
# Economic Cost, Benefit and Value for Money Analysis of AFCAP Research Outputs

# Final Report

**Robin Carruthers and Alberto Nogales**

***15th July 2013***

This project was funded by the Africa Community Access Programme (AFCAP) which promotes safe and sustainable access to markets, healthcare, education, employment and social and political networks for rural communities in Africa.

Launched in June 2008 and managed by Crown Agents, the five year-long, UK government (DFID) funded project, supports research and knowledge sharing between participating countries to enhance the uptake of low cost, proven solutions for rural access that maximise the use of local resources.

The programme is currently active in Ethiopia, Kenya, Ghana, Malawi, Mozambique, Tanzania, Zambia, South Africa, Democratic Republic of Congo and South Sudan and is developing relationships with a number of other countries and regional organisations across Africa.

This material has been funded by UKaid from the Department for International Development, however the views expressed do not necessarily reflect the department's or the managing agent's official policies.

For further information visit https://www.afcap.org

## Preface

There has been a wealth of studies into the engineering aspects of the Low Volume Sealed Road (LVSR) Approach to providing affordable and sustainable sealed roads where traffic volumes are too low to justify a conventional upgrade from gravel to a sealed surface. But there has been a dearth of studies into the economic benefits of such an approach, or the value for money of AFCAP's efforts to promote this approach.

The assessments described in this report address these overlooked issues. Using a standard cost benefit analysis, the assessments find that there is a substantial economic benefit from implementing and expanding the LVSR approach, and that its support from AFCAP represents a worthwhile application of its resources.

These finding are robust to a wide range of sensitivity tests on the many variables used in the analysis.

## Acronyms

| | |
|---|---|
| AADT | Average Annual Daily Traffic |
| AFCAP | Africa  Community Access Programme |
| AICD | Africa Infrastructure Country Diagnostic |
| BP | Background Paper |
| CEEC | Central and East European Countries |
| DST | Double Surface Treatment |
| ERR | Economic Rate of Return |
| GDP | Gross Domestic Product |
| GIS | Geographic Information System |
| IRI | International Roughness Index |
| LVSR | Low Volume Sealed Road |
| MERR | Modified Economic Rate of Return |
| NPV | Net Present Value |
| OECS | Organisation of Eastern Caribbean States |
| PV | Present Value |
| RAI | Rural Accessibility Index |
| RED | Roads Economic Decision model |
| ROCKS | Road Cost Knowledge System |
| RONET | Road Network Evaluation Tools |
| RUCKS | The Road User Costs Knowledge System |
| SADC | Southern Africa Development Community |
| STPR | Social time preference rate |
| SST | Single Surface Treatment |
| VOC | Vehicle Operating Cost |
| VOT | Value of Time |

## Table of Contents



## List of Tables



## List of Figures



## Acknowledgments


The authors are pleased to acknowledge the extensive advice and support that they have received from many specialists in the concept of the LVSR approach, and for the comments from them. Particular thanks are expressed to Robert Geddes, Technical Manager at AFCAP, John Hine and Les Sampson for their constructive comments on interim reports and drafts of this report. All analyses and recommendations are the sole responsibility of the authors and do not necessarily represent those of the AFCAP core management group.

# 1. Executive Summary


**Executive Summary**

This report addresses four questions related to the Low Volume Sealed Road (LVSR) approach to sealing unpaved roads. It uses an adapted and expanded version of the suite of programs used by the World Bank in its evaluation of rural roads. The results indicate that the economic benefits of:

- adopting a LVSR approach compared with a conventional design approach for paved roads has a net present value of about USD $31,000 per km;
- upgrading poor condition gravel roads to paved road standards using the LVSR approach have a net present value of about USD $50,000 per km;
- applying LVSR design standards within their road sector development programs for countries participating in the AFCAP program related to the LVSR approach would have a net present value of approximately USD $100mn; and
- AFCAP investments in supporting the LVSR approach are about USD $60mn, equivalent to a Benefit/Cost ratio of more than 7.4 and a modified economic rate of return of about 21%.

All these results were found to be robust to a wide range of alternative values for the key parameters, but they were most sensitive to the assumed volume of traffic, which would have to reduce by almost 20% for most of the results to be reversed.

The first result indicates that there is a substantial economic benefit from adopting an LVSR approach. This result is robust for a wide range of combinations of climate and terrain types, although the benefits per km are rather less in mountainous terrain and with a humid climate. The results are also robust for a wide range of construction costs and traffic volumes, which would have to increase by about 34% and reduce by about 17% respectively for the economic benefit of LVSR approach to reduce to zero.

The second result compares the benefits of sealing a poor condition gravel road using an LVSR approach with not upgrading the road, whereas the first result compares the benefits of sealing the road using an LVSR approach with using a conventional approach. The robustness and sensitivities of this result are similar to those of the first evaluation.

The third result applies the results of the first two evaluations to the length of upgradable gravel roads in the five countries in which AFCAP has been most active in promoting the adoption of an LVSR approach. The upgradable roads include those justified on a basis of increasing rural accessibility, as well as those whose justification is based on road user cost and time savings. The distribution of these benefits between countries closely parallels their available budgets for investing in the upgrade of gravel roads

The results of the final evaluation are an indication of the substantial economic benefits to be gained from sustaining the AFCAP program on LVSR roads. Much of the AFCAP investment so far has been to lay the groundwork for future benefits. Further investment would not only add to those benefits but also greatly enhance the probability of their being realized.

## 2. Objectives

The need to find an alternative to the conventional approach to the planning, design and construction of low volume rural roads has been apparent for almost two decades. The most widely applied solution to address this issue is what is now known as the LVSR approach. Despite its apparent advantages, many developing countries have not integrated LVSR design approaches into their pavement design manuals and standard specifications. Part of the reason is the lack of any recent systematic quantified assessment of its advantages and disadvantages. The analyses reported here go some way to addressing this gap.

AFCAP[1] has been a strong supporter of the LVSR approach and over the last five years (2008-2013) and has engaged in a policy of encouraging its wider application. Now that the current stage of DFID support to AFCAP is coming to an end, it is an appropriate time to undertake a quantitative assessment of the approach, while at the same time determining whether AFCAP support has been worthwhile.

The analyses described here are designed to answer four questions:

1. What are the economic costs/benefits of adopting the LVSR approach compared with the conventional design approaches for paved roads?
2. What are the economic costs/benefits of upgrading gravel and earth roads to paved road standards using the LVSR approach?
3. What are the economic costs/benefits for AFCAP-participating countries of adopting LVSR design standards within their road sector development programmes; and
4. What are the net economic benefits to countries adopting the LVSR approach compared with the cost of research under AFCAP?

[1] http://www.crownagents.com/Who-we-are.aspx

## 3. Analytical method

Answering each of the four questions required different analyses and evaluations of data that were common to all of them. This Section provides a summary of the basic methods used in these analyses.

A two stage analytical method was used. The first stage addressed Questions 1 and 2 and was at the level of individual sections of road, while the second stage, which was used to address Questions 3 and 4, was at the level of national road networks. The responses to all the Questions used as a starting point a gravel road in poor condition[2]. They then went on in different ways to assess the benefits of sealing that road using five different combinations of approach (conventional or LVSR) and surface type, three with a conventional and two with a LVSR approach. All the evaluations used a common twenty year time period and the same measures of economic benefit (Net Present Value (NPV) and Modified Economic Rate of Return (MERR)).

- For Question 1 the evaluation and analysis were based on a comparison between sealing the poor condition gravel road using the same surface type (a double surface treatment) with conventional and LVSR approaches. This comparison gave a direct estimate of the benefits of an LVSR compared to a conventional approach;
- For Question 2 the evaluation and analysis were based on upgrading the same gravel road poor condition, but instead of comparing different ways of upgrading the road, they compared each of the five approach/surface type combinations with a base case of the poor condition gravel road remaining in that condition;
- For Question 3, the results of the analysis for Question 1 were expanded from an average section of road to the whole length of upgradable gravel roads in each country;
- The analysis for Question 4 modified the results from Question 1 by assuming that the LVSR approach would involve a mix of double surface treatments and Otta Seals. These modified results were applied to the estimated upgradable network that might be undertaken using an LVSR approach, and the outcome was compared to the cost of the AFCAP programme.

**Two approaches to the development of low volume sealed roads**

Although the concept of the LVSR approach has been used for a long time, there is a wide range of understandings of what it means and what it implies. While many of the objectives of the LVSR approach have been achieved[3] (such as a reduction in the design costs of sealed roads), others (such as a more social approach to the evaluation of such roads) have proven more difficult to implement. The framework of the method described in the next section is not based on any particular interpretation of what is meant by the LVSR approach, rather it is designed to be as broadly based as possible.

The four questions are all expressed in economic rather than engineering terms, so the analytical method focuses on economics rather than on engineering. However some consideration of the engineering aspects of LVSRs is necessary even in an analytical framework based on cost benefit analysis. The framework is such that it can be readily adapted to meet any specific interpretation of the LVSR or understanding of the engineering aspects of the LVSR approach.

---

[2] The only source that provides indications of the condition of unpaved roads in all five countries is Annex A to BP14 for the Africa Infrastructure Country Diagnostic (AICD). The indication is that on average about 50% of the unpaved roads in the five countries are in poor condition.

[3] The Guideline Low Volume Roads, SADC, (2005) provides a comprehensive description of what an LVSR approach is expected to achieve.

**Cost savings of the LVSR approach**

The main differences between the conventional and LVSR approach to upgrading low volume roads that have been taken into account in the analyses are in terms of the costs of:

I. Initial appraisal of the proposal to upgrade the road including economic and environmental assessments, and the design of the road, including its horizontal[4] and vertical curvature;
II. Procurement of a contractor to construct the road;
III. Specifications for materials used in construction;
IV. Supervision of its construction; and
V. Periodic maintenance

The ways that an LVSR approach can differ from a conventional approach have been described many times in other documents[5], so what we present here is only a description of how those differences have been reflected in the economic costs of upgrading a typical gravel road in poor condition to a sealed road in good condition.

I. Planning, appraisal and design: Given that the design of LVSRs tend to be simpler than those of roads built using a conventional approach, there can be savings of cost (and time) in their planning. In part this comes by avoiding the need to rely on relatively costly international consultants for these activities. An example of the simplification that is often used is the use of a cost effectiveness method of appraisal rather than the more time and resource intensive cost benefit method that is part of the conventional approach[6]. An example of a simplified design approach is the use of "design by eye[7]" for the geometric alignment that avoids many of the detailed engineering data and procedures needed in a conventional approach.
II. Procurement: One of the objectives of an LVSR approach is to make maximum use of local consultants and contractors, both of which tend to have lower fees and charges than their international counterparts. In addition to reducing these direct costs, by replacing the lengthy and costly process of international procurement with the simpler ones of national procurement, further cost reductions can be achieved;
III. Materials: One of the objectives of designing roads using an LVSR approach is to provide materials specifications that can be met by locally sourced materials rather than using the higher specification of conventional designs that require the use of scarce and more distantly sourced materials. As an example, laterite dug from a nearby borrow pit is typically less costly and less environmentally damaging than crushed stone obtained from a quarry. Since many of the materials for a road developed using an LVSR approach are locally sourced, not only are the materials less costly, but the costs to transport the materials are also lower. Laterite meeting the specifications for a LVSR pavement can often be sourced within a few kilometres of the construction site, whereas rock meeting the specifications for crushed stone base may need to be transported more than 50km.
IV. Supervision of construction: Depending on the type of road pavement and surfacing included in the design of an LVSR road, the needs for supervision of construction might be

[4] So far as has been possible, the costs of upgrading exclude those of any horizontal realignment
[5] For example, Guideline Low Volume Sealed Roads, SADC, 2005
[6] See When to use cost effectiveness techniques rather than cost benefit analysis, Transport Note TRN9, World Bank, January 2005
[7] Guideline Low Volume Sealed Roads, SADC, 2000

considerably less than for a conventional design. For example, more detailed supervision is required where natural gravel materials are stabilised using cement or lime in order to meet conventional specifications. There are also instances where a higher level of supervision is required for the successful implementation of the LVSR approach, for example in the selection of natural materials in borrow pits and in optimizing the performance of natural materials through high levels of compaction.

V. Periodic maintenance: We have not found any evidence of a difference between the two approaches in respect of routine maintenance, but have applied the same proportionate cost savings to periodic maintenance as for the original upgrading. This is based on the assumption that graded aggregate seals (e.g. Otta Seals) are part of the LVSR approach.

We have assumed that using an LVSR approach can reduce the initial costs of upgrading to about two thirds of what they would be using a conventional approach.

For the evaluation and analysis in Stage 1 extensive used was made of a suite of programs developed by the World Bank for the analysis of road developments at the level of individual sections of the road. For the evaluation and analysis of Stage 2 use was made of another program developed by the World Bank specifically for the analysis of road developments at the network level.

**Stage One**

The programs used in Stage 1 were:

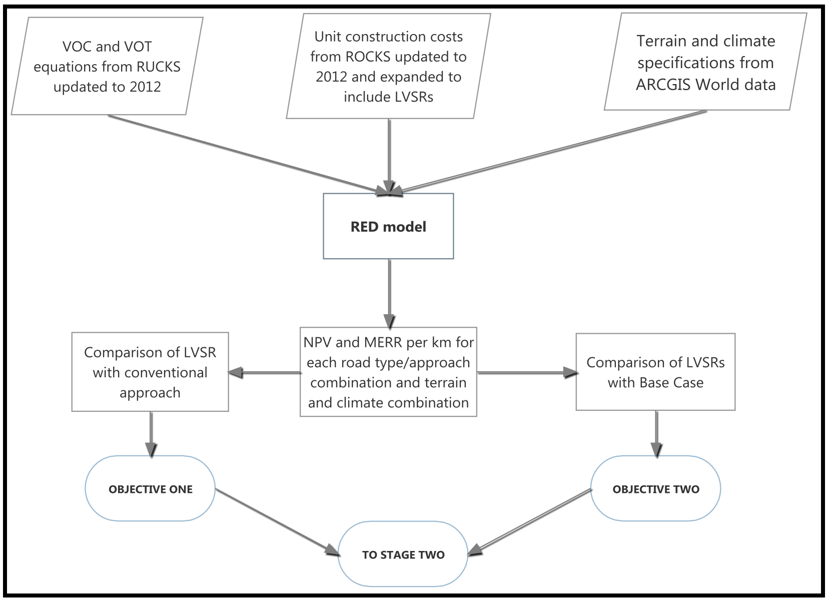
***The Road Cost Knowledge System (ROCKS)***, a database of the financial costs of road construction and maintenance for roads with different economic functions (such as national and local roads) and with different road surfaces. The costs taken from this model were those for secondary and tertiary roads with gravel, single surface and double surface treatments. The ROCKS does not include costs for LVSR roads. These were estimated separately by applying different percentages to relevant components of the conventional approach for a double surface treatment road that is included in the ROCKS.

***The Road User Costs Knowledge System (RUCKS***) is a database for estimating financial vehicle operating costs (VOC) and occupants time costs, value of time (VOT), for use in the economic evaluation of different types of road upgrading. The VOC and VOT estimates for any particular type of road surface are related to the roughness of the surface and the horizontal and vertical curvature of road and not to the method (conventional or LVSR) that was used for its planning and design.

***The Roads Economic Decision model (RED)*** was specifically designed for the making of economic decisions relating to low volume roads. Its main input data come from the ROCKS and RUCKS systems, but it also makes use of other parameters such as the terrain (as measured by its average rise and fall) and the climate zone (as measured by the number of days in the year that traffic has to operate on wet surfaces) in which the road is located.

The RED was used for comparisons at the link level in Stage 1 to estimate the costs of upgrading a standard 1km section of road under different combinations of terrain and climate. The RED allows for comparisons to be made between five different types of road and for economic evaluations to be made by comparing any four of them to the fifth (that is used as the basis for comparison). Some additions were made to the standard RED model. These allowed for the measurement of the net benefits of any road upgrading to be expressed in terms of its net present value (NPV), economic rate of return (ERR) and modified economic rate of return (MERR) and inclusion of the results of the RED for different combinations of terrain and climate (from other runs of the RED) model. The final results of applying the RED model are expressed in the four combinations of financial and economic and undiscounted and discounted costs.

Figure 1 Flowchart for Stage One




**Stage Two**

For assessing the network wide impacts of an LVSR approach (for Questions 3 and 4) the model would have to apply the benefits per km of one combination of approach and surface type relative to another to the lengths of road that have actually been upgraded. For Question 4 it would also have been useful to know the length of road upgraded using the LVSR approach that could be attributed to the impact of AFCAP. But there is no recent data on the first of these, and the length of road upgrading attributable to AFCAP is only about 70km, too little on which to base an economic assessment. Instead we have assumed that the main impact of the LVSR approach and the AFCAP contribution to it are both in the future rather than in the past. So we have based all the estimates of the benefits of the LVSR approach on the expected future lengths of road that might be upgraded using the approach.

The second network stage of the analysis applied the results of the Stage 1 to all the upgradable roads in a country's road network that could be expected to be upgraded using an LVSR approach. The five principal inputs to this stage of the analysis were:

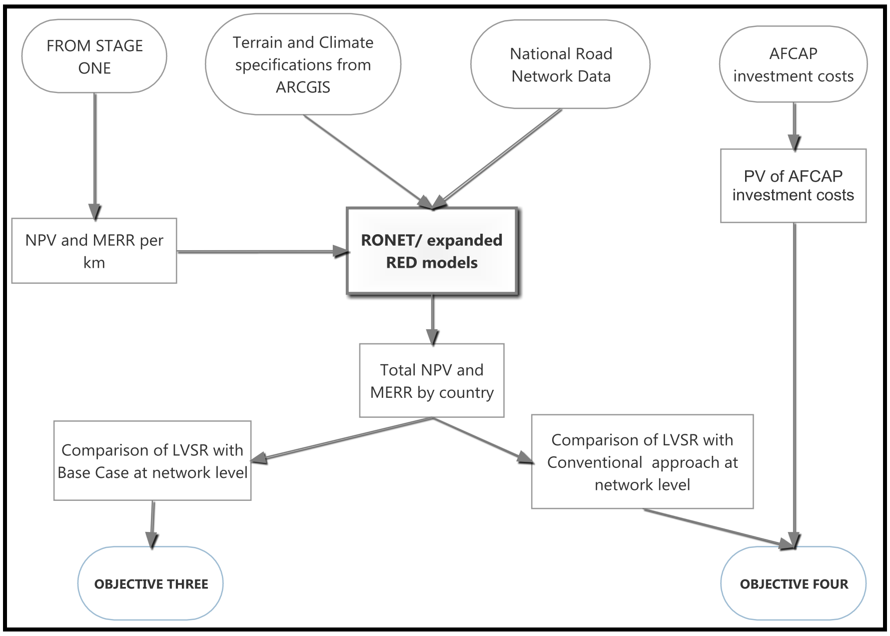
i. the results from Stage One (the NPV and MERR for 1km sections of road under different combinations of terrain and climate);
ii. estimates of the total length of upgradable gravel roads in the road networks of each country;
iii. the share of upgradable roads that are in each combination of terrain and climate;
iv. the share of upgradable roads that might be implemented using an LVSR approach and the share of these applications that could be attributed to AFCAP, and;
v. the costs of the AFCAP programme in each country and overall (including administration costs).

Although some use was made of the RONET model, its operation required more detail on the condition of the national road networks than was readily available for all of the five countries. To retain compatibility in the analysis of all countries and avoid the need to make many assumptions about the condition of gravel roads throughout the national road networks, an alternative and simpler analysis was made at the network level. This analysis used just the information of lengths of upgradable road, an assumption that all upgradable roads are currently in poor condition, and the available data on terrain and climate in each country. This simpler method was organised as a further add-on to the RED model.

**Non-quantified benefits**

Some benefits of the LVSR approach are not included in the evaluations. The omitted benefits are social, environmental and institutional. The non-quantified social benefits include those of reduced accident costs, while two of the environmental benefits are the lesser use of an increasingly scarce natural resource – crushed gravel that has many other uses (mostly construction) and reduced dust pollution[8] from sealed roads compared to gravel roads. The main un-quantified institutional benefit of the LVSR approach is that of the knowledge and skills learnt through its application that can be applied to contexts where there are substantial economic benefits but the conventional methods of implementing them are not cost-effective.

Figure 2 Flowchart for Stage Two




To address Question 3, the analysis of data from the expanded RED model was used to compare a base case in which the starting poor condition rural road was retained in this condition (with minimum routine maintenance to prevent its condition deteriorating too much), with different combinations of sealed roads and approaches (conventional and LVSR) to their upgrading to sealed roads (the same as for Question 2 applied to the network level).

For Question 4 two comparisons were made. In the first instance, between the road network costs of using a conventional and LVSR approach, and then between the difference in these costs (expressed as a benefit) and the costs of the AFCAP research programme.

Table 1 provides a summary of the comparisons used in the evaluations to address each of the Questions. The first part of the Table indicates the different combinations of approach and road surface for which costs and benefits were estimated, while the second part shows which of these combinations was used (and with what road length) to address each of the Questions.

[88] Many road construction contracts include a requirement for the contractor to minimize dust pollution. While adding to the construction cost, the measures at best minimise and do not eliminate dust pollution, so there is always a residual environmental cost of road construction.

Table 1 Comparisons used to address each Question

| Alternative | Approach | Surface type |
|---|---|---|
| A<br>B<br>C<br>D | Conventional | Unimproved gravel road<br>Improved gravel road<br>Single surface treatment<br>Double surface treatment |
| E<br>F | LVSR | Double surface treatment<br>Otta and Sand Seal |
| Question | NPV comparison between PVs of | Road length |
| 1<br>2<br>3<br>4 | D and E<br>A and B, A and C, A and D, A and E, and A and F<br>A and average of E and F<br>D and E | 1 km<br>1 km<br>National network upgradable length<br>National network upgradable length |

*Source: Authors' analytical method*

**Evaluation criteria**[9]

There are at least three criteria that can be used to measure the net economic benefit of the upgrading of gravel roads[10]. These are the net present value (NPV)[11], the economic rate of return (ERR) and the modified economic rate of return (MERR).

The basic RED model estimates the annual financial costs of road construction and maintenance and road vehicle operation and road users' time costs of each alternative over an analysis period of twenty years. The stream of annual financial costs is converted to economic costs which are then discounted to give their present value. By subtracting the annual economic costs of one project relative to another, the result is the net present value (NPV) of one project relative to the other. It can also be the NPV for one project if the annual difference is between the costs and benefits of that project

**Net Present Value (NPV)**

The NPV is a measure of the absolute welfare gain over the whole life of the upgrading being considered, or of the difference between two upgrading alternatives. There is no generally accepted rate (percentage) at which the annual costs and benefits are discounted to give a present value. One approach is to select a rate that represents the opportunity cost of the capital used for the investment, another is to use an estimate of the social time preference rate (STPR), while yet a third option is to the opportunity cost of capital to discount the investment costs and the STPR to discount all the other costs and benefits. The opportunity cost of capital for investment in infrastructure in developing countries is variously estimated at between 8% and 15%, while estimates of the STPR are more often in the range of 3% to 6%. The base discount rate used for both investment and other costs and benefits in the evaluations reported here is 12%, which is the rate used by the World Bank for its infrastructure projects. Other international lending institutions use different, mostly lower, discount rates that can be between 3% and 15%[12].

[9] When and how to use NPV, IRR and modified IRR, Transport Note TRN6, World Bank, January 2005

[10] Cost Effectiveness methods, often applied used in the LVSR approach were not appropriate to the assessments needed to address the four Questions.

[11] Present Value (PV) us used to describe the results of discounting a single stream of annual costs or benefits. When the annual costs and benefits are combined to produce a net annual cost, the results of the discounting are referred to as a net present value (NPV)

[12] http://development.asia/issue01/analysis-04.asp and http://development.asia/issue01/analysis-04.asp

One disadvantage of the NPV criterion is related to project size. When comparing the economic benefits of alternative projects, the project with the largest size might give a larger NPV just because of its size, and not because it represents a better use of resources. One solution to this problem of scale is to replace the NPV criterion with an NPV/C criterion where C is a measure of the undiscounted (or discounted) investment cost of the project.

**Economic Rate of Return (ERR)**

The ERR is the rate at which benefits are realized following an initial transport investment. It can be thought of as the constant compound rate of return which is equivalent to the actual – fluctuating – rate of return over the project lifetime. The ERR of a project is closely related to the discount rate used to calculate its NPV: it is the rate of discount at which the NPV of the project is reduced to zero.

**Modified Economic Rate of Return (MERR)**

MERR is similar to the ERR, but addresses two of its weaknesses. First, the ERR assumes that all the annual benefits of the project are re-invested at the internally generated rate of return, yielding further benefits in the next period. So for a project that has a calculated ERR of say 35%, not unusual for a transport investment, there is a built in assumption that the annual benefits of the project are being reinvested at the same 35%.

But some of the benefits of transport projects, such are travel time savings, are difficult to re-invest directly, while it is improbable that the other benefits can be invested at such a high rate.[13] If the benefits cannot be re- invested or if they are re-investible at a rate that is significantly different to the ERR of the project, then the ERR will either over or under state the true rate of return.

The MERR corrects for this by allowing the user to choose the rate at which the annual benefits are reinvested, often assumed to be the opportunity cost of capital or the same as the discount rate used in an NPV calculation. It then calculates the MERR, a better estimate of the true economic rate of return on the investment than that given by the ERR.

The MERR addresses another problem of the ERR. The annual net benefits of the project can change more than once between being positive and negative (not unusual for a road investment or upgrading, with a large investment (that is, a negative benefit) in the first years, followed by several years in which there are positive benefits of vehicle operating cost and user travel time savings, followed by another year(s) in which there is a second large investment when a rehabilitation is needed, giving a overall negative benefits again for that year). With the typical one change between negative and positive annual net costs, the ERR will give a unique result, but with more than one change it can give multiple results with no way of determining which one is appropriate.

**Evaluation criterion selected**

All of the questions to be addressed by the evaluation ask about "net economic benefits" and these can be expressed as NPVs, ERRs or MERRs. We used the NPV as the main evaluation criterion, supplemented by the MERR in preference to the ERR. When the net economic benefit of a typical 1km for one combination of terrain and climate needs to be multiplied by the network length of upgradable road in that combination, and the results summed over roads in all combinations of

http://www.ppiaf.org/sites/ppiaf.org/files/documents/toolkits/Cross-Border-Infrastructure-Toolkit/Cross-Border%20Compilation%20ver%2029%20Jan%2007/Resources/Adhikari%20Weiss%20-%20Methodological%20Framework%20for%20Economic%20Analysis.pdf

[13] There is comparable problem with investment projects that have low rates of return, say of only 3%. There is a built in assumption in the calculation of this rate that its annual benefits are being reinvested in projects that yield a rate of return of only 3%

terrain and climate, the MERR cannot easily be used[14] while the NPVs are easier to multiply and sum. So in most cases the net economic benefit of comparing one project with another was measured using the NPV, and the MERR only provided as a validation check.

**Additions to the basic RED model**

Several worksheets were added to the standard RED model. Some of these additions were to develop base data as inputs for the RED model, others are to provide estimates of road network impacts (that is, to substitute for running of the RONET model) while others provide economic evaluations based on comparisons of road types/design approaches.

The additional worksheets to develop base data were:

**INVEST:** This provides International Monetary Fund projections of the GDP of each of the five countries and then applies assumptions to the total GDP over the period 2014 to 2018 to derive estimates of the funding that might be available for rural road construction. The main assumptions relate to:

- The share of GDP likely to be allocated to the transport sector.
- The percentage of this share that might be allocated to rural roads.
- The percentage of this share that might be allocated to sealing of low volume gravel roads.

Another key assumption included in this worksheet is the expected share of sealed low volume roads that might be developed using an LVSR approach in the next five years. An estimate of this share was considered necessary given the slow uptake of this approach over the last two decades.

**Const cost:** In this worksheet the basic road investment costs for each type of surface/approach combination are estimated and updated to end-2012 prices. The main inputs are the unit costs from RONET for 2006, and a check on the 2012 prices was provided by the AFCAP costs for Malawi and Mozambique. This worksheet shows the assumptions made about the composition of the total costs of roads with each type of surface, the inflation rates used to update prices and the assumptions made to derive the costs for roads developed with an LVSR approach.

**C and T:** This worksheet provides the share of land area in each of the nine combinations of terrain types and climate groups derived from the GIS database (the data for five terrain types and six climate groups and 42 Sub-Saharan countries is available separately).

**Terrain & Climate**: This worksheet provides the specification for the nine combinations of terrain and climate used in the RED model (in terms of rise and fall, curvature and super-elevation for terrain and % of time that the road has a wet surface for climate type).

The worksheets to facilitate comparative evaluations are:

**ECONOMICS**: This allows an estimation of the net costs of using one type of surface/approach compared to another.

**R and F**: This worksheet provides the results (NPV and MERR) of the nine runs of the RONET model, one for each combination of terrain and climate for four types of road surface/design approach and from which the results for other combinations were estimated. The worksheet also weights these NPVs and MERRs by the frequency of occurrence of each terrain/climate combination to derive averages.

**LENGTHS**: This allows an estimate to be made of the lengths of low volume gravel roads that could be potentially sealed that are in each terrain/climate combination for each country. It also provides

[14] It is possible to use average MERRs to estimate a network average MERR but the result is difficult to interpret

an estimate of the length of additional road that could be sealed if an LVSR approach rather than a conventional approach is used. The share of roads upgraded using an LVSR approach is a user specified parameter in this worksheet.

**NPV**: This worksheet provides the estimates of NPV for each of the Questions. It makes use of the NPV per km for each combination of terrain and climate derived from the ECONOMICS worksheet and the lengths of road in each terrain/climate combination from the LENGTHS worksheet. It also provided an estimate of the NPV of the benefits from allocating all the cost savings from using an LVSR approach to sealing more roads, using the average NPVs derived in the ECONOMICS worksheet.

**AFCAP:** This is the worksheet where the benefits of the AFCAP programme are estimated, using the NPVs estimated in the NPV worksheet and the AFCAP investment costs, converted to USD $ and discounted at the same rate as the benefits.

**CONNECT**: The contents of this worksheet were used to estimate the additional number of people who would live within 2km of a sealed road and the increase in the value of agricultural output that would have sealed road access to its local market.

# 4. Types of road and their costs

Five different combinations of approach to road development and road surface type were assessed in the economic evaluations. These were:

- Conventional approach: Double Surface Treatment (DST)
  Single Surface Treatment (SST)
  Reconstructed and maintained Gravel Surface
- Low Volume Sealed Road approach: Double Surface Treatment (DST)
  Otta Seal with Sand Seal

For the analyses to respond to Questions 1 and 4, a comparison was made between the Present Values of the first and fourth combinations. For the Questions 2 and 3, the Present Values of each of the five combinations was compared with that of a poor condition gravel roads that was not improved.

<u>Conventional approach</u>

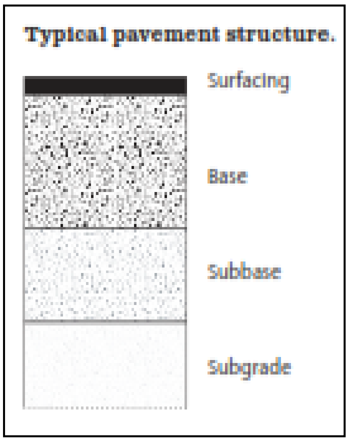
For the conventional approach the three types of road were included to cover the main options for providing low volume roads. A single surface treatment was included as it is often the least initial cost (but not very often the least lifetime cost) method of sealing a low volume road, but experience has indicated that it can have a higher present value that a road with a double surface treatment when actual maintenance practices and road user costs are taken into account. However, it was included in the evaluations as it is still sometimes used for very low volume roads. The road with a double surface treatment was included as it is the most widely used approach/surface type combination for low volume roads in Sub-Saharan countries. The gravel surface option was included as it can be the option with the highest NPV when traffic volumes are very low.

<u>LVSR approach</u>

Given its widespread use in a conventional approach, it was considered useful also to include a double surface treatment as an LVSR option for two reasons. First, this would allow a comparison to be made between roads with similar structures developed under the two approaches without the analysis being influenced by different types of road surface, and; second, under many circumstances it is considered the most appropriate type of surface to be used under an LVSR approach.

There are many other types of road surface that are developed using an LVSR approach, the choice of which one to use in any particular situation depends very much on the local circumstances, including the availability of materials and local experience with constructing low volume sealed roads with one particular type of surface. We have used an Otta Seal, with the addition of a Sand Seal as representative of all these other types of road surface, not to indicate any preference but because it is the most widely promoted of these surfaces and there is more data relating to its construction and maintenance costs than for the other surface types (but still very little).

We assumed that all combinations of approach and surface type would have the same three component structure below the surface, comprising a base, sub-base and subgrade. We also assumed that for all the combinations other than the unimproved poor condition gravel road, that the base and sub base would be reconstructed together




*Source: Guidelines: Low Volume Sealed Roads, SADC, 2003*, with the provision of a new surface in the first year of the analysis period. Subsequent maintenance was assumed to provide a new surface when the roughness of the road surface (as measured by the International Roughness Index, the IRI) exceeded a value of between 6 and 10, depending on the surface type. The base and sub base were assumed to be reconstructed at every other resurfacing. The maximum IRI value for the base case road was assumed to be 12 (Table 4).

**Road reconstruction costs**

The estimate of initial reconstruction costs for the conventional approach with DST, SST and gravel surface roads was based on data in the ROCKS system. However, most of this data relates to the period 2006 to 2008, so it was updated to end-2012 prices by applying different inflation factors to the main components of the ROCKS costs. The results were compared with those for some actual DST and SST roads constructed in the region in the last two years and found to be broadly compatible, given the wide variation in actual prices within and between countries.

The initial reconstruction costs for roads using an LVSR approach were also based on those in ROCKS for roads developed using a conventional approach, but with the further application of percentages to the components of the total cost that would be reduced (or in the case of construction supervision, increased) through use of an LVSR approach.

The resulting estimates of the initial upgrading costs for each combination of approach and surface type are shown in Table 2, together with the cost differences for each combination compared to an upgrade using a conventional approach with a DST[15]. It is these cost differences which, together with the assessment of road user costs, are the basis of the estimated benefits of the LVSR approach[16].

Table 2 Estimated investment costs of upgrading a poor condition gravel road

| Approach | Surface type | Investment cost US$/km | Investment cost difference compared to conventional DST US$/km |
|---|---|---|---|
| Conventional | Unimproved gravel | 19,400 | 203,200 |
| Conventional | Improved gravel | 96,900 | 125,700 |
| LVSR | Otta + Sand Seal | 165,700 | 56,900 |
| LVSR | LVSR Double Surface Treatment | 180,500 | 42,100 |
| Conventional | Conventional Single Surface Treatment | 209,500 | 13,100 |
| Conventional | Conventional Double Surface | 222,600 | 0 |

*Source: Authors' estimates based on ROCKS*

There is some doubt as to whether a road with a DST surface constructed using an LVSR approach will attract the same savings in materials costs as would other types of LVSR road. The costs excluding the materials cost savings were used in a sensitivity test.

[15] Details of the derivation of these costs are available

[16] These construction costs are only about one third of those used in another evaluation of AFCAP (unpublished but available), which range from about USD $300,000 to USD $1,100,000 per km. Also the cost difference between conventional and LVSR approaches is much less than in the other evaluation which are of the order USD $150,000 to USD $600,000 per km. That is a saving of between 33% and 50% of that of a conventional approach. In part the cost differences are attributable to a different understanding of the scale of road for which an LVSR approach might be appropriate.

**Road maintenance costs**

The consideration of maintenance costs followed the structure used in the ROCKS system, which distinguishes between routine and periodic maintenance[17].

Routine maintenance - This is undertaken each year and is funded from the recurrent budget of the agency responsible for the road. The activities can be grouped into cyclic and reactive works types. Cyclic works are those undertaken where the maintenance standard indicates the frequency at which activities should be undertaken. Examples are verge cutting and culvert cleaning, both of which are dependent on environmental effects rather than on traffic levels. Reactive works are those where intervention levels, defined in the maintenance standard, are used to determine when maintenance is needed. An example is patching, which is carried out in response to the appearance of cracks or pot-holes. Since cracking is in part a response to the volume of traffic and the incidence of high axle loads, the cost tends to increase over time between periodic maintenance activities. In the version of the RED model used in this analysis, the cost of routine maintenance was expressed as a function of the IRI of the surface, an indication of the need for patching (or regrading/regravelling for a gravel surface road).

Roads with a gravel surface need more routine maintenance than those with sealed surfaces, such as the need to regrade the gravel surface at frequent intervals, up to twice per year depending on the climate, the volume of traffic and how well some of the other routine maintenance activities have been carried out. We were unable to find any data on the routine maintenance costs of roads with Otta Seals or other similar types of surface, so assumed that they are the same as other road surfaces that are surface treatments.

We have not found any reliable data on the difference in routine maintenance costs between conventional and LVSR approaches for roads with similar surfaces and structures, but the evaluations do take account of differences in routine maintenance costs between roads with different surface types, based on data in ROCKS.

Table 3 Routine maintenance costs

| Condition | IRI value | Surface treatment and Otta Seal USD $/km | Gravel road with periodic maintenance USD $/km | Gravel road without periodic maintenance USD $/km |
|---|---|---|---|---|
| Very Good | less than 8 | 1,100 | 1,400 | 1,800 |
| Good | 8 – less than | 1,100 | 1,400 | 1,800 |
| Fair | 11- less than | 2,000 | 2,500 | 3,100 |
| Poor | 14 to less than | 2,100 | 2,700 | 3,400 |
| Very poor | 20 and above | 2,200 | 2,900 | 3,600 |

*Source: Authors' analysis based on ROCKS data*

Periodic maintenance - This includes activities undertaken at intervals of several years to preserve the structural integrity of the road, or to enable the road to carry increased axle loadings. It excludes activities that change the geometry of a road by widening or realignment. Activities are grouped into preventive, resurfacing, overlay and pavement reconstruction. Examples are resealing and overlay works, which are carried out in response to measured deterioration in road conditions. Periodic works are expected at regular, but relatively long, intervals. As such, they can be budgeted for on a regular basis and can be included in the recurrent budget. However, many countries consider these activities as discrete projects and fund them from the capital budget. The version of the RED model

[17] http://www.worldbank.org/transport/roads/con&main.htm#maintenance

used in this analysis, expressed the need for periodic maintenance as a function of the IRI of the surface.

Estimating the frequency and time between the need for periodic maintenance interventions depends on the assumed level of IRI after the previous intervention, the rate of deterioration of the surface and the assumed level of IRI at which a subsequent intervention would be justified. The values used for these variables in the version of the RED used here are shown in Table 4. These values assume that the level of traffic is so low as to not impact on the life of the surface. The values for a DST were the same for both approaches[18].

The evaluations include differences in periodic maintenance costs between the conventional and LVSR approach, which were assumed to be proportional to the differences in initial upgrading costs, and between roads with different surface types, based on data in the ROCKS. The impact of periodic maintenance costs on the results of the evaluations depends on the assumed frequency that they are needed. The parameters used to estimate these frequencies were the IRI value at which an intervention would be made, the number of years before deterioration of the surface starts, and the subsequent rate of deterioration.

Table 4 Parameter values for estimating periodic maintenance interventions

| | Type of surface | | | | |
|---|---|---|---|---|---|
| | Unimproved gravel road | Improved gravel road | DST | SST | Otta Seal |
| Initial IRI after first intervention | 6.0 | 6.0 | 2.5 | 2.5 | 2.8 |
| Years before deterioration starts | 0.0 | 0.0 | 4.0 | 3.0 | 3.0 |
| Rate of deterioration | 1.8 | 1.6 | 0.4 | 0.5 | 0.4 |
| Threshold IRI for next intervention | 12.0 | 10.0 | 6.0 | 6.0 | 6.0 |
| Years to next intervention | 3 | 3 | 13 | 11 | 11 |

*Source: Authors assumptions*

There are no generally accepted values for these variables since the characteristics of the road and the maintenance regime will have an impact at least as significant that of the variables shown. Given the range of uncertainty of the values, they were subject to several sensitivity tests.

We assumed that the first intervention after the initial reconstruction of the road would be a reseal and that the next intervention would be a partial reconstruction, sometimes referred to as rehabilitation. This activity extends the life of an existing pavement structures either by restoring existing structural capacity through the removal and replacement of deteriorated pavement surface or by increasing pavement thickness to strengthen existing pavement sections to accommodate existing or projected traffic loading conditions. They are very effective for pavements that are deteriorated, but not to the point that reconstruction is required. We have assumed that the cost of resurfacing is 20% of the cost of reconstruction and that of rehabilitation is 50% that of reconstruction.

[18] Although different assumptions can be made for each of these variables, their only importance is in the outcome, the assumed period between interventions.

## 5. Length of upgradable gravel roads

Two different methods were used to estimate the length of gravel roads[19] that could justifiably be upgraded to a sealed surface. The first method was based on the estimated length of gravel roads in each country that have a traffic level of at least 200 Annual Average Daily Traffic (AADT)[20]. The second method was based on estimates of the additional length of sealed road that would be needed to connect at least 80% of each country's agricultural output to markets[21].

**Length of upgradable roads**

For the first method a single source[22] was used to provide consistent date for the lengths of gravel roads in the national road network of each of the five countries. In addition to the length of gravel roads, it indicated the distribution of traffic levels, from which it was possible to estimate the length of gravel roads with at least 200 AADT. This method resulted in an estimate that almost 45,000km of gravel roads have at least this volume of traffic in the AFCAP participating countries.

The second method made use of a GIS referenced database of potential agricultural output, and a GIS based road network that includes roads by surface type. A simple model was used to estimate the minimum length of road that would be needed to achieve specific levels of connectivity of the projected agricultural output. The length of sealed road needed to achieve 80% connectivity was compared to the length of existing sealed roads, and the difference considered as the length of additional sealed road needed. It was found that most of the approximately 30,000km of additional sealed roads needed would come from the upgrading of existing gravel roads rather than the construction of completely new roads.

Figure 3 Importance of connectivity of people and agricultural output

> *Countries in Africa, including Mozambique, are potentially rich in agriculture...and we recognize the weakness in terms of access both for the flow of agricultural goods as well as to deliver a wide variety of inputs that rural people need in their day-to-day lives. It is the government's desire that all stakeholders share the responsibility in defining innovative policies for the provision of rural access and mobility.*
>
> His Excellency Deputy Minister Francisco Pereira of Mozambique's Ministry of Public Works and Housing
>
> AFCAP Conference, July 2012

Since these two methods used alternative approaches and neither was considered preferable to the other, an unweighted average of the two was used, with the results as shown in Table 5. While the connectivity method indicates a shorter overall length of upgradable road, for Ethiopia and Mozambique it indicated a much longer length[23].

[19] We have not included roads with an earth surface as they do not usually have enough traffic to justify their upgrading to a sealed surface on an economic criterion and they are rarely needed for upgrading to achieve the connectivity standard.
[20] This is the minimum level of traffic that usually justifies an upgrading based on savings in VOC and VOT.
[21] Details of how the road lengths needed to achieve this level of connectivity are estimated can be found in Africa Infrastructure Country Diagnostic, Background Paper 7, World Bank 2008.
[22] Tables 4 and 10 of the Annex to Background Paper 14 for the Africa Infrastructure Country Diagnostics (AICD).
[23] These upgradable road lengths are much shorter than the 130,000km to 200,000km assumed in the alternative evaluation of AFCAP. But these estimates include South Sudan and Democratic Republic of Congo which together account for about half of the total length.

Table 5 Length of potentially upgradable road in each country

| Country | Based on traffic volume km | Based on Connectivity standard km | Average km |
|---|---|---|---|
| Ethiopia | 6,200 | 8,500 | 7,350 |
| Kenya | 11,800 | 2,700 | 7,250 |
| Malawi | 2,000 | 900 | 1,450 |
| Mozambique | 2,300 | 9,300 | 5,800 |
| Tanzania | 22,600 | 8,300 | 15,450 |
| Total | 44,900 | 29,700 | 37,300 |

*Source: Authors analysis of data in Tables 4 and 10 of Background Paper (BP) 14, Annex and the connectivity data used in Background Paper (BP) 7*

**Allocation of road lengths to terrain and climate groups**

The next step of the analysis was to allocate these road lengths to each of the nine combinations of terrain and climate type. Another assumption made here was that the distribution of upgradable roads is the same as that of the land area between the combinations of terrain and climate. This is a strong assumption, as it might be that the upgradable roads are more concentrated in the land areas that have a higher agricultural production or a higher population. However, it might also be that the earth and gravel roads in these regions have already been upgraded as they have a higher economic and social justification, so the remaining upgradable roads might be more concentrated where there is less production and population. The assumption used is neutral between these two extremes.

There are several sources from which the distribution of land between terrain and climate groups can be determined. The source used here was the ARCGIS World Basemap, as used by the World Bank in the Africa Infrastructure Country Diagnostic (AICD). This source provides five terrain types based on their average gradient. The Undulating and Rolling categories were combined for this analysis, as have the Moderately Steep and Steep categories. The specification of the five categories is shown in Table 6.

Table 6 ARCGIS Land Gradient Categories

| Gradient category | Specification |
|---|---|
| Flat | < 2% slope |
| Undulating | 2% - 8% slope |
| Rolling | 8% - 15% slope |
| Moderately steep | 15% - 30% slope |
| Steep | > 30% slope |

*Source: World Bank*

The same source includes six categories of climate, and as with the terrain categories these five zones were reduced to three, by combining desert and arid, and semi-arid and sub-humid. The specification of the six climate zones is shown in Table 7.

Table 7 ARCGIS Climate Zones

| Climate Zone | Specification |
|---|---|
| Desert | < 100 mm average annual rainfall |
| Arid | 100 - 400 mm average annual rainfall |
| Semi-arid | 400 - 600 mm average annual rainfall |
| Sub-humid | 600 - 1200 mm average annual rainfall |
| Moist sub-humid | 1200 - 1500 mm average annual rainfall |
| Humid | > 1500 mm average annual rainfall |

*Source: World Bank*

The data from the 30 combinations of category and zone have been aggregated for each country, to give the following distribution of land area between the nine combinations of terrain and climate for each country.

Table 8 Distribution of land area by terrain and climate

| | Flat | | | |
|---|---|---|---|---|
| | Dry | Semi | Humid | Sub total |
| Ethiopia | 24% | 18% | 2% | 44% |
| Kenya | 35% | 37% | 1% | 73% |
| Malawi | 0% | 38% | 6% | 44% |
| Mozambique | 0% | 55% | 6% | 62% |
| Tanzania | 0% | 53% | 4% | 56% |
| | Undulating | | | |
| | Dry | Semi | Humid | Sub total |
| Ethiopia | 3% | 15% | 10% | 29% |
| Kenya | 2% | 13% | 5% | 20% |
| Malawi | 0% | 33% | 7% | 40% |
| Mozambique | 0% | 23% | 12% | 35% |
| Tanzania | 0% | 28% | 6% | 34% |
| | Mountainous | | | |
| | Dry | Semi | Humid | Sub total |
| Ethiopia | 1% | 18% | 8% | 27% |
| Kenya | 1% | 5% | 2% | 7% |
| Malawi | 0% | 9% | 7% | 16% |
| Mozambique | 0% | 2% | 1% | 3% |
| Tanzania | 0% | 5% | 5% | 10% |

*Source: Authors analysis based on World Bank data from ARCGIS World Database*

Once the shares of road length in each combination of terrain and climate type were known, the total upgradable road lengths were allocated to each terrain and climate combination by applying the percentages in Table 5 to the distribution in Table 8.

**Available funding**

The road lengths that could be upgraded will depend on the funding that might be available. The available funding was estimated by applying a series of percentages to the estimated future GDP in each of the countries. This method proved difficult to apply as other than for the first two parameters - public investment in transport infrastructure as a percentage of GDP and investment in roads as a percentage of transport infrastructure investment[24], there is little published data on the other percentages. Even for first two parameters, most of the published data relates countries of the EU and OECD rather than to developing countries.

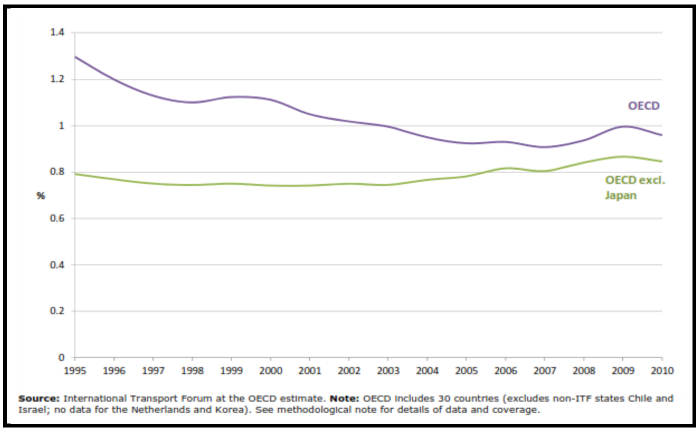
The other parameters are:

- the share of road investment that goes to rural roads
- the share of rural road investment that goes to new construction
- the share of new construction in rural roads investment that goes to upgrading low-volume roads

The share of GDP dedicated to transport infrastructure has tended to remain constant in many countries, suggesting investment levels are affected by factors other than real investment needs, such as institutional budget allocation procedures or budgetary constraints

[24] This is not the same as the transport share of GDP, which is readily available from IMF sources, but is not relevant to the estimation method described here.

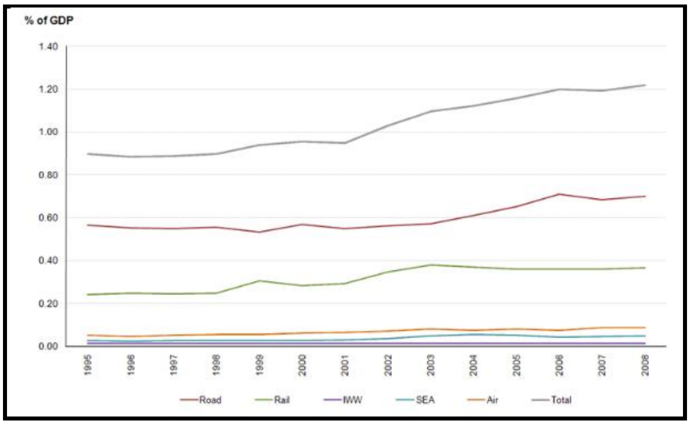
Figure 4 Transport investment as % of GDP for Organisation for Economic Co-operation and Development (OECD)




*Source;* [*http://www.internationaltransportforum.org/statistics/StatBrief/2012-06.pdf*](http://www.internationaltransportforum.org/statistics/StatBrief/2012-06.pdf)

An investment level of 1% per GDP remained a norm for developed countries for many years, such that it became *de facto* political benchmark in the 1980s, though with no theoretical basis to support it. The investment needs for transport infrastructure depend on a number of factors, such as the quality and age of the existing infrastructure, geography of the country and transport-intensity of the country's productive sector, among other things. Investment levels for developing and transition economies tend to be higher. Central and Eastern European countries (CEECs) had invested about 1.0% of GDP, in the 1980s, close to the informal benchmark, but this increased sharply, reaching 2.0% in 2009. The current percentages for OECD countries is about 0.8% and that of the non-CEEC EU countries is about the same. World Bank data for an earlier period- the 1960s to 1980s - showed that rapidly developing economies, such as were Japan and South Korea in that period, tended to invest between 3% and 4% of GDP.

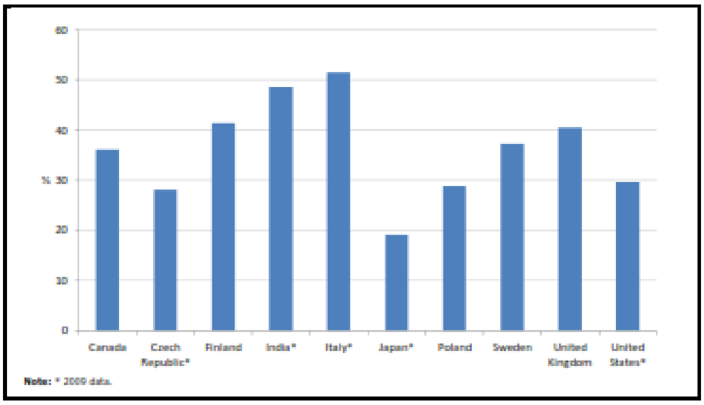
Figure 5 Transport investment as % of GDP by mode, EU Countries 1995 to 2008




*Source:* [*http://www.eea.europa.eu/data-and-maps/figures/term19-percentage-of-gdp-used-1*](http://www.eea.europa.eu/data-and-maps/figures/term19-percentage-of-gdp-used-1)

All countries for which data is available allocate by far the largest share of transport investment to roads. Even in the EU countries which between them have extensive rail and inland waterway networks and many airports and ports, the road share is typically about 60% to 75% of the total. In OECD countries the investment share of road investment is typically about 70% (Figure 6 Shows the maintanance share, not the investment share). For developing countries that share is typically higher, between 80% and 90%. For developing countries that have less extensive rail and waterway networks, and fewer ports and airports, the share is typically between 85% and 95%.

Figure 6 Maintenance share of road investment for selected OECD countries




*Source:* *http://www.internationaltransportforum.org/statistics/StatBrief/2012-06.pdf*

**Projected investment in upgrading low volume rural roads**

In the analyses described here, the IMF projections of GDP for the next five years for the five countries have been used. The projected total is a little more than USD $1.1 billion. For the other parameters we have used what little available evidence there is as a guide, but as there is so little that all of the further assumptions were subject to wide ranging sensitivity tests.

What little data that is available for the countries of Sub Saharan Africa[25] indicates that in the period 1995 to 2005 they invested about 2% of their GDP in transport infrastructure, but with a wide variation in the range of 1% to 3.5%. With an increasing understanding of the importance of transport investment as a necessary contributor to increased GDP, there is an expectation that the share of GDP allocated to transport in the five countries of the study could increase over the next five years. We have assumed that the funding for the transport investment will average 2.5% of GDP over the next five years.

Table 9 % shares for investment in upgrading low volume rural roads

| Parameter | Basic Share | Low estimate | High estimate |
|---|---|---|---|
| Transport share of GDP | 2.5% | 2.0% | 3.0% |
| Roads share of transport investment | 90% | 80% | 95% |
| Rural share of roads investment | 33% | 20% | 40% |
| Investment share of rural roads | 75% | 60% | 85% |
| Low volume share of rural roads | 33% | 20% | 40% |

*Source: Authors' assumptions*

We have further assumed that 90% of transport investment will be allocated to roads, and of that that one third (33%) will be allocated to rural roads. Of the rural road share we have assumed that 80% will be allocated to new investment rather than maintenance (although the share would be much less to optimize the economic benefit of road investment) and that 50% of rural road investment will be allocated to low volume roads.

The resulting values assumed for the parameters used to derive the investment funds that might be available for upgrading low volume rural roads are shown in Table 9. The table also shows the low and high estimates that were used in sensitivity tests.

[25] From unpublished Working Papers for the AICD, 2008

When these shares are applied to the IMF estimates of GDP and the result divided by the average cost of an LVSR road in each country, the resulting road lengths that can be upgraded (using a conventional approach and a DST) are those shown in Table 10.

Table 10 Fundable length of upgradable roads

| | Average GDP from 2014 to 2018 | Available for upgrading LVSR | Maximum Fundable length | Share of total km | Country share of upgradeable roads that can be funded |
|---|---|---|---|---|---|
| Country | USD $bn | USD $bn | km | % | |
| Ethiopia | 343.5 | 0.46 | 2,052 | 25% | 31% |
| Kenya | 371.4 | 0.60 | 2,682 | 33% | 42% |
| Malawi | 28.6 | 0.05 | 205 | 2% | 15% |
| Mozambique | 124.1 | 0.37 | 1,642 | 20% | 31% |
| Tanzania | 233.5 | 0.37 | 1,665 | 20% | 12% |
| Total | 1,101.1 | 1.84 | 8,246 | 100% | 25% |

*Source: Authors' assumptions*

Of the total GDP for the five countries of a little more than USD $1,100 billion over the five years, less than USD $2 billion would be available for investment in upgrading low volume roads, enough to upgrade about 8,250km if a conventional approach is used for all the upgrading and sealing of gravel roads. Of this length, about one third is in Kenya, one third in Ethiopia, about one fifth in each of Mozambique and Tanzania and only 2% in Malawi. The shares of total upgradeable roads in each country that can be funded follows a similar pattern, Kenya will have funding for about 42% of its upgradeable roads, Ethiopia and Mozambique for about 31%, Malawi for about 15% and Tanzania for only about 12%.

## 6. Evaluation results

The results of applying the two Stage assessment method are presented in the form of responses to the four questions indicated in the Objectives Section.

**Question 1: What are the economic costs/benefits of adopting the Low Volume Sealed Road (LVSR) approach compared with conventional design approaches for paved roads?**

This question has a more limited objective than the others. The economic comparison that was needed was a direct comparison between reconstructing a gravel road using the conventional and LVSR approaches. It did not require the specification of a base case (a "Do Nothing" option) or an evaluation of whether either the conventional or LVSR approach was economically justified.

To avoid the comparison between ***approaches*** being influenced by different types of ***road surface*** being considered for each of them, a road with a double surface treatment on a three part underlying pavement structure was used for both approaches. The costs included in the measures were those of the initial reconstruction and upgrading, and its subsequent maintenance in good condition. However, we assumed that once the reconstruction and upgrading had been completed, the structure of the road and its surface would be so similar that there would not be any difference in their routine maintenance costs or in the vehicle operating and users' time costs. There was an assumed difference in subsequent periodic maintenance and rehabilitation costs that reflected the differences in the original reconstruction costs,[26] but this added little to the result of the evaluation.

The evaluation was repeated for each of the nine combinations of terrain and climate, and the results summed over all combinations to give a measure of the weighted average net economic benefit. Using an LVSR approach compared to the conventional approach was found to give a net present value of about USD $31,300 per km, almost 15% of the undiscounted economic investment cost of the conventional DST road.

Table 11 Economic evaluation of an LVSR compared to a conventional approach

| Evaluation assumptions | | NPV USD $/km |
|---|---|---|
| Basic evaluation | | 31,300 |
| Investment costs of LVSR DST +10% | | 22,000 |
| VOT and VOC costs of LVSR DST +5% | | 22,100 |
| Both increases together | | 12,800 |
| Switching values | Investment | 34% |
| | VOC and VOT | 17% |
| | Both | 13.5% |

*Source: Author's application of RED model*

Sensitivity tests carried out in which the investment costs under the LVSR approach were assumed to increase by 10% compared to those of the conventional approach, and the VOC and VOT costs assumed to increase by 5%, and taking both assumptions together. The impact of each of the first two changes was to reduce the NPV of the LVSR approach by about 30% and taking the two together by about 59%. The investment cost for both types of road would need to increase by about 34% (and therefore the investment cost difference) to reduce the NPV to zero. Taking the two variables together, each would need to increase by about 34% to bring about a zero NPV.

***The results of these evaluations indicate that using an LVSR rather than a conventional approach provides a significant economic benefit***, and that this benefit is robust to possible changes in two of the assumptions that are most likely to influence the result. The only possible caveat to this conclusion is taking the two assumptions together which brings the evaluation results, particularly

[26] We were unable to find any reliable data on the routine maintenance costs of roads designed and built using the LVSR approach.

the MERR, close to their benchmark values. To bring about an increase of 13.5% in VOC and VOT for the LVSR approach, the roughness of the road surface would have to increase by more than 25%, and this is at the margin of plausibility, and an increase of 34% in the investment cost of an LVSR relative to that of a conventional DST is implausible since it would make their investment costs very similar.

**Question 2: What are the economic costs/benefits of upgrading gravel and earth roads to paved road?**

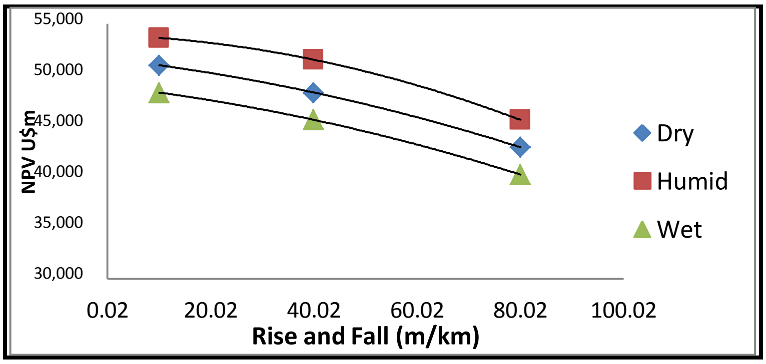
The data and analyses needed to address this question are rather more complex than those needed for the first. The evaluation requires a base case of a gravel road to be specified, including its maintenance regime and costs, and its road vehicle operating costs and users' time costs to be estimated. These in turn require estimates to be made of the changes in the IRI of a gravel road that is subject to the specified maintenance regime.

To prevent the IRI of the unimproved gravel road from deteriorating below its threshold value, we had to assume that it would receive some minor periodic maintenance - that it would be regravelled every three years. Routine maintenance would be increased, including regrading[27] once per year, so that its IRI does not rise above a value of 20.

Since the economic comparisons for this question are of different development options compared to a base case, the restriction of using the same surface type as needed to address Question 1 no longer applies, so we added an Otta Seal with a Sand Seal as another LVSR alternative.

The base case unimproved gravel road was compared with each of the five different combinations of surface type and development approach described earlier – three using a conventional approach and two using an LVSR approach.

Figure 7 Variation of NPV for upgrading a gravel road using a DST with an LVSR approach




*Source: RED Model*

The estimated costs of the LVSR were varied by up to 15% for different terrain and climate combinations and for different design approach and surface combinations. The largest assumed increase was for an Otta Seal surfaced road in mountainous terrain with a wet climate. The vehicle operating costs and users' time costs were also different for each combination of terrain and climate as the maximum vehicle speed changes as does the average gradient and number of wet days. These impacts are estimated within the RED model.

The evaluations were repeated for each of the nine combinations of terrain and climate, and an average result for each combination of surface type and development approach derived by weighting the results for each terrain/climate combination by its share of the total land area.

Evaluation results are presented only for the NPVs as these were subsequently used in the evaluations for Questions 4 and 5. The average NPV per km of road was positive for each combination of development approach and road surface, as were the results for each combination of terrain and climate, even at the relatively low traffic volume of 200 AADT.

For all nine terrain/climate categories an LVSR approach would have a higher economic benefit than a conventional approach.  An LVSR road with a DST has a slightly higher average NPV than one with an Otta Seal. The results vary by climate group, with LVSRs with an Otta Seal having a slight edge in dry climates and those with a DST in humid climates. There is no significant difference between the NPVs for temperate climates. For each combination of terrain and climate as well as on average the results for the LVSR alternatives are within 2% of each other, so the results should not be interpreted as showing that one type of LVSR surface is preferable to another.

Table 12 Economic benefits per km of upgrading low volume roads

| Climate | Terrain | NPV USD $/km | | | | |
|---|---|---|---|---|---|---|
| | | Conventional | | | LVSR | |
| | | Upgraded gravel | SST | DST | DST | Otta |
| Dry | Flat | 21,700 | 24,600 | 21,600 | 50,900 | 52,300 |
| | Rolling | 27,500 | 23,200 | 20,400 | 48,300 | 49,300 |
| | Mountainous | 21,100 | 21,400 | 17,900 | 42,900 | 45,400 |
| Temperate | Flat | 30,100 | 25,100 | 22,300 | 53,600 | 53,500 |
| | Rolling | 26,600 | 23,400 | 21,100 | 51,500 | 49,900 |
| | Mountainous | 18,800 | 21,400 | 20,800 | 45,600 | 45,400 |
| Humid | Flat | 23,600 | 21,400 | 21,200 | 48,300 | 45,400 |
| | Rolling | 20,100 | 20,100 | 20,100 | 45,600 | 42,800 |
| | Mountainous | 14,000 | 20,100 | 19,000 | 42,900 | 40,100 |
| Average | | 25,400 | 23,600 | 21,400 | 50,700 | 50,000 |

*Source: Application of Roads Evaluation Model (RED), combined with RUCKS (Road User Costs Model)*

***The results indicate that upgrading a gravel road in poor condition using an LVSR approach would give a higher economic return than an upgrading using a conventional approach.***

**Question 3: What are the economic costs/benefits for AFCAP-participating countries of adopting LVSR design standards within their road sector development programmes?**

The additional data and analysis to respond to this Question were those relating to the length of gravel roads that could justify upgrading to a sealed surface, and of this length, how much could be undertaken within the available budget over the next five years. The road lengths were estimated for each country and then allocated to terrain and climate categories on an assumption that the distribution of upgradable and affordable gravel roads would be the same as the distribution of land area. The total upgradable roads lengths per country were taken from Table 13 and their distribution by terrain and climate from Table 8.

**Additional length of road that could be upgraded**

There is an investment cost saving of bout USD $54,000 per km (from Tables 2 and 3 with minor variations by country taking into account terrain and climate) when comparing a road with a DST using a conventional approach with the average investment costs of an Otta Seal and a DST using the LVSR approach. If this saving were to apply to all 2,060km of roads that might be upgraded using the LVSR approach there would be a cost saving of about USD $109 million. If this saving was applied to upgrading more gravel roads, and if the same 25% of these upgrades were to be made using an LVSR approach, a total of about 500km could be upgraded.

Table 13 Length of roads upgradable by LVSR approach

| Country | Estimated upgradable road length using an LVSR approach<br><br>km | Total investment saving of LVSR approach<br><br>USD $mn | Extra upgradable road length<br><br>km |
|---|---|---|---|
| Ethiopia | 513 | 25.7 | 122 |
| Kenya | 671 | 35.5 | 164 |
| Malawi | 51 | 2.8 | 13 |
| Mozambique | 411 | 21.9 | 99 |
| Tanzania | 416 | 23.1 | 105 |
| Total | 2,061 | 109.0 | 501 |

*Source: Authors analysis based on data in preceding tables*

The benefits of this additional upgrading would be in the form of reduced vehicle operating costs and users' time saving, but also through increased connectivity of agricultural produce and of people to social and market services. While the benefits of the former can be estimated using standard methods such as those we have used here, the benefits of increased connectivity are more difficult to estimate. Indicative results of this analysis are included in Annex 1.

Table 13 shows the total upgradable road length for each country, the share that might be upgraded using an LVSR and the additional road length that could be upgraded from the cost savings of using an LVSR approach for 25% of the upgrades.

The benefits of upgrading the basic road lengths from gravel to an LVSR sealed surface road are different to the benefits of the additional road lengths than could be sealed from the cost savings from adopting an LVSR approach to sealing the basic road lengths. Evaluation of the former was based on the difference between a conventional and LVSR approach to sealing a gravel road, whereas the benefits of the latter were based on the difference between sealing the gravel road and leaving it an unimproved condition.

**Estimation of benefits**

The total benefit of investing in an LVSR road compared to continuing with a poor condition gravel road is about USD $50,700 (taking the unweighted average over all terrain and climate combinations from Table 12, and assuming the LVSR road has a DST surface).

This total can be considered in two parts. One is the benefit of a conventional road with a DST surface compared to continuing with the poor condition gravel road. This benefit is estimated at about USD $21,400 (also from Table 12). The other is the benefit of using an LVSR rather than a conventional approach for the DST surfaced road, and this is estimated at about USD $29,300 (from a comparison of the NPV/km for a DST and LVSR DST in Table 12).

*NPV of investing in poor condition gravel road to achieve a sealed road using an LVSR approach*

*= NPV of investing in a poor condition gravel road to achieve a sealed road using a conventional approach*

*+ NPV of investing in a sealed road using an LVSR approach compared to using a conventional approach*

The benefits per km of road from Table 12 were applied to the distribution of land in each country by terrain and climate type from Table 8. The resulting NPVs per km for each country were then subject to two adjustments. The first was for the basic length of upgraded roads and was to take account of the distribution of investments over a five year period, as the values in Table 12 assume that all the investments are made in the first year of the investment period. Using a discount rate of 12% and assuming that the investments are spread equally over the five year period (a simplification that slightly over-estimates the benefits as the funds available for investment will increase by about 4% per year), the average benefit per km of road would be reduced to about 81% of the value based on the estimates in Table 12.

A second adjustment was to the benefits of the additional lengths of upgraded roads. These are roads that would be upgraded at some time even if an LVSR approach were not to be used for some of the basic length of upgraded roads. Using the investment cost savings from implementing an LVSR approach would allow investment in these roads to be advanced in time. Two alternative assumptions could be made as to how the cost savings would become available and be used. The first is that the additional roads would be upgraded in the same years as the cost savings are realized. This assumption is appropriate if rural road investments are based on long term planning and secure funding availability. The second is that the additional upgrading would only be made once the cost savings had been realized, and this assumption would be appropriate if the planning of rural road investment were less well planned or if funding was not secured more than one year in advance.

Even though rural road development might be well planned, the second requirement of the first assumption regarding funding availability is almost certain not to be realized in practice. Budget constraints invariably result in less funding being available than was anticipated at the time the planning schedule was made. Cost over-runs can also result in the planned investment costing more than was anticipated, resulting in fewer roads being upgraded than was planned and any cost savings from using an LVSR approach being applied to the basic rather than any additional upgrading.

With the first assumption, no further adjustment to the benefits would be needed, while for the latter at least one and up to five years further discounting of benefits would be needed. The NPVs per km used to derive the adjusted benefits shown in Table 14 are neutral between the two assumptions, allowing for 50% of the investments in additional upgrading to be made in the year that the LVSR savings are realized and the other 50% to be made once the savings have actually been realized. Using this average of the two alternatives, the benefit per km of additional upgraded road is reduced to 63% of that based on the values in Table 12.

Table 14 Original and Revised benefits per km

| | For basic upgraded road length | | For additional upgraded road length | |
|---|---|---|---|---|
| | See Source Note | Adjusted for phasing | See Source Note | Adjusted for phasing |
| Country | USD $/km | USD $/km | USD $/km | USD $/km |
| Ethiopia | 49,100 | 39,700 | 49,100 | 30,500 |
| Kenya | 51,200 | 41,400 | 51,200 | 31,800 |
| Malawi | 50,600 | 40,800 | 50,600 | 31,400 |
| Mozambique | 51,500 | 41,600 | 51,500 | 32,000 |
| Tanzania | 51,400 | 41,500 | 51,400 | 32,000 |

*Source: Authors' estimates based on RED model and data from Table 4-4 and Table 5-2*

When these benefits per km are applied to the lengths of basic and additional roads in Table 13, the resulting total NPV of each country investing in rural roads using an LVSR approach are those shown in Table 15. The total benefit for the five countries is a little more than USD $100mn, with about 84% coming from investment in basic length of roads to be upgraded and about 16% from investment in the additional length of road upgrading that would be possible using the investment cost savings from using an LVSR approach.

Table 15 Economic benefits of adopting LVSR standards in road development programmes

| | Total NPV | | | Country share |
|---|---|---|---|---|
| | Basic length | Additional length | Total | of benefits |
| Country | USD $mn | USD $mn | USD $mn | % |
| Ethiopia | 20.3 | 3.7 | 24.0 | 24% |
| Kenya | 27.7 | 5.2 | 32.9 | 33% |
| Malawi | 2.1 | 0.4 | 2.5 | 2% |
| Mozambique | 17.1 | 3.2 | 20.3 | 20% |
| Tanzania | 17.3 | 3.3 | 20.6 | 21% |
| Total | 84.5 | 15.8 | 100.3 | 100% |

*Source: Authors' estimates based on RED model and data from previous Tables*

***This analysis indicates that each of the five countries would achieve significant economic benefits from adopting an LVSR approach. The distribution of benefits between countries is very similar to that of the upgradable road length, with Kenya estimated to receive about 33%, Ethiopia about 24%, Mozambique and Tanzania about 20% each, and Malawi the remaining 2%.***

**Question 4: What are the net economic benefits to countries adopting the LVSR approach compared with the cost of research under AFCAP?**

Much of the data used to address this Question is the same as needed to address Question 3, but there are some significant differences and changes.

The estimates of road lengths are also those from Table 13 and the NPVs per km are also based on those in Table 12. However, the comparison here is between upgrading to a road with a double surface treatment using a conventional and an average of the results of a double surface treatment and an Otta plus Sand Seal for the LVSR approach. Each of these benefits per km can be derived for each country from the data in Table 8 and Table 12.

Whereas the benefit of the basic road length to answer Question 3 is based on the sum of the two parts of the total benefit, for Question 4 the benefit for the basis roads is based only on the second part of the total benefit, that attributable to the difference between using a LVSR and conventional approaches, as this is the only part of the benefit that could be attributed to the AFCAP programme[28]. As for the estimate of benefits for Question 3, this difference in benefits needs to be adjusted to take account of the phasing of investments, which reduces the NPV per km to 81% of the values based on Table 12. The estimate of the benefit of the additional road length is the same as for Question 3 (with the same adjustment for phasing that reduces the NPV per km to 63% of that based on Table 12), as all of this benefit can be attributed to the implementation of an LVSR programme.

A final important assumption needs to be made about what share of the benefits of future LVSR implementation could be attributed to the recently completed AFCAP programme. There has been a long and sustained effort by other international agencies as well as AFCAP to promote a broader use of a LVSR approach. While AFCAP has been the most significant recent supporter of this approach, it would be unreasonable to credit AFCAP with all the success of any future implementation. Any assumption of what share could be attributable to AFCAP would be totally subjective but have a very large impact on the outcome of the Value for Money analysis.

Rather than making such a subjective assessment, an alternative method has been used. This is to estimate the minimum share of credit that could be attributed to AFCAP and still retain a positive outcome of the analysis. Then the plausibility of this minimum share of credit can be assessed, still a subjective exercise but less so than selecting an arbitrary share.

[28]The evaluation for Q3 was designed to show the **total** benefit of upgrading roads using an LVSR approach, while that for Question 4 was to show that of using an LVSR approach **instead of** a conventional approach.

Much of the AFCAP investment in the LVSR approach so far has been preparing the groundwork for its future application. Many pilot projects have been completed that have been used not only to demonstrate how the LVSR approach is best applied but also to give training and practical experience to those who will be responsible for its future implementation and expansion. While there is a high probability that the projected future benefits of adopting a LVSR approach will be realized, that probability would be greatly enhanced if the AFCAP program related to the LVSR approach were to be sustained.

Table 16 shows the estimated present value of benefits per km and the total present value (for the basic and additional lengths of roads) of adopting an LVSR rather than a conventional approach. The last column of the table shows the estimated present value of the AFCAP investments. 50% of the AFCAP investments in Mozambique and 25% of the investments in Malawi have been assumed to be for the benefit of the whole AFCAP programme and have been transferred to the Regional cost. AFCAP investments are also shown for South Sudan although no estimate of benefits has been made.

Table 16 also provides an estimate of the MERR[29] and ERR. These estimates depend on several additional assumptions regarding the phasing of investments in sealing additional road lengths and the realization of the benefits of those investments. So less reliance is based on these than on other evaluation parameters, but they indicate the same conclusions.

If all the benefits of the LVSR approach were to be attributed to the AFCAP programme, the NPV of benefits would be about USD $60 million and the Benefit/Cost ratio would be about 7.4. The MERR would be about 21% and the ERR about 38%.

Table 16 Benefits and costs of AFCAP LVSR programme

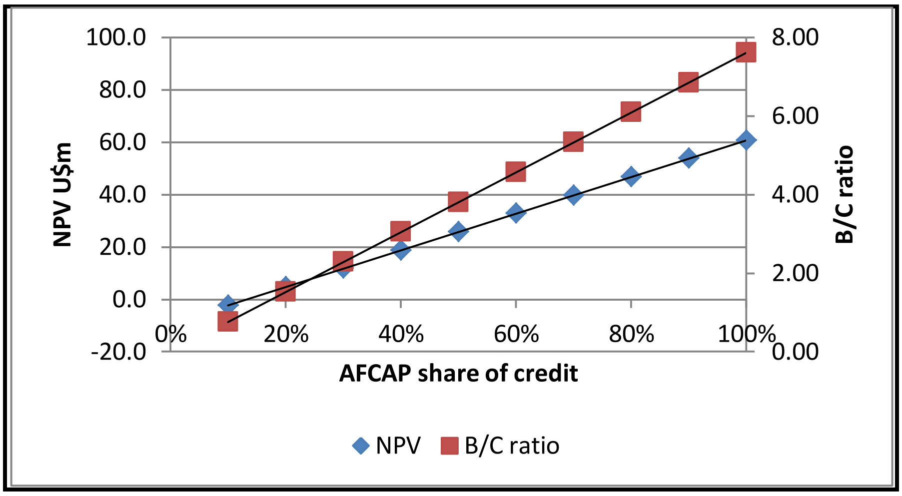
| | PV of Benefits per km | | PV of Total benefits | | | AFCAP Investment | |
|---|---|---|---|---|---|---|---|
| | Basic length | Additional length | Basic length | Additional length | Total | PV | NPV |
| Country | USD $/km | USD $/km | USD $mn | USD $mn | USD $mn | USD $mn | USD $mn |
| Ethiopia | 26,500 | 30,500 | 13.6 | 3.7 | 17.3 | 2.2 | 15.1 |
| Kenya | 25,800 | 31,800 | 17.3 | 5.2 | 22.5 | 0.3 | 22.2 |
| Malawi | 26,500 | 31,400 | 1.4 | 0.4 | 1.8 | 0.1 | 1.6 |
| Mozambique | 26,000 | 32,000 | 10.7 | 3.2 | 13.9 | 0.5 | 13.3 |
| Tanzania | 26,200 | 32,000 | 10.9 | 3.3 | 14.2 | 1.4 | 12.9 |
| South Sudan | | | | | 0.0 | 0.3 | -0.3 |
| Regional | | | | | 0.0 | 4.3 | -4.3 |
| Total | | | 53.8 | 15.8 | 69.7 | 9.2 | 60.5 |
| B/C ratio | | | | | | 7.42 | |
| MERR | | | | | | 21% | |
| ERR | | | | | | 38% | |

*Source: Authors' estimates based on previous tables and data from AFCAP on investment costs*

The estimate of the present value of benefits and the Benefit/Cost ratio shown in Table 15 assume that all the benefits are attributable to the AFCAP programme. Figure 8 illustrates the effect of assuming other shares of the benefits being attributable to AFCAP. Two measures of benefit are included in the Figure. The first is the NPV of the investment, based on the difference between the PV of benefits and of AFCAP investments shown in Table 15, while the second is the Benefit/Cost ratio based on the same data. The Figure shows how these two measures of benefit increase as the share of benefits attributed to AFCAP increases from 10% to 100%.

[29] See page 6

Figure 8 Relationship between NPV, B/C ratio and AFCAP share of credit




*Source Authors' analysis based on data in previous tables*

The NPV becomes positive and the B/C ratio reaches a value of 1.0 when the AFCAP share of credit for the LVSR programme reaches about 14%. For the B/C ratio to reach a value of 2.0, which is sometimes considered an indication of a highly worthwhile investment, the AFCAP share of the credit would need to reach about 27%.

Both of these shares are much less than the minimum share previously considered plausible and reasonable -informal estimates have been in the range of 50% to 75%. An AFCAP share of 33% would give an NPV of about USD $14m and a B/C ratio of 2.5 while a share of 50% would give an NPV of almost USD $26mn and a B/C ratio of 3.8. So it is reasonable to conclude that the AFCAP programme has produced a positive value for money outcome.

The 14% share of credit to AFCAP that gives an overall positive Value for Money outcome, also gives a positive outcome for four of the five countries included in the assessment. The exception is Ethiopia, for which the share of benefits attributable to AFCAP would need to increase to only 18%.

***The assessment of Question 4 indicates that the overall AFCAP programme is likely to have a large positive economic benefit as well as a Benefit/Cost ratio of more than 1.0 if AFCAP is attributed more than 17% of the credit for the benefits of any expansion of the LVSR programme., These positive outcomes apply to each of the five countries for which benefits have been estimated, although for Malawi the AFCAP share of the credit would have to reach 70% to give a positive value for money of the AFCAP investment.***

These estimated positive outcomes are an indication that further expenditure on the programme would be very worthwhile.

## 7. Sensitivity tests

**The following sensitivity tests were only applied to the evaluations for Questions 2 and for the comparison of a conventional upgrade of a gravel road to a DST with LVSR upgrade based on the average outcomes for an upgrade to a DST and an Otta plus Sand Seal.**

1. Lengths of upgradable roads: The length of upgradable gravel roads was an average of two estimates. The first was based on a rather outdated source (AICD, BP14, 2009) and the traffic levels used to estimate the length of road with more than 200 AADT were based on limited survey data. Since 2009 a substantial proportion of the gravel roads with high traffic volumes will already have been sealed, so as a sensitivity test the length of roads with a minimum traffic level to possibly justify upgrading to a sealed surface was reduced by 25%, from 45,000km to 33,750km.
2. Condition of gravel roads: The condition of the base case gravel road was assumed to be poor, but the limited survey data available indicates that on average little more than one third of the unpaved networks were in poor condition. Since about 40% were assessed to be in fair condition, a sensitivity test was made using an average of poor and fair condition for the base case gravel road. This change reduces the initial investment needed for all the upgrade options and reduces the maintenance and VOC and VOT costs of the base case gravel road used in some of the evaluations.
3. Difference in construction costs between conventional and LVSR DST: Sensitivity tests were made assuming that the cost difference between conventional and LVSR approaches were 20% higher and 20% lower than estimated.
4. Deterioration rates of gravel and paved roads: The deterioration rates for paved roads were set such as that without taking account of the volume of traffic (which has very little impact at the low level of 200 AADT) the life of a sealed pavement would be about 14 years if the criterion for resealing were an IRI of 6. Similarly, the deterioration rate set for a gravel surface would give a life of 4 years. Sensitivity tests were made with faster and slower deterioration rates and with different IRI criteria for resealing, giving a life for a sealed surface of 10 years with the accelerated deterioration and 16 years with slower deterioration.
5. Shares between terrain/climate groups: It was assumed that the distribution of upgradable gravel roads between terrain/climate groups is the same as that of the land area. Sensitivity tests were made assuming that the distribution was more concentrated on flat terrain and dry climates and on mountainous terrain and humid climates.
6. Unit costs of LVSR DST without materials cost savings: It is not clear whether the materials cost savings that apply to other types of road developed using an LVSR approach apply to those with a DST. A sensitivity test was made assuming that these cost savings do not apply.
7. Traffic levels: All the assumptions assumed a traffic level of 200 AADT. Sensitivity tests were made with 100 AADT and 300 AADT.
8. Investment Budget: The estimated investment budget for upgrading low volume roads is based on several assumptions. In Table 9 there are alternative sets of assumptions that lead to lower and higher estimates.
9. % of roads upgradable using LVSR: It was assumed that 25% of gravel roads would be upgradable using an LVSR approach.

Results of Sensitivity tests

Table 17 indicates the impact of the various individual sensitivity tests on the total NPV of applying an LVSR approach to the upgradable gravel road networks. The tests were applied to the same evaluation assumptions as used to derive the results shown in Table 14.

Table 17 Results of Sensitivity Tests with one parameter

| | Sensitivity test | Values | NPV USD $mn |
|---|---|---|---|
| | Basic evaluation | | 95.6 |
| **1** | Length of upgradable road | Reduce by 25% | 71.0 |
| **2** | Condition of gravel roads | Average of good and fair | 74.9 |
| **3** | Cost difference between Conventional and LVSR | +25%<br>-25% | 118.8<br>83.5 |
| **4** | Road deterioration rates | Sealed road life: 10 years | 74.4 |
| | | 16 years | 105.1 |
| **4** | Upgradable road shares between terrain/climate groups | 10% larger share in flat and dry<br>10% smaller share in flat and dry | 99.8<br>91.7 |
| **5** | Materials cost saving for LVSR DST | None | 86.4 |
| **6** | Traffic level | 100 AADT | -41.4 |
| | | 150 AADT | 29.8 |
| | | 300 AADT | 161.4 |
| **7** | Investment budget | Table 9 Low assumptions<br>Table 9 High assumptions | 18.1<br>204.9 |
| **8** | % of roads of upgradable roads that would use LVSR approach | 15% | 63.1 |
| | | 40% | 144.3 |

*Source: Authors analyses based on expanded RED model*

Interpretation of sensitivity test results

Only one of the tests on a single parameter results in an overall negative NPV; that with a traffic level of 100 AADT. This negative outcome for a low traffic volume accords with general experience, that sealing of gravel roads at this low level of traffic needs to be justified on grounds other than savings in VOC and VOT. All of the other tests indicate that, even with more conservative estimates, using an LVSR approach to upgrade the length of gravel roads would produce a positive economic benefit. However, some of the tests indicate a high sensitivity of the NPV to the change in assumptions so combinations of assumptions that include these variables could also lead to negative outcomes.

The sensitivity tests (other than that for a low traffic level) that have the greatest impact are those relating to the investment budget and percentage of upgrading of gravel roads that might be undertaken with an LVSR approach. Both of these have a wide range of values in the tests and a directly proportional impact on the value of the NPV. Other parameters (such as the construction and maintenance cost difference between roads developed using conventional and LVSR approaches) also have a directly proportional impact but their range of plausible values is much smaller. Some tests (such as changing the distribution of upgradable roads between terrain/climate groups have little impact on the NPV.

A separate sensitivity test was carried out on the additional assumption for Question 4, the percentage of LVSR approach upgrades that is attributable to AFCAP. The impact of this parameter on the NPV for this analysis is also directly proportional to the assumed value of the parameter. If the percentage were to be only 40%, the NPV of the programme would be zero.

Multiple parameter sensitivity tests – switching values

There is a probability associated with the range of values for each of the parameters, and each probability has a distribution. These distributions are expected to be symmetrical, that is the probability of the value of the parameter being lower than the base value would be the same as it being higher. But the economic significance of the impacts is heavily skewed towards the lower values. In other words, while the numerical value of economic impact of a higher parameter value might be the same as that of a lower value, a decrease in benefits can have a higher significance than the same numeric increase.

For multiple parameter sensitivity tests it is important to know what combinations of values give a zero or close to zero NPV, and then to assess the probability of those values occurring.

Some pairings of sensitivity parameters have little greater impact than individual tests. For example, reducing the available budget for upgrading gravel roads (Test 7) would negate any impact of reducing the length of potentially upgradable roads (Test 1) since there would not be the budget to upgrade them anyway. The combinations that were tested and their results are shown in Table 19. A subjective assessment of the probability of each of the combination of values occurring is about 10%, based on each of them having about a 33% probability.

Table 18 Results of Sensitivity Tests with two parameters

| Combinations of parameters | | NPV USD $mn |
|---|---|---|
| Low budget (from Table 4.5) | Low share of LVSR approach in upgrades (15%) | 35.2 |
| Low budget (from Table 4.5) | Intermediate traffic level (150 AADT) | 10.0 |
| Intermediate traffic (150 AADT) | Low share of LVSR approach in upgrades (15%) | 16.3 |
| Low traffic (80 AADT) | Low construction costs | 5.2 |

*Source: Authors' estimates based on expanded RED model*

Switching values for key parameters

A switching value for any parameter is that value that would result in a zero NPV. If the switching values are assessed to have a low probability, then the probability is also low that the LVSR approach would have a zero or negative probability. Table 21 indicates the switching values for the same parameters as used for Table 17.

Table 19 Results of Sensitivity tests on Switching Values

| Parameter | Switching value |
|---|---|
| Traffic level | 132 AADT |
| Budget level | No switching value, as even with 1km there is a positive NPV |
| Cost difference of LVSR DST compared to conventional DST | 35% of that used in basic evaluation |
| Sealed road life | 4 years |
| Share of LVSR implementation attributable to AFCAP | 40% |
| Traffic level and construction cost | 80 AADT and 25% reduction in LVSR construction cost |

*Source: Authors' analysis based on expanded RED model*

A traffic level of 132 AADT is plausible and has a relatively high probability, at least for some low volume roads. But as an average value for the 2,060km included in the evaluation it has a low probability. A 35% smaller cost difference between upgrades undertaken with conventional and LVSR approach is assessed to be relatively improbable, as is a life of only 4 years for the surface of a sealed road with an average of 200 AADT. The share of future LVSR implementation that can be attributed to AFCAP is too subjective to assess, but 40% is perhaps too low to be plausible.

We have also carried out one switching test on two parameters together – volume of traffic and construction cost. Efforts are currently being made by AFCAP to find ways to reduce the construction cost of LVSR roads for very low traffic volumes. To assist in these efforts, we undertook a series of evaluations changing these two parameters at the same time, to see what reduction in construction costs would be needed to bring about a positive NPV at low traffic volumes.

Table 20 Variation of NPV with AADT and construction cost

| | Construction cost reduction for LVSR DST as % of basic cost | | | | | |
|---|---|---|---|---|---|---|
| | 35% | 30% | 25% | 20% | 15% | 0% |
| AADT | USD $mn | USD $mn | USD $mn | USD $mn | USD $mn | USD $mn |
| 60 | 8.7 | -7.5 | -23.2 | -38.6 | -53.6 | -96.2 |
| 80 | 37.5 | 21.1 | 5.2 | -10.4 | -25.6 | -68.8 |
| 100 | 66.3 | 49.7 | 33.5 | 17.8 | 2.4 | -41.4 |

*Source: Authors' analysis based on expanded RED model*

The results show that for a road with a current AADT of 100 vehicles, a cost reduction of about 15% would be sufficient to bring about a positive NPV, whereas for an AADT of 80 vehicles the cost reduction would need to be about 26% and at 60 AADT it would need to be about 32%

***So all the switching value analyses confirm the robustness of the basic assessments, that an LVSR approach and AFCAPs contribution to expanding its application, are likely to have high economic returns.***

## 8. References


Adhikari, R and Weiss, J (2003), A Methodological Framework for the Economic Analysis of Sub-regional Projects, Asian Development Bank

Reviewing Social Discount Rates Emma-Kate Kunth Symons Development Asia, Asian Development Bank

Gourley C.S, Toole T, and Morosiuk, G. (2001) Cost effective designs for low-volume sealed roads in tropical and sub-tropical countries, IRF Conference

European Environmental Agency (2012) Percentage of GDP used for transport infrastructure investment by mode (EEA32), 2010 - International Transport Forum, Statistics Brief

SADC (2005) Guideline Low Volume Sealed Roads

World Bank (2009), Africa Infrastructure Country Diagnostic (AICD), Background Papers 7 and 14

World Bank (2005) When to use cost effectiveness rather than cost benefit analysis, Transport Note TRN9

World Bank (2005) When and how to use NPV, IRR and modified IRR, Transport Note TRN6, World Bank, January

World Bank (2006) Rural Accessibility Index: A Key Development Indicator, Transport Paper No. 10

## Annex 1 - Impact of an increase in sealed road length on connectivity

One of the advantages of using an LVSR approach is that the initial investment costs are less than those for similar roads constructed using a conventional approach. The evaluation method applies this reduction in investment costs to the estimated length of upgradable gravel roads (Chapter 4) and the proportion of these for which an LVSR approach might be used (Chapter 5). If the resulting cost savings were to be applied to upgrading additional lengths of gravel road, there would be benefits of increased connectivity as well as of reduced vehicle operating cost and increased users' time savings.

While it was not possible to estimate the economic benefit of this increased connectivity with the resources available, it was possible to estimate two impacts, one on the additional number of people who will be within 2km of a sealed road (that is, the increase in the Rural Accessibility Index, the RAI) and the other an increase in the proportion of agricultural output that will have sealed road access to markets.

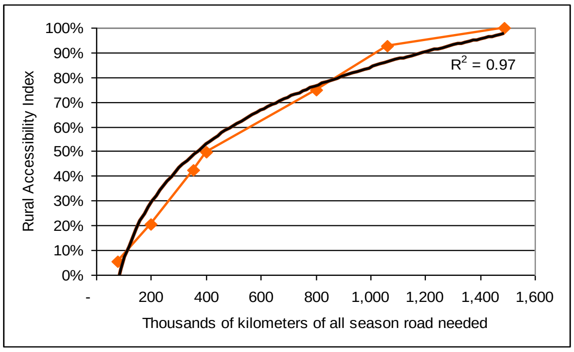
For both of these estimates we used the previous work done for the AICD and in particular the work reported in Background Paper 7, Improving Connectivity: Investing in Transport Infrastructure in Sub-Saharan Africa.

The analyses for both measures of connectivity used a GIS reference database of roads. This was supplemented by a GIS referenced population and agricultural databases, to relate road infrastructure to distributions of population and agricultural output, and to estimate the additional lengths of sealed roads needed to increase the RAI and access of agricultural output to the nearest large population center. Connectivity formula were developed based on the road lengths used here to estimate the increase in the RAI and connectivity of agricultural output that might result from the additional lengths of sealed road that would result from implanting the LVSR approach.

**The Rural Accessibility Index**

This measure of rural accessibility is based on the percentage of the rural population of a country that lives within 2km of an all-weather road. Its values were estimated from survey data in 2006 for 32 countries, with an update in 2008 that covered all countries in Sub-Sahara Afriaca. In the world's middle-income countries the RAI is typically above 90%, but in Sub-Saharan Africa, the RAI is only 34 percent, ranging from a low of 5 percent for Sudan to a high of 67 percent for Lesotho[30].

**Figure A1 Relationship between RAI and sealed road length for all Sub-Sahara Africa**




*Source: BP7 for AICD*

Fig A1 shows the relationship between the value of the RAI and the length of sealed road, summed over 23 Sub-Saharan countries.

[30] Rural Accessibility Index: A Key Development Indicator, Transport Paper 10, World Bank, March 2006

Although the RAI has received wide acceptance as a measure or rural connectivity and was part of the results measurement system used in the fourteenth replenishment of the International Development Association, no agreement exists on appropriate RAI targets for particular countries. For BP7 of the AICD, a formula based on the GIS model data was used to estimate the total length of all-weather road needed to achieve pre-determined targets (50% and 75%) for the RAI.

We have used the formula in reverse, to estimate the increase in RAI that would result from an extension of the sealed road network (interpreting "all season road" in the RAI definition as a road with a sealed surface). Applying estimates of the total rural population to the % increase in the RAI it was possible to estimate the number of people who would benefit from the increase in length of sealed road (Table A1). The additional 503 km of road that could be upgraded in the next five years would bring almost 3,500 more people within 2km of a sealed road.

**Table A1 Increase in rural population within 2km of a sealed road**

| Country | Total Population M | *Rural Population* % | m | Increase in RAI %/ 100 km | Increase in road length km | Increase in connected population |
|---|---|---|---|---|---|---|
| Ethiopia | 93.8 | *88%* | 82.5 | 0.06% | 122 | 504 |
| Kenya | 44.0 | *78%* | 34.3 | 0.34% | 164 | 1,174 |
| Malawi | 16.8 | 80% | 13.4 | 0.76% | 13 | 1,022 |
| Mozambique | 24.1 | 62% | 14.9 | 0.09% | 99 | 131 |
| Tanzania | 48.3 | 74% | 35.7 | 0.17% | 105 | 599 |
| Total | 226.9 | 74% | 180.9 | | 503 | 3,431 |

*Sources: Population and % rural population from CIA Factbook. Increase in RAI %/km from authors' analysis of data used for AICD BP7*

**Agricultural connectivity**

There is no equivalent to the RAI in relation to agricultural connectivity. An agricultural connectivity measure was used in the work for BP7 of the AICD. This was the proportion of agricultural output that had sealed road connectivity to its nearest market center (defined as being a town/city of at least 250,000 people). First the current level of this indicator was estimated using a GIS database of the crops produced within 1km squares of each country and their market values and the same GIS roads database as for the rural population to establish a baseline. From this baseline, estimates were made of the additional road length (if any) that would be needed to achieve connectivity of 20%, 40%, 60% and 80%. As for the RAI, for the estimates made here for the increase in agricultural connectivity resulting from a given increase in road length, the relationship between the two parameters was inverted.

Table A2 shows the resulting estimated increase in agricultural connectivity for each country. As for the impacts on the RAI, the increases in agricultural connectivity are relatively small, of the order of 1%, other than for Mozambique where the estimated increase is approaching 4%. The estimated increases in agricultural connectivity should not be interpreted as increases in output. Estimates of this would need further estimates or assumptions about the elasticity of the value of agricultural output to improved connectivity, an exercise beyond the scope of this study.

**Table A2 Estimated increase in agricultural connectivity**

| Parameter | Ethiopia | Kenya | Malawi | Mozambique | Tanzania |
|---|---|---|---|---|---|
| Base year % of agricultural output with sealed road access | 65% | 82% | 85% | 48% | 37% |
| Road length (km) needed for 1% increase in agricultural access | 119 | 77 | 25 | 27 | 129 |
| Additional road length to upgrade | 122 | 164 | 13 | 99 | 105 |
| Increase in % agricultural output with sealed road access | 1.0% | 2.1% | 0.5% | 3.7% | 0.8% |
| New % agricultural output with sealed road access | 66% | 84% | 86% | 52% | 38% |

*Source: Authors estimates based on analysis of road network and agricultural output (FAOSTAT, Food and Agriculture Administration, FAO)*