Research on Sustainable Paving/Surfacing for Low Volume Rural Roads in Vietnam

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ABSTRACT

Due to increasing concerns as to the suitability of unsealed gravel as the default rural road surfacing in the high rainfall climates of South East Asia, DFID and World Bank have co-funded research into appropriate Low Volume Rural Road (LVRR) pavement and surfacing options in cooperation with the government of Vietnam. The research has been managed through the South East Asia Community Access Programme (SEACAP). The previous widespread provision of unsealed gravel roads was influenced by relatively cheap construction costs in a constrained resource environment. However project SEACAP 4 research on previously constructed gravel roads has shown that in many circumstances these surfaces demonstrate unsustainable levels of material loss and deterioration due to a range of factors such as: high rainfall, flooding incidence, steep gradients, incompatible traffic loading, inadequate quality assurance, and insufficient maintenance capacity.

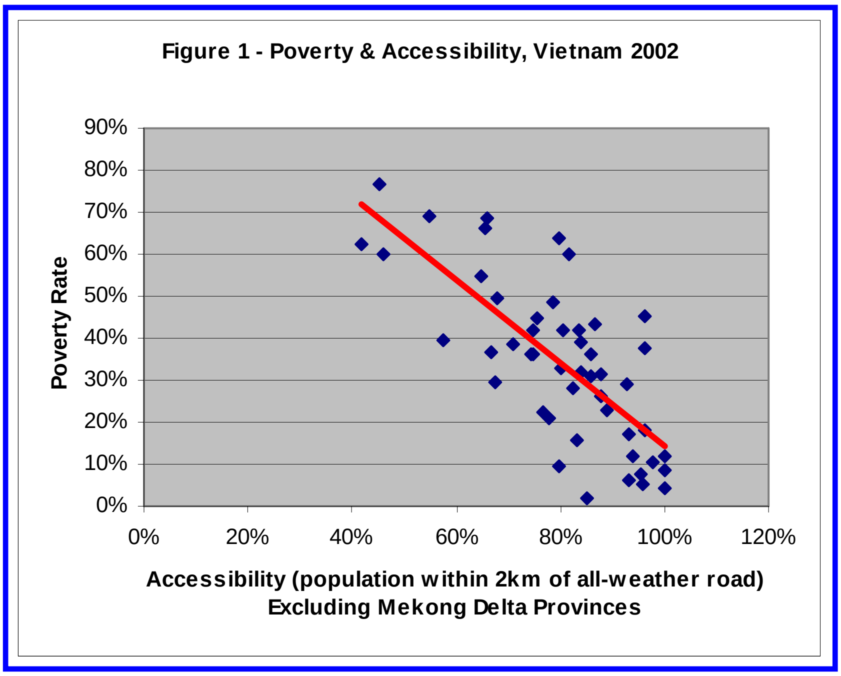
The complementary SEACAP 1 project involved the construction of low volume trial roads using a range of locally available materials in a representative selection of road environments throughout Vietnam. A wide range of sub-base, base and surfacing options have been trialled including bitumen emulsion stone chip and sand seals, un-reinforced, steel reinforced and bamboo reinforced concrete slabs, concrete bricks, fired clay bricks, cobble stone, dressed stone paving, and lime, cement and emulsion stabilisation. Standard local practice; hot bitumen seals and unsealed options, have been constructed as comparative control sections. Construction of the trials was completed between June 2005 and July 2007 and representative lengths have been selected for long term condition monitoring which is now proceeding. Initial trial road performance information is now becoming available and this, together with the construction cost and construction quality assessment data, is allowing the development of practical Whole Life Cost and Option Selection models.

This paper summarises the outcomes of the SEACAP 1 and 4 projects with particular focus on the guidelines developed for improved rural road pavement/surface selection, design, construction and maintenance in challenging tropical environments.

KEY WORDS: Road Surface Gravel Paving Vietnam

1. BACKGROUND – THE CHALLENGE

In many developing countries, the main road network carries about 80 to 90 per cent of passenger and freight transport and it is, therefore, of key importance to the national economy. Main road networks are understandably given high priority in the allocation of investment and maintenance funds in recognition of their economic importance. Conversely, Low Volume Rural Roads (LVRRs) may make up over 80 per cent of the road network length, but are given lower priority in the allocation of funding because they carry much lower volumes of motorised traffic. Despite this, these rural roads are of vital importance to rural communities for their economic and social wellbeing and reduction of poverty. There is an established link between poverty and poor access (example Figure 1).



Source: Vietnam 2002 Living Standards Survey

The rural poor do not have motor cars. However they need reliable access for affordable transport or services (both motorised and non-motorised) such as bicycles, motorcycles, animal carts, minibuses, local trucks, buses, whether owned or hired. Even if a vehicle ride is too expensive for them, they will still depend on the transporters that bring the medicine and teachers to the village, or carry crops. The essential challenge for engineers and road managers is therefore how to provide and maintain this rural access for the types of traffic currently in use, on a sustainable basis with the limited resources available, to minimise transport costs to the nation and community.

Unsealed rural roads with earth and gravel/laterite surfaces comprise the greater proportion of the length of public roads in rural areas in developing regions[1]. Globally, they account for almost 60 per cent of the main road network, or about 1.2 million kilometres. In addition, there exists an estimated 5 to 6 million kilometres of designated minor roads and motorable tracks, and an extensive network of undesignated tracks and paths, probably several times the extent of the designated network[2].

Engineers have traditionally relied on the use of natural gravel/laterite as a rural road surface, due to its initial low costs and simplicity of use. However recent research[3] confirms the serious problems relating to maintenance and sustainability of such surfaces in many situations common in South East Asia. This experience is relevant to certain combinations of conditions in other regions. There are also health and environmental concerns regarding the widespread use of gravel. These concerns led to the Vietnam Government, World Bank and DFID carrying out investigations into gravel road

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1 Vietnam has a road network of approximately 210,000 km, of which over 100,000 km are to earth standard.

2 Paving the way for rural development & poverty reduction, Gourley, Greening Jones & Petts, CAFEO 20, 2002.

3 Rural Road Gravel Performance Assessment investigations in Vietnam, SEACAP 4, by Intech-TRL.

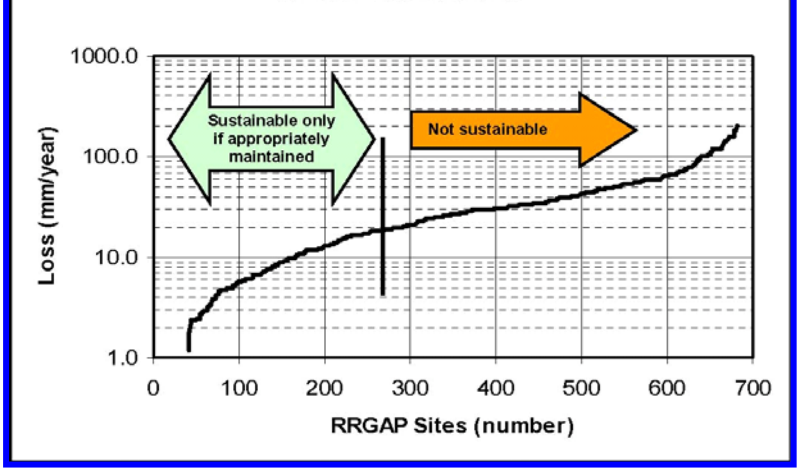
performance and viable alternative surfaces for LVRRs under a Rural Road Surfacing Research ((RRSR) programme. The research was carried out by Intech-TRL with local partners through the South East Asia Community Access Programme (SEACAP) for the second Rural Transport Project (RT2).

2. THE CONSTRAINTS OF TRADITIONAL GRAVEL SURFACING

The word gravel is used within this document to denote any naturally occurring granular material, including laterite gravel, used as a road surfacing material. The experiences also apply in many circumstances to (often more expensive) graded crushed rock aggregate. Gravel has been widely adopted as a surfacing material for low cost rural roads, as it has been relatively cheap and until recently reasonably available in many locations. This is an intermediate initial cost solution between a basic earth road construction and the more robust, but costly, bituminous or other types of paving.

The SEACAP 4 - Rural Road Gravel Assessment Programme (RRGAP) investigations carried out insitu and laboratory testing and studied road deterioration at 766 road sites on 269 roads in regions of Vietnam with varying characteristics. Rainfall regimes varied between 850 and 3,000mm/year. The research found serious constraints to the use of gravel in most of the studied 16 programme provinces due to factors relating to material quality, material availability, climate, terrain, drainage provision and maintenance. Overall gravel loss figures indicate that around **58%** of the surveyed sites were suffering unsustainable deterioration (<20mm/year), while **28%** were losing material at twice the sustainable rate; refer to Figure 2.

Figure 2



Of particular concern is the fact that gravel roads require regular routine maintenance and also programmes of re-gravelling to replace the surface material lost through the effects of traffic and climate. These have substantial funding and logistical implications and can put a substantial demand on the authorities or communities responsible. General evidence suggests that these demands are rarely satisfied and many gravel roads in time inevitably revert to earth standard. Furthermore as the gravel is a non-renewable natural resource, there are significant environmental degradation consequences.

Analysis of the results has been finalised[4]. Issues identified relating to the general use of gravel materials on rural roads include the following:

a. Gravel material loss from the road surface is highly variable (Figure 2), with material type, drainage, sub-grade condition, gradient and rainfall being key factors. Many gravel roads have typically 80-90% of the road in fair to good condition after only a year or two of service, with some sections (10-20% of the length) in poor condition. This suggests a need to consider a spot improvement, or composite construction

4 Intech-TRL, Rural Road Gravel Assessment Programme (RRGAP),Vietnam, Module 4 Final Report, July 2005.

approach, in which at-risk or difficult sections are given a higher quality, more durable surface.

b. Many of the materials are not within widely accepted specification parameters. Hence a need to consider a design and quality assurance approach that specifies appropriate local materials rather than a blanket overall specification. Also a pragmatic approach is required to materials selection and approval, particularly in a remote location, constrained-resource environment, lacking good testing facilities and arrangements.

c. 75% of the surveyed roads have received no effective maintenance at all since construction. This emphasises the need either to construct road surfaces that are robust enough to withstand a low maintenance regime, or to put in place effective road maintenance arrangements that are not hampered by local funding or operational constraints, or skill and resource shortages. A coherent design and maintenance strategy is required, that recognises life cycle costs and the realities of maintenance capacity. It should be appreciated that effective maintenance regimes usually take decades, rather than years, to develop.

d. Two provinces outside of the RRGAP programme with very high rainfall (>3500mm/year) immediately overlaid the development agency funded gravel surfaces at their own cost, usually with concrete or bitumen penetration macadam. Besides the need for better surface selection procedures, this suggests the possibility of a staged construction approach to some rural roads, in which an initial unsealed surface may be overlain at a later date with an appropriate seal. However, indications are that a gravel wearing course would not usually be suitable for this approach unless sealing was guaranteed to be undertaken within a short period, or certainly before the onset of the first rainy season in high rainfall areas.

3. RECOMMENDATIONS ARISING FROM THE RRGAP

The RRGAP investigations confirmed the following recommendations regarding the future use of gravel as a rural road surfacing material in Vietnam, and for environments with similar characteristics.

Gravel is a ‘wasting’ surface. Material is lost from the surface of the road due to the action of traffic and rainfall. Natural gravel should only be used for rural road surface applications in situations where certain conditions are fulfilled. In general, **gravel should <u>not</u> be used where**:-

- ❑ **Gravel quality is poor** – Gravel should comply with grading and plasticity requirements, and not break down under traffic, otherwise it will be lost from the surface at a high rate. Natural gravel quality varies substantially within each pit location and with depth. Great care is essential to ensure that only suitable material is selected, and that mixing of marginal/unsuitable material is avoided,
- ❑ **Compaction & thickness cannot be assured** – uncompacted surface gravel will be less durable. Supervision arrangements should ensure that the full specified compacted thickness is placed,
- ❑ **Haul distances are long** – if haul distances are longer than 10km, then other surface types may be cheaper in whole life cost terms. Hauling gravel for construction and periodic maintenance causes damage or further maintenance liabilities to the haul routes,
- ❑ **Rainfall is very high** – Gravel loss is related to rainfall and may be excessive with intense storms or where annual precipitation is greater than 2,000mm,

- **There are dry season dust problems** – long dry seasons can allow the binding fines to be removed from the surface by traffic or wind. This is particularly problematic where communities live beside the road or their crops and property are regularly coated in dust. Inhalation of road dust is unhealthy and there are also visibility-safety issues,
- **Traffic levels are high** – gravel loss is related to traffic flows. It is unlikely that a gravel surface will be cost-effective at traffic flows of more than 200 motor (2 or more axles) vehicles per day.
- **There are Longitudinal Gradients** – Gravel should not be used in low rainfall situations (< 1,000mm/year) on longitudinal road gradients of more than 6%. In medium rainfall areas (1,000 – 2,000 mm/year) gravel loss by erosion will be high on gradients of more than 4%.
- **Adequate maintenance cannot be provided** – Gravel is a high maintenance surface requiring both routine reshaping/grading and expensive periodic re-gravelling. Neither are achieved to adequate levels in many Emerging and Developing nations due to funding and operational constraints [5, 6] .
- **Sub-grade is weak or soaked (flood risk) –** Weak subgrades (in-situ foundations) require additional thickness of residual gravel to prevent traffic 'punching through' to the subgrade. Flooding can seriously damage gravel surfaces, or,
- **Gravel deposits are limited/environmentally sensitive** – Gravel is a natural and finite resource, usually occurring in limited quantities. Once deposits are used up, subsequent periodic re-gravelling will involve longer hauls and higher maintenance costs.

The Vietnam Rural Road Surfacing Research (RRSR) has developed detailed guidance on the parameters for appropriate use of gravel as a surfacing. Recommendations have also been made for using gravel as a non-wearing layer within a pavement option, or as a component of a spot improvement road link strategy. Part of the guidance on LVRR surfacing selection with respect to the gravel option is shown in Figure 3.

4. PREVIOUS 'RULES OF THUMB'

Previous sector 'Rules of Thumb' indicated that gravel could be suitable for roads with traffic flows of between 50 and 200 motor vehicles per day (vpd). These guidelines suggested that earth roads would be suitable for traffic flows up to 50 vpd. However, such guidelines are extremely misleading, as some soils are totally inappropriate to support any traffic flows whatsoever. Furthermore, the criteria listed previously demonstrate that even gravel should never be considered for some combinations of conditions. Furthermore, research in Southern Africa has shown that low cost bituminous seals can be justified at flows of only 70 motor vehicles per day[7,8]. It is likely that full whole life costing of surface options will show that natural gravel is <u>**NOT**</u> the most cost-effective surface in most situations in Vietnam. It is necessary to be more rigorous in evaluating the options for rural

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5 In Cambodia it is estimated that a gravel rural road typically requires about US$1,600 per km per year for maintenance. These resources are simply not available on a national network basis - Rural Road Investment, Maintenance and Sustainability, A Case Study on the Experience in the Cambodian Province of Battambang, D Johnston and D Salter, May 2001.

6 Roads 2000, a programme for labour and tractor based maintenance of the classified road network, paper for the RMI road maintenance policy seminar, Nairobi 2 – 5, Petts June 1992

7 Performance of low-volume sealed roads: Results and recommendations from studies in southern Africa. TRL Project Report PR/OSC/167/99. Transport Research Laboratory, Crowthorne, Berkshire, UK, CS Gourley and PAK Greening, November 1999.

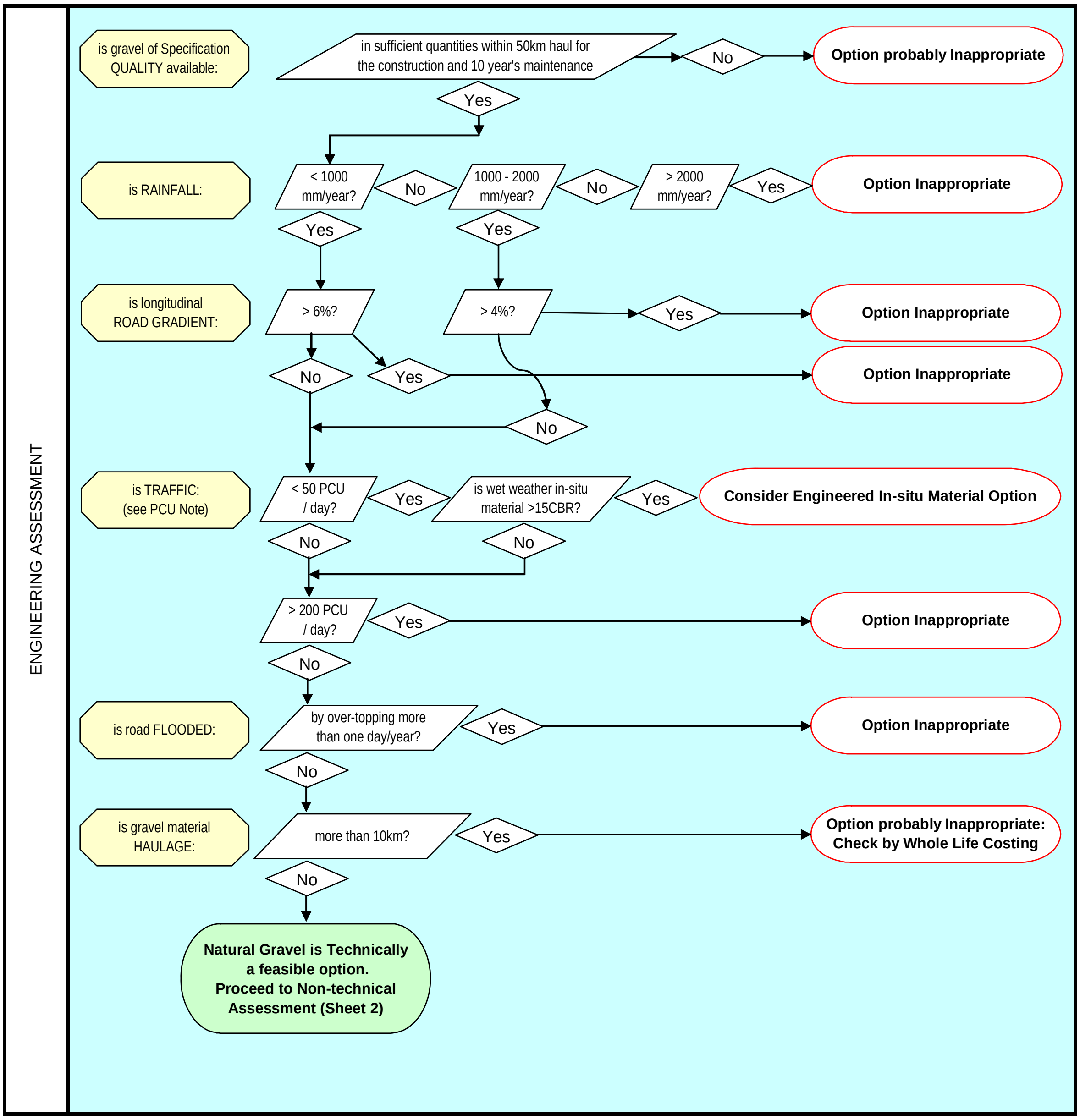
8 New approaches for the provision of low volume sealed roads. 20th Annual South African Transport Conference. Pretoria, South Africa, PAK Greening and CS Gourley, July 2001.

and access road surfacing. Long hauls, high rainfall, high traffic, poor material, steep gradients, flooding, poor construction practices, lack of maintenance capacity and other extremes of condition will exclude gravel from being the most appropriate surface in many circumstances.

Figure 3

Decision Flow Chart for the Consideration of Natural Gravel as a Rural Road Surface Option

SHEET 1 - Engineering Assessment



NOTES: PCU = Passenger Car Unit (other vehicle types to be converted from traffic surveys and maximum predicted daily flows for next 3 years).
CBR = California Bearing Ratio - Strength in situ measured by DCP, or to be decided by visual assessment
DCP = Dynamic Cone Penetrometer
Engineered Insitu Material = Earth Road Standard with maintained camber and effective drainage system

5. THE PROVEN ALTERNATIVES TO GRAVEL

Fortunately there is a range of proven alternatives to natural gravel. Some of these have similar initial construction costs to gravel in certain circumstances. They can have better whole life cost[9] attributes and usually lower maintenance liabilities than gravel.

Poor people often rely on non-motorised transport, motorcycles and simple trucks for their transport needs. On many soils, an engineered earth road is sufficient to provide basic access for these vehicle types, provided that specific, limited location constraints, such as watercourse crossings and steep gradients are adequately engineered with spot improvements. Soils with a CBR of about 15 or more are likely to be suitable for this Engineered Natural Surface (ENS) application[10]. The camber and drainage must of course be maintained using appropriate, low cost techniques. Engineered Natural Surfaces therefore have enormous scope to improve access at very low costs for many poor rural communities.

Engineers need to give greater attention to improving these basic access routes which often constitute more than 50% of the rural networks in developing countries. Low cost construction and maintenance techniques using local labour and simple equipment have an important role to play. These techniques are particularly suitable for implementation by small enterprises or communities. They use the locally available labour and have negligible capital requirements. Such ENS can be provided for less than US$2,000 per km in many situations, including the necessary low cost drainage measures. Low cost grading of ENS can be achieved for as little as US$25 per km of grading using simple locally made equipment.

However in some circumstances the in-situ soils are just too weak to support any traffic in the wet, and must be covered. For these situations, there is a range of alternative surfacing and paving options already proven in various countries that could provide appropriate, economical and sustainable alternatives to natural gravel in developing countries. Suitability will depend on local circumstances. These alternatives, involving the appropriate use of locally available materials, may be cheaper in whole-life-cost terms. Many can be carried out by small and medium enterprises using low-capital, labour based and light equipment methods.

Communities themselves could use some of the techniques to improve their own access. The alternative surfaces should have lower (and more manageable) maintenance requirements than gravel, not only in terms of cost but also by reducing the need for (imported) heavy equipment to transport and compact. Their environmental impact could be substantially less.

6. RRSR SURFACING TRIALS IN VIETNAM

6.1 Trials Objectives

The aim of the RRSR programme was to establish a range of sustainable road surfaces and paving technologies as alternatives to unsealed gravel that would improve overall rural access while making better use of local resources, minimise Whole-life-Costs and support the Vietnam Government's poverty alleviation and road maintenance policies. The project

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[9] Whole Life Costs – discounted total construction and maintenance costs through the nominal life of the road.
[10] Rolt, TRL (2007), Behaviour of Engineered Natural Surfaced Roads.

team designed, costed and drew up specifications for monitoring and control sections on 41 trial roads in 12 provinces based on the following guiding principles:

- Designs should be appropriate to the traffic, climatic and terrain environments.
- Local construction materials should be used where possible.
- Maintenance requirements must be sensibly in line with local community resources.
- Construction techniques should be suitable for small contractors and local employment.

The technical outputs of the trials project were defined as:-

- Recommended revisions to the Vietnam Rural Road Construction and Maintenance Standards,
- Revised Guidelines on the selection of Rural Road Surfacing for Provincial Authorities.

6.2 The Trials Programme

The Rural Road Surfacing Trials (RRST) studies contained two main phases of trial construction between 2004 and 2006 with a total construction cost of US$4,400,000 which together comprised over 140 km of trial lengths from which a representative 107 sections of between 80m to 200m length have been selected for ongoing performance and whole-life-cost monitoring. Key aspects of the two phases are as follows:

RRST-I. The RRST programme was concentrated on 4 roads in the Mekong Delta and the Central Coastal area. Short lengths (100-200m) of different pavement options appropriate to the province were constructed on each trial road under the close instruction and supervision of the specialist consultants Intech-TRL. Each trial road had in addition short lengths (100m) of control sections of unsealed road or penetration macadam sealed road.

RRST-II 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 500m to more the 2 km and was seen as an important step in the ‘roll out’ and mainstreaming of sustainable and appropriate rural surfacing solutions. Supervision was undertaken by local consultants with Intech-TRL taking an overall Quality Assurance and strategic guidance role.

The programmes included not only the stabilisation of local soils by lime, cement and bitumen emulsion but also more innovative options for Vietnam such as concrete brick, clay brick (fired using rice husk as fuel), cobble stone and stone setts surfacing. Figure 4 summarises the various pavement and surfacing options that were combined in trial matrices suitable to the requirements of each of the 12 participating provinces.

7. TRIAL OUTCOMES

7.1 Construction Issues

The successful construction of the trials demonstrated to local contractors and consultants, as well as provincial authorities, the potential for using the new surfacing and paving options as alternatives to gravel in future rural infrastructure programmes. In addition some valuable lessons were learnt with regard to modifying specifications and construction procedures. With respect to the construction of sealed options in particular the following key points were noted.

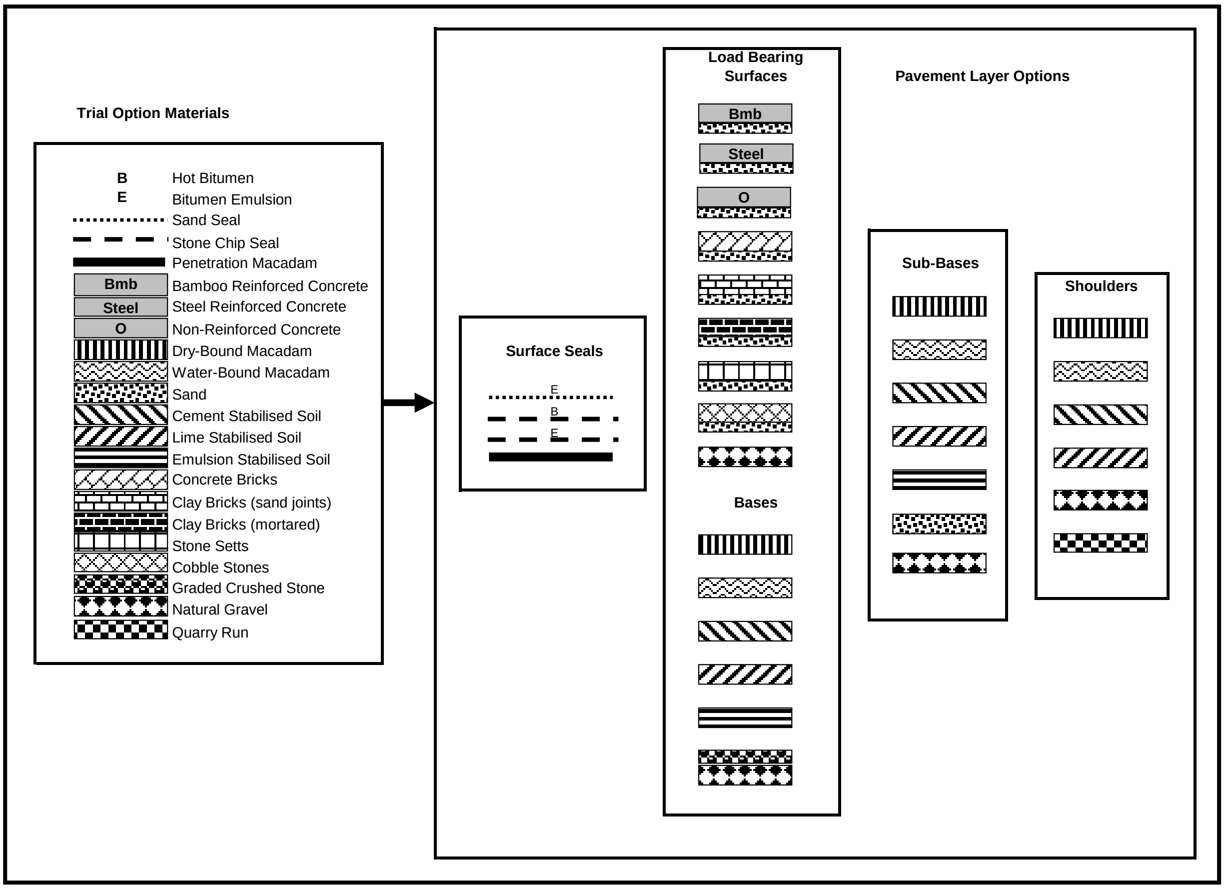

Figure 4: RRST trial layer options

The emulsions used on site, containing around 60 per cent bitumen, could be readily sprayed by hand lance or applied by manual methods at ambient temperature. In contrast the application of hot bitumen was more problematical and in most cases little or no temperature control was evident in the local procedures.

However, some difficulty was experienced with the use of bitumen emulsion, particularly with sand seals, on gradients and steep cambers. The tendency for the emulsion to 'run off' of the road surface caused problems in keeping the bitumen in place until some evaporation of water had taken place before aggregate cover was applied. There were evident bedding problems for sand and stone chip seals on rural roads where the traffic was predominantly bicycles or motorbikes. The adverse impact of rainfall on the attempted construction of emulsion seals, as with any bituminous material, highlighted the need for restricted application during the rainy season.

Despite an initial resistance from most contractors, after using what was for them a new emulsion sealing procedure, they agreed on the usefulness and potential of emulsion once they had gained experience and confidence with the techniques.

For on-site laid concrete, there was a common tendency to add too much water to the mix to aid placement. This led to some surface defects and slab cracking in some instances. The use of the slump test to control water cement ratios was not widely adopted. Current specifications allow the use of uncrushed aggregate in concrete slab paving and this results in an inferior and less durable surface.

For incremental block paving the essential requirement of laying the restraining 'kerbs' or edge blocks ahead of the main paving was not clearly appreciated in some instances.

There appears to be a significant lack of awareness of the importance of Quality Assessment (QA) in the rural road sector and a consequent lack of a quality control ethic. Hence the role of site supervisors in controlling the contractors' procedures and material usage is not yet generally accepted in the rural road sector in Vietnam. Current practice appears to be concerned largely with observation and reporting of progress rather than technical control. This aspect was particularly evident in some of the more remote and locally supervised sites in RRST-II where the QA as-built surveys revealed very poor control on surfacing aggregate size and shape. For at least the near future, this problem needs to be taken into consideration in selecting an appropriate technology.

The following tables summarise the experiences with the various surface options.

Description	Trial Location(s)	Principal Advantages	Principal Concerns
Sand bitumen emulsion	Dong Thap; Tien Giang; Hue; Da Nang	Application suitable for labour based methods because of low health and safety risks. Suitable for low volume traffic roads in areas deficient in stone aggregate but with plentiful supplies of suitable sand. Suitable for commune based maintenance operations.	Best performance with the application of a second sand seal after 5-6 months road use, in order to provide a more durable surface. Procedures not well known by local contractors; requires good site control. Sand seal on brick options show a tendency to strip and crack at brick joints. Application procedures not suitable for steep gradients. Potential difficulties in obtaining small quantities of emulsion for local maintenance.
Sand and stone chip bitumen emulsion (sand seal on chip seal)	Dong Thap; Tien Giang; Hue; Da Nang; Dak Lak	Application suitable for labour based methods because of low health and safety risks. Suitable for commune based maintenance operations	Care required in matching emulsion spray/application rates to actually available stone sizes and aggregate shape. Procedures not well known by local contractors; requires good site control. Sand seal application procedures not suitable for steep gradients. Potential difficulties in obtaining small quantities of emulsion for local maintenance.
Double stone chip bitumen emulsion	Tuyen Quang; Ha Tinh; Quang Binh; Ninh Binh; Hung Yen; Gia Lai; Dak Lak; Dak Nong	Application suitable for labour based methods because of low health and safety risks. Suitable for commune based maintenance operations	Care required in matching emulsion spray/application rates to actually available stone sizes and aggregate shape. Procedures not well known by local contractors; requires good site control. Potential difficulties in obtaining small quantities of emulsion for local maintenance.
Double stone chip hot bitumen	Tuyen Quang; Ha Tinh; Quang Binh; Ninh Binh; Hung Yen;	Well known and established procedure in Vietnam.	Generally currently very poor site control on bitumen application temperature, which affects durability. Significant health and safety hazard.
Triple stone chip hot bitumen	Dak Nong	Locally developed procedure.	Excessive use of bitumen in what is effectively similar to a semi-penetration macadam in composition and thickness. Care required in matching application rates to actually available stone sizes and shape. Generally currently very poor site control on bitumen application temperature. Significant health and safety hazard.
Penetration macadam	Dong Thap; Tien Giang; Hue; Da Nang; Dak Lak; Dak Nong	Well known and established procedure in Vietnam. Low initial maintenance if well constructed.	Does not use either locally available materials or local labour. Health hazard issues as regards hot bitumen. Difficult to control quality. The use of bitumen at 7kg/m2 means that this option carries a high cost penalty.

Table 1: Surface Seals Options

Description	Trial Location(s)	Principal Advantages	Principal Concerns
Fired clay brick	Dong Thap; Hung Yen;	Social and economic benefits to the communities through local brick manufacture. Local labour employment both in labour based construction and in ongoing maintenance. Good durability, load bearing and load spreading characteristics provided specification-compliant bricks are used. Currently produced brick sizes may be used, with smaller bricks being laid on edge in either “herringbone” or “stretcher” bond. Low maintenance and easy to repair.	Appropriate only when local brick manufacturing can supply bricks of consistently suitable quality. Current locally applied construction procedures for village roads need to be improved for Class A or Class B use. The mortared joint option may be more suitable than the sand sealed, sand joint, option. Adhesion between bricks and bitumen requires investigation prior to construction if the bitumen surface seal option is planned. Needs careful control of construction using string lines within pre-constructed edge constraints (kerbs).
Concrete brick	Hue; Hung Yen	Economic benefits to the communities through local brick manufacture. Local labour employment both in construction and in ongoing maintenance. Good durability, load bearing and load spreading characteristics. Appropriate in areas where concrete brick/block manufacturing is established. Low maintenance and easy to repair.	Needs careful control of construction using string lines within pre-constructed edge constraints (kerbs).
Dressed stone	Hue	Economic benefits to the communities through labour-based stone excavation and preparation. Local labour employment both in construction and in ongoing maintenance. Good durability, load bearing and load spreading characteristics. Suitable for staged construction options. Low maintenance and easy to repair.	High cost. Appropriate in areas only where suitable un-weathered stone (e.g. granite) is readily available. High roughness makes it unpopular with some local stakeholders. Not suitable for use with stone that polishes or is slippery when wet. Needs careful control of construction using string lines within pre-constructed edge constraints (kerbs).
Cobble Stone	Ninh Binh	Economic benefits to the communities through labour-based stone excavation and preparation. Local labour employment both in construction and in ongoing maintenance. Good durability, load bearing and load spreading characteristics. Suitable for staged construction options. Low maintenance and easy to repair.	High cost. Appropriate in areas where suitable un-weathered stone (e.g. granite) is readily available. High roughness makes it unpopular with some local stakeholders. Not suitable for use with stone that polishes or is slippery when wet. Needs careful control of construction using string lines within pre-constructed edge constraints (kerbs).

Table 2: Block Based Surface Options

Description	Trial Location(s)	Principal Advantages	Principal Concerns
Bamboo reinforced concrete	Dong Thap; Tien Giang; Hue; Tuyen Quang; Ha Tinh; Quang Binh; Ninh Binh	A realistic option where there is a plentiful supply of suitable mature bamboo. Employment of local labour, including women, in bamboo mesh preparation. Suitable for high rainfall and flood prone regions. A preferred option where there is high risk of axle overloading. Minimal maintenance if properly constructed and cured.	There is a significant lead-in time for this option as the bamboo has to be selected, cut and prepared (cured). Requires expansion and contraction joints to be incorporated with steel load transfer dowels. Wider pavements may be constructed in two side-by-side panels, however steel dowels will be required across the centreline joints to prevent differential movement under heavy loading. Requires significant curing time following initial construction; traffic diversion implications on narrow rural roads where traffic cannot be channelled alongside the concrete casting and curing work. High cost. Susceptible to price fluctuation of cost of cement.
Steel reinforced concrete	Dong Thap; Tien Giang; Hue; Da Nang; Gia Lai	Suitable for high rainfall and flood prone regions. A preferred option where there is high risk of axle overloading. Minimal maintenance if properly constructed and cured.	Requires expansion and contraction joints to be incorporated with steel load transfer dowels. Wider pavements may be constructed in two side-by-side panels, however steel dowels will be required across the centreline joints to prevent differential movement under heavy loading. Requires significant curing time following initial construction; traffic diversion implications on narrow rural roads where traffic cannot be channelled alongside the concrete casting and curing work. Potentially the most costly of the trial options. Susceptible to price fluctuation of cost of steel and cement.
Non reinforced concrete	Tuyen Quang; Ha Tinh; Ninh Binh; Hung Yen; Gia Lai; Dak Lak; Dak Nong	Suitable for high rainfall and flood prone regions. Commonly used option at commune level. Well understood by local small contractors. Minimal maintenance if properly constructed and cured.	Requires expansion and contraction joints to be incorporated. Wider pavements may be constructed in two side-by-side panels, however steel dowels will be required across the centreline joints to prevent differential movement under heavy loading. May be susceptible to shrinkage cracking unless well constructed and cured. Requires steel load transfer dowels to be installed at transverse joints, otherwise high risk of problems at joints and slab cracking caused by commercial vehicles. Requires significant curing time following initial construction; traffic diversion implications on narrow rural roads where traffic cannot be channelled alongside the concrete casting and curing work. High cost. Susceptible to price fluctuation of cost of cement.

Table 3: Concrete Slab Surface Options

Description	Trial Location(s)	Principal Advantages	Principal Concerns
Unsealed Natural gravel	Tien Giang; Hue; Gia Lai; Dak Lak; Dak Nong	Low cost option where adequate supplies of suitable material are available within reasonable haul distance, certain criteria are satisfied and an adequate maintenance regime is in place.	Monitoring results confirm the unsuitability of this option in locations/road sections that experience high rainfall, high traffic, long materials haul distances, steep gradients and in floodable areas. Should only be used with great care and knowledge of performance for surface applications, due to expected material losses in service. See SEACAP 4 (Cook and Petts 2005)[5] for details of appropriate use. Generally poor specification compliance. By its nature a very variable quality material. Usually limited quantities of good quality material available in shallow seams with unsuitable material both above and below. Usually insufficient care taken to select and mix suitable material at the quarry. A high maintenance surface. Routine maintenance reshaping not usually carried out. Resources usually not available for timely periodic regravelling.
Unsealed water-bound macadam	Dong Thap; Tien Giang; Da Nang	Low cost option where adequate supplies of suitable material are available within reasonable haul distance and a maintenance regime is in place. Potentially advantageous use within a staged construction strategy.	Early monitoring indications indicate a rapid surface roughening and potholing in high rainfall and floodable regions. Safety issues raised by local stakeholders with regard to two-wheeled traffic.

Table 4: Unsealed Surface Options

7.2 Construction Costs

Table 5 shows the cost summary for some of the paving/surface options.

Option	Road	Province	Cost(US$/km)
150mm Bamboo reinforced concrete	Lang Quan	Tuyen Quang	19,606
	Gheng tang	Ha Tinh	25,624
	Xa Kroong	Gia Lai	40,500
200mm Non-reinforced concrete	Lang Quan	Tuyen Quang	21,747
	Gheng Tang	Ha Tinh	28,828
	Xa Kroong	Gia Lia	42,913
100mm Dry Bound Macadam	Thach Minh	Ha Tinh	7,600
	Cam Lien	Quang Binh	8,778
	La Pnol	Dak Lak	13,350
Bitumen emulsion Double Chip Seal	Lang Quan	Tuyen Quang	7,147
	Thach Minh	Ha Tinh	7,616
	La Pnol	Gia Lai	10,990
Unsealed Gravel	My Phuoc Tay	Tien Giang	7,682
	Kien Duc	Dak Nong	2,918
	Cu Ne	Dak Lak	2,667

Table 5 Summary Construction Costs of Selected Surface Options

The comparative construction costs for typical bitumen and bitumen seals are evident. The table indicates the similarity of cost between the hot bitumen and bitumen emulsion seals, with the lower cost of emulsion in the Mekong area reflecting the location of production plants in the South. It also demonstrates the apparent and misleading attractiveness of unsealed gravel as a rural road option based solely on construction costs of poor quality gravel with no account taken of the sustainability or whole life costs.

The costs are indicative only and as with any costs are highly dependent on a range of local factors. These comparative costs should not be used as evidence of comparative ranking in other locations. There is no substitute for detailed local pricing taking into account all local factors.

A cost model has been developed as part of the RRSR project, to facilitate the assessment of whole life costs for the rural roads. Due to a lack of reliable data this model does not currently include vehicle operating costs (VOCs) and hence may be more reasonably considered to be a Whole Life Asset Cost Model. Initial analysis of unsealed road options based on this model demonstrates that potential maintenance costs in some areas of Vietnam can exceed construction costs in a relatively short life assessment period of eight years; in some situations by a factor in excess of 2.

In such cases the use of alternative sealed options such as Double Bituminous Emulsion Surface Treatment over dry-bound macadam becomes economically preferable to gravel without even considering sustainability issues such as the lack of essential maintenance programmes, or the lack of sufficient and timely re-gravelling resources. When additional likely VOC savings for the more durable surfaces are estimated and included, the case for the adoption of the alternative surfaces and paving techniques becomes difficult to disregard.

8. ROAD ENVIRONMENT ISSUES

The principal elements in the road design process are traditionally focussed on traffic and the choice of materials and their thickness within each pavement layer. Experience is increasingly indicating that in the case of Low Volume Rural Roads (LVRRs) this traditional approach is inadequate.

It is now appreciated that additional road environment factors must be taken into account if the selected designs are to be cost-effective and sustainable. The design engineer needs to also understand all other non-traffic external impacts on the LVRR. In reality the performance of a LVRR depends on a whole range of factors that cumulatively can be described as the "road environment". Factors important to the road environment can be broadly grouped as follows and illustrated in Figure 5:

- Available Materials – locally and within economic haulage
- Natural Environment factors – largely uncontrollable
- Road Task
- Operational Environment – largely controllable

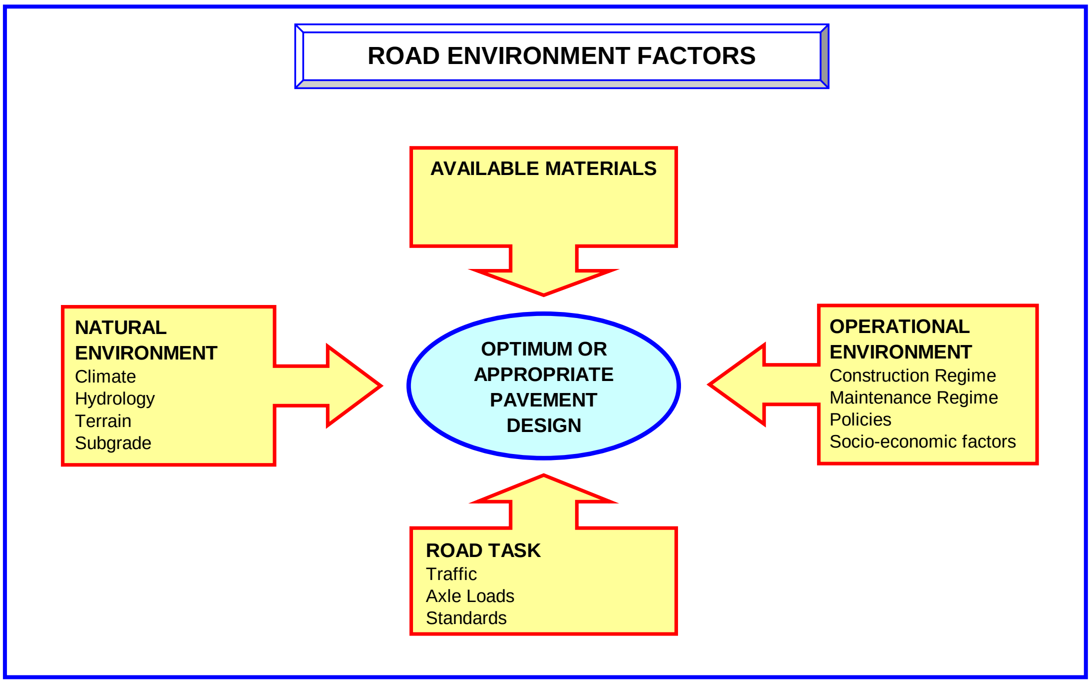

Figure 5: The Road Environment, Natural and Project Related Factors

Appropriate LVRR design should take into account the impacts and influences of the various road environment factors and their effect on:

- Earthworks,

- Drainage,
- Structures,
- Pavement.

There clearly has to be an upper limit to the traffic for the LVRR approach to design and construction. Above this limit, the traditional traffic related factors will be the predominant influence on deterioration. This limit is illustrated on Figure 6. This is a general conceptual figure which needs to be interpreted and adapted for specific regions bearing in mind their particular characteristics.

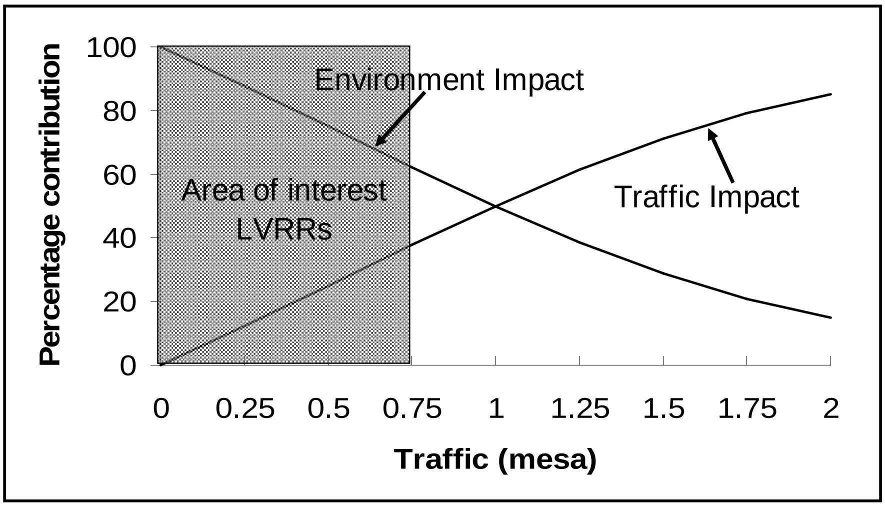

Figure 6: Conceptual - Relative Impacts of Traffic and other Road Environment Factors

This paper does not discuss general environmental issues relating to sustainable use of materials, energy or pollution issues.

9. ENVIRONMENTALLY OPTIMISED DESIGN

During the past 20 years or so, DFID and other development agencies have supported research on various aspects of LVRRs with the aim of improving their affordability and sustainability. Some of this research has led to innovative and unconventional LVRR solutions and approaches that are highly beneficial and cost effective, for example, the use of alternative pavements and surfaces.

Key to successful solutions is recognition that conventional assumptions regarding road design criteria need to be challenged. One emerging design concept is for the Environmentally Optimised Design (EOD) approach. LVRR standards and designs need to support the function that the road is providing as well as recognising the important influences of the deterioration mechanisms.

The principle of EOD implies a spectrum of practical and affordable actions for improving or creating rural access – from dealing with individual critical areas on a road link (Spot Improvements) to providing a whole length design, which, in the latter case, could comprise different design and surfacing/paving options along its length.

10. MAINTENANCE

The pavement deterioration and maintenance requirements of the trials surface options are being monitored under the ongoing RRSR programme. This will enable the costs model to be refined in terms of whole life asset costs.

Further research on vehicle operating costs will be required to enable Whole Life Costing incorporating VOC savings to be incorporated with confidence.

11. RESEARCH INTO PRACTICE

Prior to the RRSR, the Vietnam rural roads were very largely constructed with unsealed gravel surfaces. While initial construction was cheap, it became increasingly clear that the maintenance requirement for these roads was beyond the capacity of the MoT, it's Provincial Departments of Transport (PDoT) and the local communities.

The RRSR has yielded two key outcomes.

- First, the use of unimproved natural gravel as a universal rural road surfacing material has been proved to be unsustainable in over 60% of the situations in Vietnam.

- Second, there are far more sustainable alternative technologies that can be used instead of gravel. This has led to a substantial change in the technical approaches used by the MoT on rural roads and the outcomes of the RRSR will now be incorporated into the third World Bank funded RTP project (US$ 150million), as well as other investment programmes in Vietnam.

Guidelines have been produced on construction, maintenance and monitoring of the various trials surface and paving options.

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