focusses on just a few of the potential AsCAP uptake possibilities.

Table 5.1 summarises the national road network data for the AsCAP and SEACAP partner and potential countries, and the considerable scope for introducing affordable, local-resource-based surfacing and paving techniques on both the development of the unpaved networks and rehabilitation of paved roads.

Table 5.1: Road Network Data for selected AsCAP and SEACAP countries

Country	Paved Road Network (km)	Unpaved Road Network (km)	% Paved	Programme Partner	Data Source
Bangladesh (local roads only)	83,303	213,330	28	AsCAP	LGED website
Cambodia	3,500	41,300	8	SEACAP	ADB (2011)
Laos	6,500	37,100	15	SEACAP	MPWT (2012)
Myanmar	34,725	121,228	22	AsCAP	ADB 2015 (draft)
Nepal	8,145	56,000*	13	AsCAP	World Bank (2013)
Pakistan	185,063	78,879	70	AsCAP	CIA (2014)
Vietnam	150,191	145,420	51	SEACAP	DRVN (2014)

* Estimated

5.2.1 Bangladesh

Bangladesh shares a number of characteristics with the Mekong Delta region of Vietnam. Both are extensive deltaic regions with generally weak subgrades and almost total lack of hard stone resources suitable for road building.

The average annual rainfall in Bangladesh varies from about 1,000mm to over 5,000 mm per annum. This is compounded by substantial monsoon discharges into the country from the Brahmaputra, Ganges, and Meghna Rivers.

Bangladesh is situated in the tropics, the country is prone to cyclones associated with tidal surges, especially in the pre-monsoon and post-monsoon months. Because of high density of population in the flat deltaic coastal region, the loss of human lives in such cyclones can be substantial. Bangladesh is the nation most vulnerable to global climate change in the world, according to German Watch's Global Climate Risk Index (CRI) of 2011.

These issues represent a significant challenge to develop the national network of rural roads in an affordable and sustainable way. Lessons to be learnt from the SEACAP trials could make a significant positive impact on developing the Bangladesh strategy for sustainable rural access.

5.2.2 Myanmar

The AsCAP Scoping Study (Airey & Edmonds,2015) advised that the nature of Myanmar's rural access needs means that AsCAP research has the potential to have a strong policy and programming impact in the targeting and implementation of current Government of Myanmar expenditure. ADB considers that the transport sector will play a critical role in facilitating economic and social development in the country. An important priority is improved domestic connectivity through more efficient transport linkages between rural areas, markets, and urban centres.

The report identified some of the relevant issues as:

- The long years of isolation have affected the rural road sector's ability to keep up with and adopt current developments and good practise.
- This "knowledge gap" begins with the need for the current relevant institutions to "know", manage and prioritise the upgrading of its network.
- There is a likely need to update the standards, materials and specifications being used to design and build rural roads and drainage structures (in conjunction with the move to Metric).
- There is the possibility of introducing low cost surfacing technologies that might supplement the current preference for macadam and bitumen surfaces

Myanmar experiences between 1,000 and 5,000mm of rainfall per year through its varied climatic zones. With only 22% of the current road network paved, there is a substantial need to introduce climate resilient and affordable paving techniques. The current KfW funded rural access programme in Shan State has included a limited number of trial sections. Knowledge on the SEACAP approach to monitoring and analysis could prove to be extremely useful in turning these construction trials into much more valuable performance trial.

5.2.3 Nepal

Nepal's predominantly mountainous terrain and intense monsoonal climate have created substantial transport and access challenges. The AsCAP Scoping Report advised that Nepal's total road network is low in international terms and as a result less than half its population have access to all-weather roads.

DFID are funding Rural Access Programme Phase III and the Karnali Employment Programme (KEP). The former has a significant rural roads program strengthening capacity to improve and maintain the Local Road Network in 14 of the poorest districts of Nepal by labour intensive methods. The latter (KEP) is an important component of the Government of Nepal's social protection strategy in which, with RAP III and DoLIDAR support, local infrastructure is constructed by labour-intensive methods in the poorer communities of Karnali region. One of its objectives is to construct some 500 kilometres of rural roads and maintain a further 3,700 km of roads in the five districts of Karnali.

Project documents also stress poor and at time haphazard road construction techniques used on the less important Village and Agricultural roads. These often are not engineered and are not sustainable, inflicting significant environmental damage on unstable mountain slopes and valley bottoms.

With the wide variety of terrain and climatic zones the rainfall in Nepal varies between about 1,000mm and more than 3,000mm. With both an underdeveloped network and only 13% of the estimated network being paved, there is a substantial need to introduce climate resilient and affordable paving techniques, building on the SEACAP experiences. There are clear SEACAP links with the proposed AsCAP dust suppressant project in Nepal

5.2.4 Africa Uptake Potential

The Southern Africa Development Community (SADC) road network of approximately 932,000 km (excluding the Democratic Republic of Congo and the Seychelles) is one of the Community's largest public sector assets with current replacement costs estimated at approximately US$50 billion (Pinard, 2000). The World Bank estimates that only 15% of the networks in Africa were paved by 2005 (World Bank, 2008). There is therefore huge potential for adoption of affordable, local-resourced-based surfacing solutions and related benefits in this region.

6 SEACAP Trials Knowledge Base Structure and Status

6.1 Vietnam

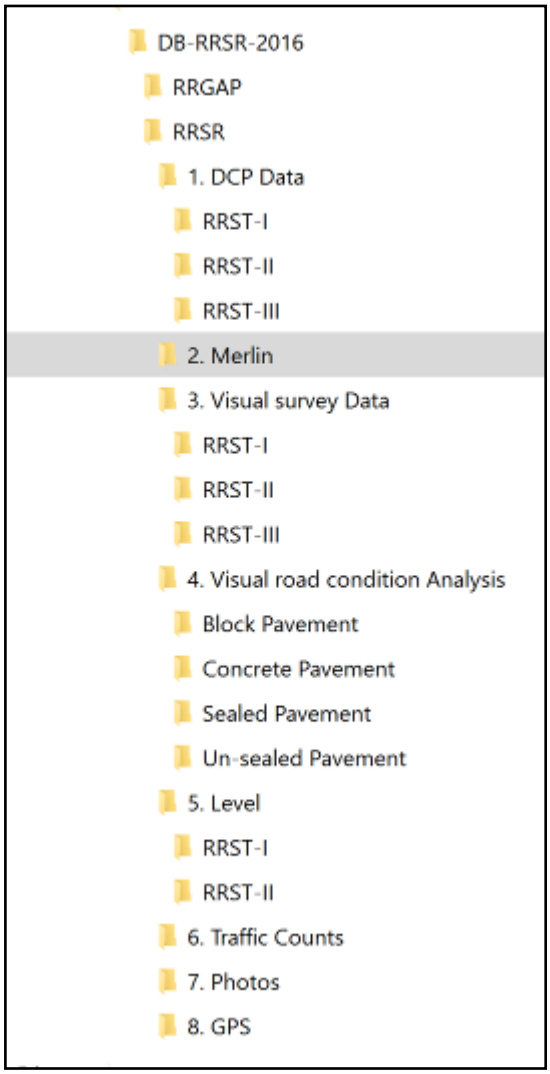
The formal Vietnam RRSR database is made up of 3 principal components;

- The RRGAP unsealed rural road condition data
- The RRST condition monitoring data and additional RRSR support data
- Supplementary data

The RRGAP component comprises two principal folders:

1. Grav: Gravel thickness data
2. Lab: Laboratory data and plots

Figure 6.1: Database Structure



The RRST structure is essentially similar to that of the database handed over to the MoT in June 2009. The current structure is shown on Figure 6.1.

The 8 principal folders are as follows:

1. DCP data: holds raw and processed DCP data from as built and condition surveys.
2. MERLIN: hold all roughness data from the trial sections. These data still require some more analysis to remove anomalous data sets.
3. Visual Survey Data: contains all raw visual un-analysed data on XLS sheets from the 16 provinces of RRST I, II, III. RRST III data comprises on as-built information.
4. Visual Road Condition Analysis: contains analysed data on XLS sheets from the 12 provinces of RRST I and II collated under surfacing group: Seals; blocks; concrete, unsealed. RRST III data from the single as-built survey is not included.
5. Level: Contains level data on all unsealed monitoring sections from RRST I and II.
6. Traffic counts: Contains traffic count data for RRST I and II roads up to 2009.
7. Photos. Contains relevant condition photographs from RRST I and II and construction photographs from RRST III.
8. GPS. Contains gps location data for trial section in “gdb” format.

The supplementary data sections comprise a number of folders that include such relevant information as:

- Pavement designs

- Construction costs
- Trial and monitoring lengths
- Construction quality assessments
- Laboratory results
- Historic rainfall

The RRSR database (2009) was handed over to the Ministry of Transport, Government of Vietnam. Copies of this database and the subsequent additions and upgrades under World Bank funding are held by OTB Engineering Ltd.

6.2 Laos

The less comprehensive and less structured database on the Laos trials and their performance comprises three main elements.

- Phase 1- A built; Contains data from surveys undertaken following completion of construction of the trials (Figure 6.2)
- Phase 2- Survey 2009: Contains data from survey a SEACAP undertaken by OTB Engineering -LTEC in 2009 with surveys of additional unsealed roads. Visual data analysed following the Vietnam RRSR procedures (Figure 6.3).
- Phase 3- Survey 2012. Additional survey undertaken in 2012 under AfCAP I funding by Roughtons-LTEC. Information on comparison with 2007 and 2009 surveys held with Technical Report.

Figure 6.2. Phase 1 Data Files

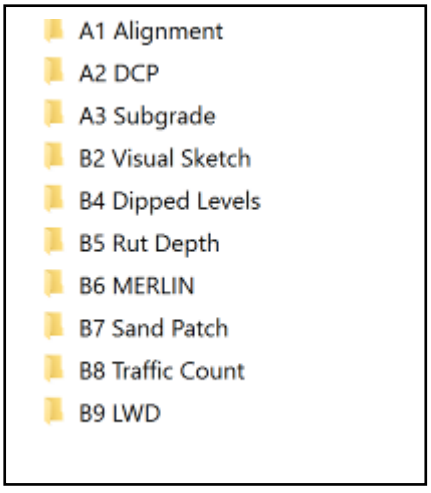
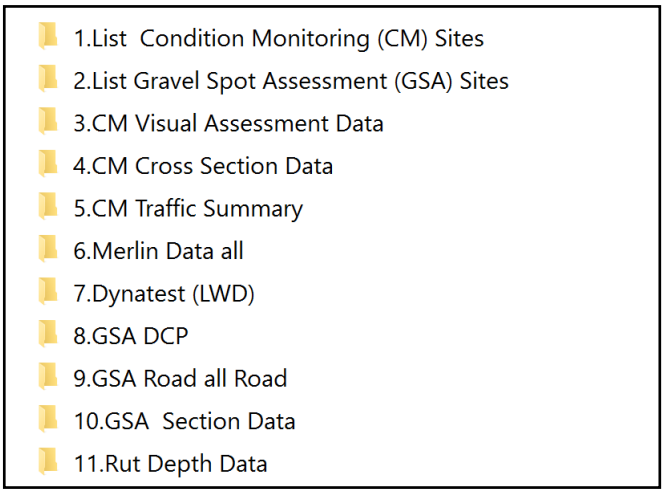


Figure 6.3. Phase 2 Data Files



The differing Lao database files require collation into a single database and consequent re-analysis.

6.3 Cambodia

No overall formal database was set-up for the Cambodia surfacing trials and other relevant data sets such as those from the Engineered Natural Surface (ENS) trials (SEACAP 19). Relevant Cambodian Rural Road Performance Data (RRPD) has been gathered into one main folder with sub-folders as follows.

Main Folder: Cambodia RRPD

Sub-Folders

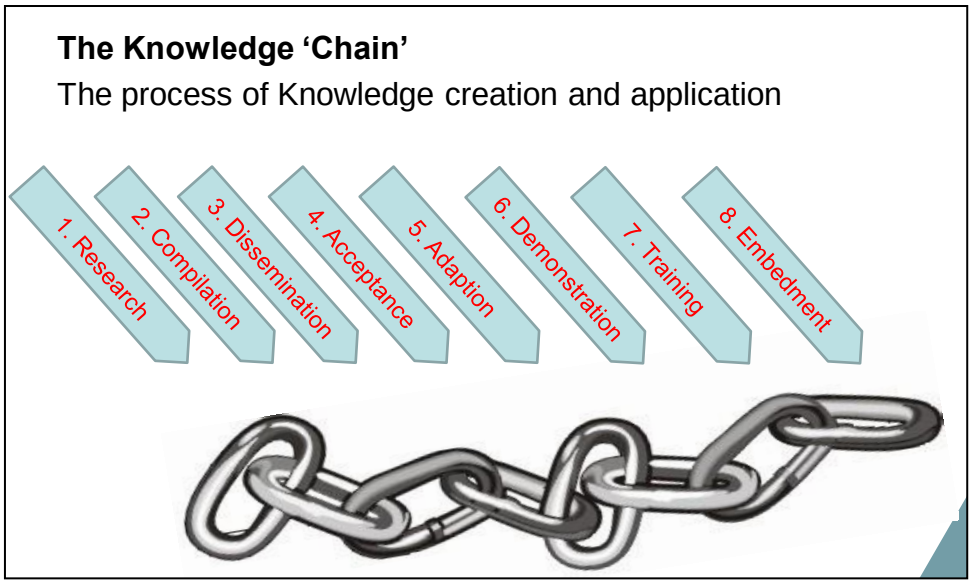
1. Puok: reports relating to the various construction, deterioration, repair and assessment of the Puok surfacing trials in Sim Reap Province. Data is contained within tables in the reports' text or Appendices/Annexes.
2. ENS: Reports and associated databases (Microsoft Access) relating to the SEACAP 19 (Task 2) research into performance ENS roads in Cambodia.

The Cambodian data is currently held by one or more of: Intech Associates; TRL Ltd or OTB Engineering Ltd with copies of all final reports held by the Ministry of Rural Development, Royal Government of Cambodia. As with the Lao data this information requires collation into a structured format.

7 Proposed Strategy for Consolidation and Uptake of the SEACAP Trials Knowledge Base

The process of developing knowledge and mainstreaming the results is represented in Figure 7.1

Figure 7.1 – The Knowledge Chain Concept (Source: Intech Associates)



Note: Feedback loops in the process removed for clarity.

Many past sector research initiatives have not realised the potential economic and social benefits due to the 'Knowledge Chain' not being carried through to its final 'embedment' stage.

It is clear that the very valuable research generated by the SECAP trials has brought some benefits already. However, a planned programme of analysis, dissemination and uptake is required to realise the considerable potential additional benefits.

The following coordinated programme of initiatives and task groups is proposed to achieve this objective.

TASK GROUP 1 – Trials Research Consolidation and Data Analysis

- Carry out Final Round of Condition Surveys on all Vietnam monitoring, Puok and Laos Trial Sections

- Carry out traffic surveys on Trial Sections
- Develop criteria for acceptable serviceability for each LVR paving type
- Identify Surface/Sub-base/Base types with useful data sets
- Carry out consolidated data analysis and develop amalgamated SEACAP research findings and recommendations
- Consolidate and assess the cost data available, particularly from Vietnam, for immediate application related to ongoing ReCAP work on cost-benefit analyses of LVRR research and its uptake.

TASK GROUP 2 – Investigate Regional, AsCAP and AfCAP Synergies and Application Potential

- Review Vietnam RRSR trials, Cambodia and Laos data for usefulness in other Asian and African environments
- Identify influential/limiting factors: e.g. traffic, maintenance regime, climate, axle loading regime etc.
- Confer with AsCAP and AfCAP partners regarding uptake potential
- Confer with RAF2069A Sealed LVR Back Analysis Project on potential common knowledge applications
- Review other AfCAP Surfacing Research Outcomes

TASK GROUP 3 – Dissemination

- Develop 2-3 page Technical Information Notes (TINs) for each surfacing and paving option for general knowledge dissemination
- Update the AFCAP Low Volume Rural Road Surfacing and Pavements - A Guide to Good Practice (LVRRSPG), and rebrand as a ReCAP document
- Seek endorsements for TINs & LVRRSPG from key institutions (e.g. ADB & WB)
- Programme of dissemination through key conference events, professional papers, and knowledge, professional and training fora (e.g. Birmingham University in-career training courses)

TASK GROUP 4 – Technology Transfer & Uptake

These tasks will require the support and involvement of a range of partners for local technology transfer and uptake of the knowledge. The TINs should be used as the basic tool for facilitating discussion, adaption/adoption, acceptance and mainstreaming of the surfacing trials knowledge.

- Develop the Standards and Specifications for the different Surface types (could initially be on a provisional basis)
- Develop the Maintenance standards and Specifications for the different Surface types
- Develop training dissemination and uptake strategy for national application
- Media and public awareness campaign
- Carry out training and dissemination. Embed in local university and technical college courses

- Agree further research and seek funding – e.g. Cement & Soil Stabilisation of sub-base and road base, Continuous un-reinforced concrete pavement, axle loading for minor roads, stage construction and upgrade strategies.

8 Conclusions

In recognition of the asset management and sustainability challenges of LVRR natural gravel surfacing in many locations, an extensive series of surfacing and paving trials was carried out between 2001 and 2012 in Vietnam, Cambodia and Laos under various initiatives; including EngKaR & SEACAP.

A range of materials and surface/paving types were trialled in various environmental and climatic conditions.

Considerable investments have been made by the various local and international stakeholders.

From these initiatives, there is a considerable amount of un-analysed cost and performance data for a range of low cost surfacing types that is unique and could benefit the design and construction of low volume rural roads in the region and elsewhere. Analysis of this data could lead to guidance and significant cost savings in the provision of affordable and sustainable access to rural and poor communities in whole-life-cost orientated road infrastructure asset management in many Asian and African countries.

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