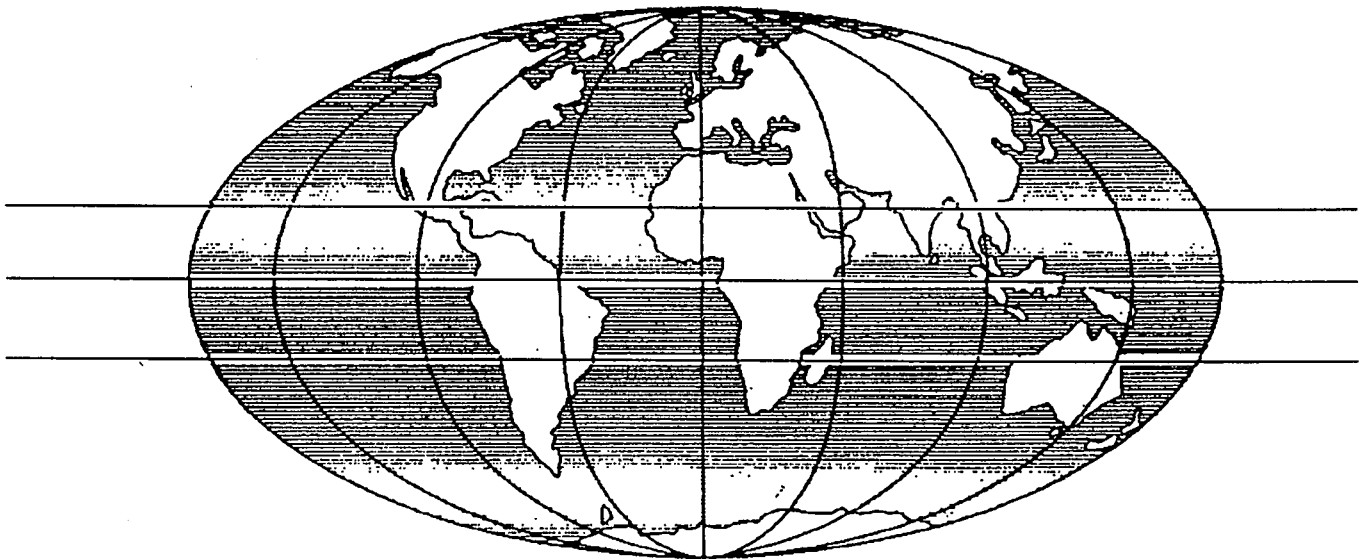




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**TITLE Highway earthwork management; A need  
for strategies to control slope problems**

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## Highway Earthwork Management; A Need for Strategies to Control Slope Problems.

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### Summary

There is a need for some revision in the way earthwork maintenance and repair tasks are carried out particularly on many steep sections of road in developing countries. There are a number of reasons why a more efficient *preventative* rather than the existing *predict or repair* strategy of upkeep for such roads cannot be adopted at present. Research at TRL has resulted in finding ways of overcoming the difficulties and provides the tools for road authorities to develop preventative maintenance measures. These methods have been tested on more than 600 km of road with more than 10,000 earthworks in five countries.

The potential benefits of strategic planning for a preventative programme of maintenance are i) time savings, ii) cost savings, iii) provides easily accessible and updatable information about roads and iv) provides a basis for planning.

## Background

The majority of third world countries are in the process of developing an effective infrastructure of which road networks are a major component. In Southeast Asia alone such infrastructure projects are reported to be costing \$(US)273 million a day. Whilst road construction and upkeep accounts for a significant proportion of this amount its importance is often underestimated because of its low-technological status. This applies in particular to the highway maintenance and upkeep processes which now operate in many developing countries. It results in inadequate investment in both funds and resources which in turn leads to roads having a poor serviceable life. Taken in terms of the overall investment in infrastructure, and road construction in particular, the waste due to poor maintenance methods accounts for the loss of countless millions of dollars annually.

The most serious situation appears to be in those countries with mountainous terrain where road construction is a very demanding process because of the need for complex earthworks. The high investment in mountain roads can be lost in as little as ten years due to uncontrollable earthwork and slope failure as a result of poor maintenance methods. In addition there are incalculable costs to the overall economy, caused by constant traffic delays when these roads are blocked and the hazard to road-users. There are three primary reasons given for the poor quality of highway maintenance in some developing countries.

i) The effectiveness of a highway maintenance programme is largely dependant on having good quality information that can be used to support maintenance strategies and rehabilitation programmes. In many developing counties highways are often in remote areas, and rugged terrain makes them difficult to examine in sufficient detail to collect good information. There may also be a shortage of experienced engineers to carry out inspection tasks.

ii) There needs to be a steady investment of funds into road maintenance which some sources indicate should be as high as 2 to 3% per annum of the highways value. Most developing countries appear to operate a spasmodic maintenance policy with periods of relatively high investment followed by almost no activity. Competition for public expenditure funds comes from new road building projects and other programmes of national importance and means that even in the best years allocation for road maintenance is low and generally below 1% of the value of the road network.

iii) Mountain roads when constructed to a tight budget with inadequate protection measures need increased maintenance resources. However, extremes of climate, including very heavy rainfall, are often blamed for the rapid deterioration of such roads, distracting from the main reason for deterioration, which is inadequate maintenance.

Unfortunately there is some complacency to these difficulties amongst road authorities, and even amongst multilateral loan agencies who finance many of the road programmes, despite the very high cost penalties already mentioned.

This is not altogether surprising taking into account the difficulties of managing road maintenance programmes without effective road-condition information. Infrastructure development is largely about information technology and there is a need to apply such information technology to highway maintenance methods. Of the three reasons given for poorly

maintained roads, the value of better information is self evident in item i). It is likely that public funds would be more readily available if modern information technology was used to highlight maintenance needs, item ii). The same information would show that it is a lack of maintenance and not other conditions that are the main factor in some roads deterioration, item iii).

TRL is making contributions to providing highway authorities with reliable information about the condition of roads, Heath et al (1995). One aspect is the development of a highway monitoring system, ECAT, that includes three important components: i) a rapid and relatively inexpensive method of collecting data; ii) the production of computer generated risk maps and engineering drawings quickly and cheaply; and iii) an information database and earthwork inventory system. It contains no technologies or equipment that are not already available in all developing countries, and can be applied by road authorities using their own staff with the minimum of training requirements.

### **The ECAT system.**

#### **The scope of the information requirements.**

The failure of mountain roads results from three effects: i) earthwork deterioration; ii) natural slope failure; and iii) the break-up of the road pavement. The latter is often connected with earthwork or slope problems and seldom results solely from traffic usage.

The two methods of dealing with problems rely on either prediction or observation. Predictive methods are commonly based on slope material properties including geological studies or statistical methods, however neither has been found to be reliable unless the slope materials are uniform and common over a wide area, which is not the case in the majority of developing countries.

Observational methods are based on looking for the physical effects of earthwork deterioration at specific intervals. The study of more than 5,000 very large scale aerial photographs of earthworks on 600 kilometres of road in five countries, involving problems on approximately 10,000 earthworks, has shown that the majority of problems affecting a highway stem from gradual physical changes. These changes may be caused, for example, by erosion, scouring and culvert discharge. The range of factors associated with earthwork deterioration is quite extensive, as shown in Table 1. Normally the terrain conditions, catchment size, geomorphology, etc. all give the experienced engineer clues to what forms of deterioration are likely to be found. Also the types of problems on a particular highway tend to be repetitive. More complex and unique problems connected with groundwater hydrology and geological conditions, etc., are much rarer events.

#### **The level of information required.**

Site investigations generally yield extensive and detailed information about a road. Such information has relevance but often at different periods during the life of a road. Having direct access to the right information when it is required presents more of a problem. Therefore what is needed are three stages of information.

- i) At the initial stage of a maintenance programme general details are needed about where the main earthwork and slope problems are and the overall condition of a road. This may consist of a hazard risk assessment for all earthworks and medium scale hazard mapping.
- ii) At the maintenance planning stage more detailed information is needed, including the cause

and extent of the deterioration, for those earthworks where attention is required.

iii) At the implementation stage very detailed information should be collected which can be used to plan site investigations or to carry out straightforward repairs. This may include maps to a scale of 1:500 of individual slopes.

<b>Design:</b>	1) Slope section constructed to an oversteep angle. 2) Road-bench in very steep hillside. 3) Toe cut oversteep. 4) Inadequate drainage on slopes. 5) Inadequate road-side drains.
<b>Deterioration:</b>	1) Oversteep upper section from loss at toe. 2) Splash/erosion from traffic undercuts toe. 3) River erosion at base. 4) Deep hillside gullies discharging onto road.
<b>General:</b>	1) Degrading natural vegetation cover on slopes. 2) Large rainfall catchment discharging onto slope. 3) Natural gullies becoming large. 4) End-tipping of debris over embankments. 5) Unravelling on folded/fractured slopes. 6) Non-contained flow off road and embankment erosion. 7) Splash erosion of slopes on flooded road sections.
<b>Road work:</b>	1) Road widening resulting in steep toe sections. 2) Installation of drains leaving toe oversteep. 3) End-tipping causing erosion and vegetation loss.
<b>Communities:</b>	1) Agricultural area discharge onto earthworks. 2) De-forestation of slopes and infiltration. 3) Poor waste water management in ribbon development. 4) Construction on road slopes. 5) Quarrying material above road slopes. 6) Drain system damage from off-road traffic. 7) Top-loading of slopes due to stock-piling.
<b>River:</b>	1) Cutting into toe of embankment. 2) Over-topping road when in flood. 3) River bed rise from sedimentation. 4) Slide blocking river and causing flooding.
<b>Potential Landslides</b>	1) By river eroding toe. 2) Slope vulnerable to heavy rainfall, ie. poor protection. 3) Left over effect of construction disturbance. 4) Oversteep upper slopes. 5) Ancient slides that might re-activate. 6) Signs of creep and hummocky ground.
<b>Rockfall:</b>	1) Plucking of rock and boulders. 2) Excessive blasting during construction. 3) Loose debris above the road. 4) Poor angle of rock bedding. 5) Areas of weak foliated rock.
<b>Embankments</b>	1) Poor toe support. 2) Oversteep embankment section. 3) Culvert discharge erosion. 4) Subsidence due to foundation collapse. 5) Poor compaction resulting in subsidence. 6) River scour. 7) River turbulence or other flow characteristic causing erosion.

**Table 1** List of earthwork deterioration features that can be identified on the images.

### Suitable earthwork Records.

As already mentioned, the main limitation to obtaining useful highway condition information, particularly when there are large earthworks, is in the arduous task of inspecting roads on foot. A study has been made at TRL to determine the best method of recording earthworks on highways. The records must contain sufficient detailed information to detect potential failure problems as well as covering a large area on and at the side of roads. The records must be easy and quick to analyse.

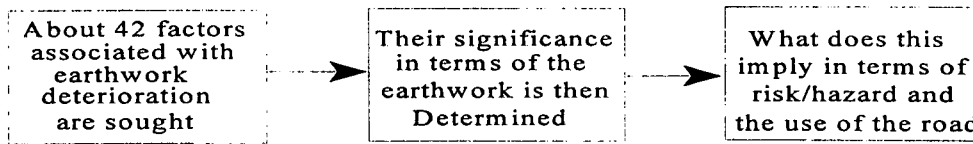
Based on these factors the results of trials at TRL, Heath & McKinnon (1994), indicate that the ideal earthwork record consists of colour aerial photographs at an image scale of approximately 1:1,500, which in survey terms is very large indeed. The photographs are obtained using a helicopter which has been found to be economical providing there is a reasonable length of road to evaluate and sensible planning precedes the operation.

The aerial photographs provide a continuous record along a road, railtrack or coast line, with each image recording a 250m long section. This is termed a 'sector' and has, within the data system, a unique reference with its location and grid coordinates. An automatic method of determining the precise location of all earthworks has been developed based on instrumentation that collects kilometre chainage and GPS coordinate data. The first task prior to analysing the

earthworks is to fix the ground location of all earthworks from the location data records.

**The analysis and condition information.**

There are three aspects of the earthwork condition analysis: i) finding any signs of deterioration; ii) the likely cause and likely consequences of the deterioration; iii) what the deterioration and any potential failure implies in terms of the engineering aspect of the earthwork, see Figure 1.



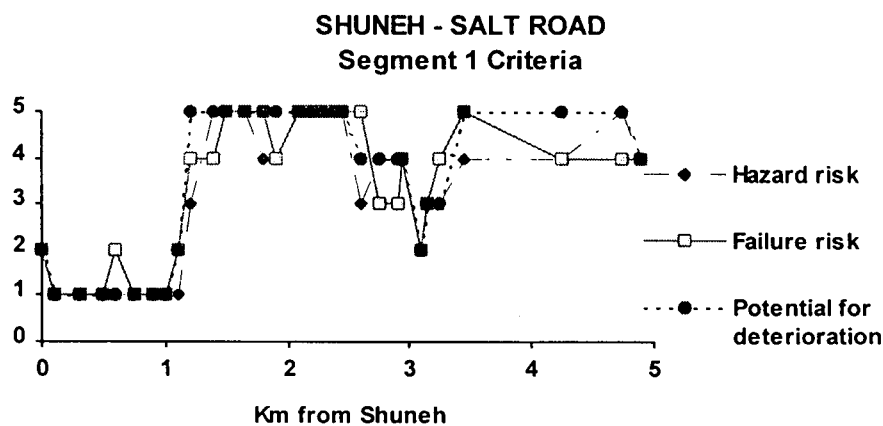
**Figure 1.** The three main factors connected with the analysis of earthworks

Of immediate concern must be the consequences of any problems to road users and traffic. Limiting any hazard risk is normally an important priority, and this extends beyond preventing the failure of earthworks. For example there may be situations where excess water from slopes makes the road slippery, or there are steep unprotected embankments.

**Determining repair priorities to produce risk maps.**

For the analysis, five criteria covering the following conditions are used: i) the hazard risk to road users; ii) the earthwork failure risk; iii) the difficulties of repair; iv) the likely effects on traffic if failure occurs; v) likely long term earthwork problems. Each criterion is given a rating from 1, low risk, to 5 high risk and the results entered into a database.

The database uses a “look-up” table to allocate a repair category and hence a priority based on the rating given to the criteria. As an example, Figure 2 shows three criteria: hazard; failure; and potential deterioration plotted for a 5 kilometre section of road. The chart shows that for the first kilometre the earthworks are good with very low criteria scores. Between 1.25 and 2.5km the earthworks are poor with a high criteria value. Finally, for the remaining part of the road they are average with some mixed scores.



**Figure 2.** Chart showing the five risk criteria and repair priority.

The second chart, Figure 3, shows that for a particular road more than 40% of sectors are graded 4 and 5 in the criteria, with the exception of ‘repair cost’ and potential road loss. For hazard risk to road users 20% of sectors appear to have a high risk and failure risk is also significant, 23% of sectors graded as 5. This is reflected in the overall state of the road with almost 40% of earthwork sectors requiring immediate attention, repair priority ‘A’. From this the road can be assumed to be in average condition.

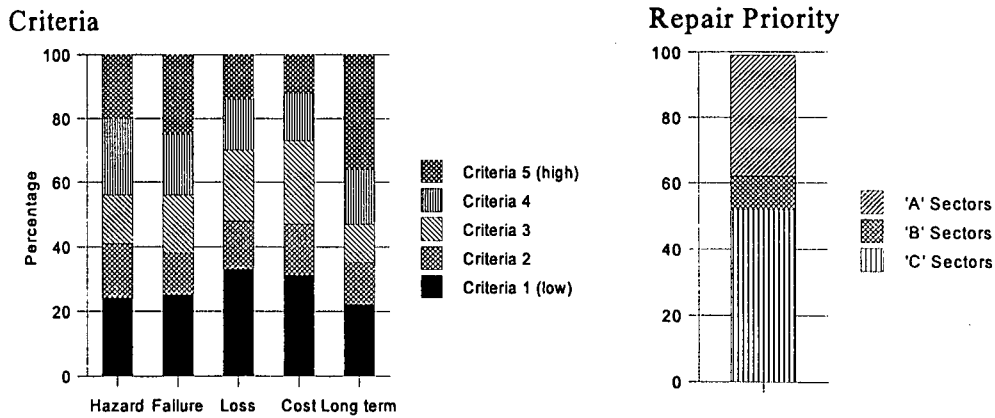


Figure 3. Charts showing the distribution of risk criteria for one road section.

### Hazard maps.

Using information from the database hazard maps can be produced economically. Initially maps are produced to show where on a road there are 'A' sector (urgent) earthworks, where the hazard risk to road users is high, where slope failure risks are high and the consequences to the road are severe and finally where there is a high risk of long term deterioration of a road. Other maps can be generated from the earthwork inventory to show features such as urban development along a road, the general pavement condition, locations where a river is undercutting the toe of embankments, etc. The maps, for example Figure 4, are quick to produce and provide relevant information in a form that is easy to use.

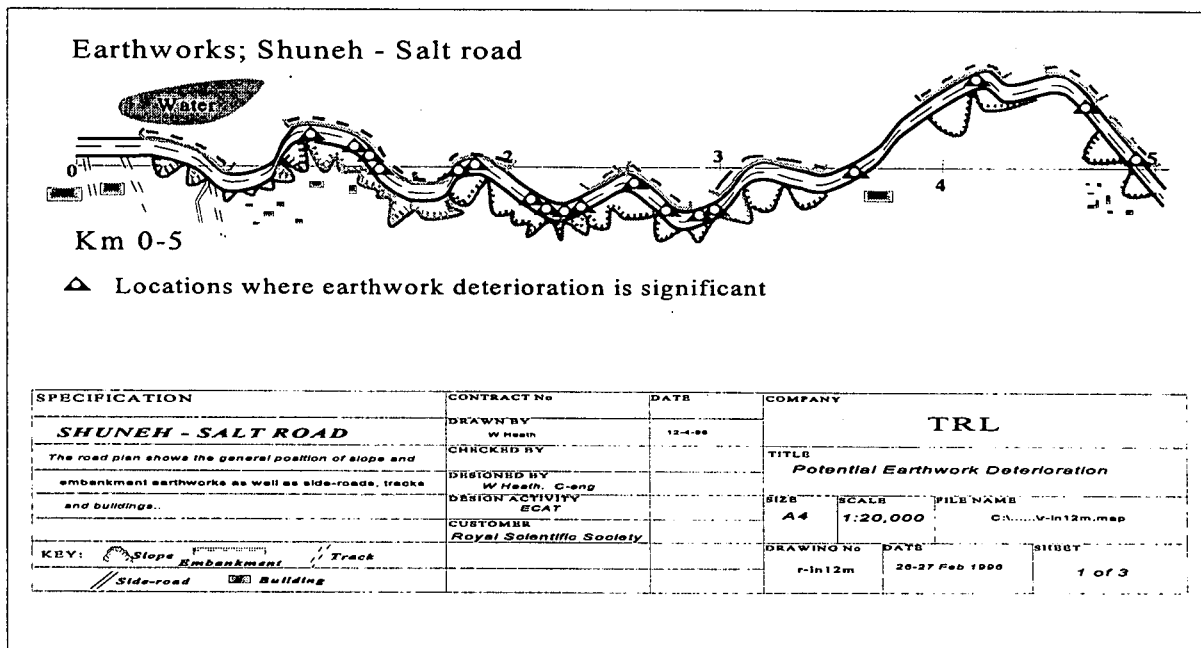


Figure 4. A risk map showing where long-term earthwork deterioration is significant.

### More detailed maps.

On all sectors of a road where there are serious earthwork problems, classified as 'A' category priority, an extra stage of analysis can be carried out so that the cause of the problem and the options for repairs can be determined. This is based upon drawing details of the failure found in the oblique aerial photograph on an overlay. For this purpose earthwork failure types are divided



into eighteen categories. The database has a diagram for each type of failure that helps the engineer carrying out the analysis to identify relevant features.

More detailed maps of small sections of road or individual earthworks can be produced from the earthwork records and database information system. Whilst these are not to planimetric standards, they do contain sufficient detail for the planning and implementation of most repair work and can be produced at a fraction of the cost of surveyed maps. An example of a 1:1,000 map is shown in Figure 5.

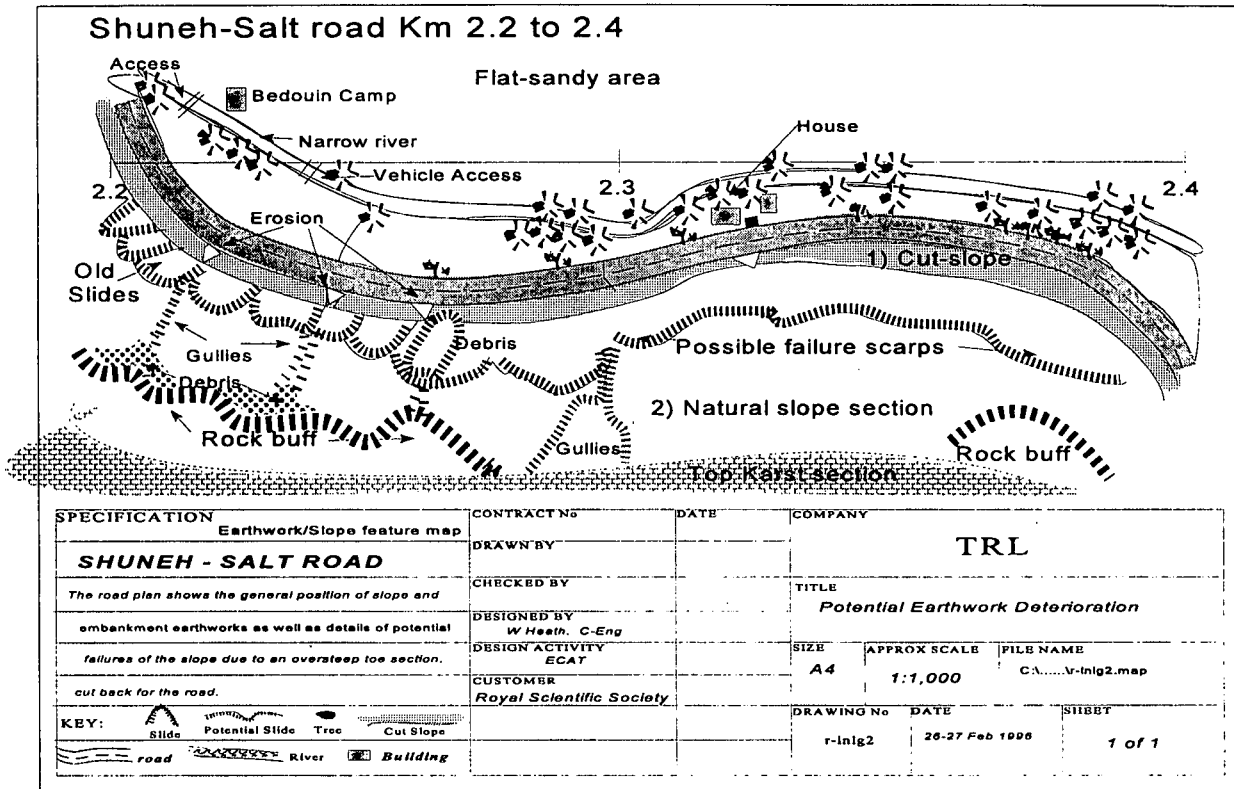


Figure 5. Large scale, 1:1,000 map of a section of road and earthwork.

### The Database and Inventory.

A computer database provides the means of storing the data, collected from the earthwork records using a series of pro-formas with over 70 parameters, that can help in determining the overall condition of a road, implementing repairs to individual earthworks and making improvements to future earthwork design and construction methods. The database contains sufficient support information about earthwork specifications and design to enable it to meet such requirements. Information is accessed by referring to a sector number for each earthwork, or the chainage and road name.

Two important functions of the earthwork inventory are: i) a long term storage system for earthwork data that can be used for developing empirical design methods based on the experience of how certain earthwork features have functioned in the past; ii) using statistical analysis procedures, to compare the quality and functioning of earthworks within a linear system or different linear systems within a network.

### Cost.

The cost of undertaking a condition assessment of a road, using ECAT, is 0.05% of the value

of the road<sup>1</sup>. If undertaken once every two years the condition assessment cost is 0.075% of the recommended repair and upkeep costs of a road. This condition assessment cost is based on a maximum of \$(US)250 per km which includes all time, equipment and mobilization charges. Such costs are unlikely to be exceeded and could be significantly reduced if highway authorities in developing countries undertook some or all of the tasks themselves.

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<sup>1</sup> This assumes a road value of \$(US)500,000 per Km. A low value for a mountain road. Repair and upkeep costs are assumed to be 3% of this figure.