Overseas Road Note 5

A guide to road project appraisal
ACKNOWLEDGEMENTS

This Note was produced in the Overseas Unit of the Transport and Road Research Laboratory Head: Mr J S Yerrell) on behalf of the Overseas Development Administration. The following members of the Unit contributed to the draft: Dr R Robinson (Project Leader and Editor), Mr P J Beaven, Mr D M Brooks, Dr M A Cundill, Mr A J Downing, Dr B L Hills, Mr J L Hine, Dr G D Jacobs, Mr C J Lawrance, Mr R S Mansfield, Mr D Newill, Mr P W D H Roberts, Dr J Rolt and Mrs J M White. The section on cost estimating is based on the ODA draft cost estimating manual prepared by UMIST. The Note was reviewed for ODA by Mr J B Wilmshurst.

First published 1988

OVERSEAS ROAD NOTES

Overseas Road Notes are prepared principally for road and transport authorities in countries receiving technical assistance from the British Government. A limited number of copies is available to other organisations and to individuals with an interest in roads overseas, and may be obtained from:

Transport and Road Research Laboratory
Crowthorne, Berkshire, RG11 6AU
United Kingdom

© Crown copyright 1988
Limited extracts from the text may be produced provided the source is acknowledged. For more extensive reproduction, please write to Head of Overseas Unit, Transport and Road Research Laboratory

ISSN 0951-8987
# CONTENTS

1. Introduction
   - Purpose of this Note 1
   - The project cycle 1
   - Identification 1
   - Feasibility 1
   - Design 1
   - Commitment and negotiation 1
   - Implementation 1
   - Operation 2
   - Evaluation 2
   - Structure of this Note 2
   - Project types 3
     - Factors to be considered 3
     - Upgrading and new construction 3
     - Reconstruction and rehabilitation 4
     - Stage construction 5
     - Maintenance projects 5
     - Network considerations 5
   - Preliminary project considerations 6
   - Setting objectives 6
   - Analysis period and design life 6

2. Underlying issues
   - Uncertainty and risk 7
   - Choice of technology 7
   - Institutional issues 8
     - The institutional framework 8
     - Improving institutional development 8
     - Road maintenance organisations 9
     - Assessment of maintenance capability 9
   - Socio-economic considerations 10
   - Environmental considerations 11
     - Factors to be considered 11
     - Environmental assessment 12

3. Assessing traffic demand
   - Types of traffic 13
   - Baseline traffic flows 13
     - Traffic counts 13
     - Traffic counters 14
     - Moving observer counters 14
   - Traffic forecasting 15
     - Normal traffic 15
     - Diverted traffic 15
     - Generated traffic 15
   - Uncertainty of traffic estimates 16

4. Cost estimation
   - Purpose of the estimate 17
   - Cost estimating stages 17
   - The estimator 18
   - Information in the estimate 19
   - Estimating techniques 19
<table>
<thead>
<tr>
<th>Chapter</th>
<th>Title</th>
<th>Pages</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.</td>
<td>Geotechnics</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Object of geotechnical surveys</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Information needed</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Route location</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Subgrade strength</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Materials</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Earthworks</td>
<td>27</td>
</tr>
<tr>
<td></td>
<td>Drainage</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Structures</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Sources of information</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>Steps in the survey process</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Project identification</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Feasibility</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Design for project implementation</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Costs and accuracies of geotechnical surveys</td>
<td>30</td>
</tr>
<tr>
<td>6.</td>
<td>Pavement design</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Structural classification</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Earth roads</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Gravel roads</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>Choice of paved road construction type</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Rigid pavements</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Flexible pavements materials</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Surfacings</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Road bases</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Sub-bases and other pavement layers</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Use of marginal materials</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Factors affecting flexible pavement design</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Subgrade strength</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Traffic loading</td>
<td>34</td>
</tr>
<tr>
<td></td>
<td>Materials</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Variability and uncertainty</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Shoulders</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Drainage of pavement layers</td>
<td>36</td>
</tr>
<tr>
<td></td>
<td>Preparation and checking of flexible pavement designs</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Collection of information</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Choice of design method</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Strengthening flexible pavements</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Costing</td>
<td>38</td>
</tr>
<tr>
<td>7.</td>
<td>Geometric design</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Purpose of geometric design</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Elements of geometric design</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Rational basis for geometric design</td>
<td>40</td>
</tr>
</tbody>
</table>
Design related to terrain 40
Horizontal alignment 41
Vertical alignment 42
Cross-section 42
Road reserve 43
Junction design 43
Signs and road markings 43
Costing earthworks 44

8. Drainage and structures 44
   The drainage system 44
   Side drains 44
   Requirements for cross drainage 45
   Fords and drifts 45
   Culverts 46
   Bridges 46
   Bridge design 46
   Site conditions 46
   Abutments and piers 47
   Timber decks 47
   Concrete decks 47
   Steel decks 48
   Arch bridges 48
   Replacement of existing bridges 48
   Costing bridges 49
   Maintenance 49
   Ferries 49

9. Introduction of the assessment of benefits 50

10. Vehicle operating cost savings 51
    Factors affecting vehicle operating costs 51
    Road investment models 51
    Vehicle operating cost tables 51
    Data requirements 52
        Measured values 52
        Relative importance of data items 52
        Physical parameters of the road 52
        Vehicle descriptions 53
    Determining costs 56

11. Road maintenance benefits 57
    Paving gravel roads 57
    Strengthening and reconstruction 57
    Concrete roads 57
    Diverted traffic 58
    Traffic delays during maintenance works 58
    Determining costs 58

12. Time savings 59
    General considerations 59
    Vehicle fleet 59
    Vehicle occupants 59
    Freight 60

13. Reduction in road accidents 61
    Forecasting accident reductions 61
Factors leading to reductions 61
Effect of highway design 61
Low cost remedial measures 61
Effects of traffic 63
Road accident costs 63
Material and subjective factors 63
Methods available for costing road accidents 63
The relevance of alternative methods for developing countries 64
Recommended method of costing 64

14. Economic development benefits 65
The impact of different forms of road investment 65
Consumer surplus 65
Producer surplus 66

15. Cost-benefit analysis 67
Principles 67
Prices 68
Inflation 68
Discounting 68
Shadow prices 68
Comparison of alternatives 69
Net present value 69
Internal rate of return 69
Project timing 70
Recommended approach 70

16. Rural access roads 71
The need for special considerations 71
Non economic considerations 71
Screening and simplification of data collection 72
Upgrading and maintaining existing access 72
New road access 72

17. Analysis of uncertainty 73
Scenario and risk analysis 73
Expected values 73
Contingency 74
Sensitivity analysis 74
Traffic 74
Project costs 74
Delay 74
Generated traffic 74
Time and accident savings 75
Shadow prices 75
Maintenance 75
Special factors 75
Investment models 75
Risk analysis 75

18. The feasibility study report 76
Preparation 76
Presentation 77

19. Checklist of key points 78
Objectives 78
Background 78
Institutional and managerial aspects 78
1. **INTRODUCTION**

**PURPOSE OF THIS NOTE**

1.1 This Note gives guidance on carrying out feasibility studies for road projects in developing countries. It is intended for administrators, economists, transport planners and engineers in road and transport ministries in developing countries who are responsible for preparing or appraising project submissions. It will also be of interest to personnel in aid agencies and consultancies who are responsible for road projects.

1.2 The Note deals with rural (non urban) road projects for new construction, upgrading, rehabilitation, stage construction and maintenance. A background description of the engineering and transport issues involved is provided, and guidance is given as to which aspects of feasibility studies should be undertaken by a transport planner and which require the advice of a road engineer. The phases involved in executing a road project are outlined and attention is drawn to the need to collect good data and to identify which data and decisions are the most important.

1.3 The document is consistent in its approach with ODA's 'Appraisal of projects in developing countries: a guide for economists' (Overseas Development Administration 1988) and its book on planning development projects (Bridger and Winpenny 1983). It is the document to which staff at ODA will refer when appraising road projects, and should be used by consultants when preparing project submissions for ODA.

**THE PROJECT CYCLE**

1.4 Projects are planned and carried out using a sequence of activities known as the 'project cycle'. There are many ways of defining the steps in this sequence but, in this Note, the following terminology is used: identification, feasibility, design, commitment and negotiation, implementation, operation, and evaluation.

**Identification**

1.5 The first stage of the cycle is to find potential projects. This is sometimes known as the 'pre-feasibility' stage. There are many sources from which suggestions may come including well-informed technical specialists and local leaders. Ideas for new projects will also come from proposals to extend existing programmes or projects. In the process of preparing an economic development plan, specific suggestions for projects may come from operating agencies responsible for project implementation. Sometimes a sector survey will identify the need for specific projects.

1.6 It must be remembered that the decision to proceed to the feasibility stage arouses expectations for the project which can create their own momentum. Dubious projects should therefore be rejected at the identification stage, particularly if there is no lack of more promising ones. It becomes increasingly difficult to stop a project at the later stages in the cycle when minor changes of detail are often all that is possible.

**Feasibility**

1.7 The feasibility study will provide enough information for deciding whether to proceed to a more advanced stage of planning. The level of detail of this study will depend on the complexity of the project and how much is known already about the proposal. Sometimes, a succession of increasingly detailed studies will be needed. The feasibility study should define the objectives of the project. It should consider alternative ways of achieving these and eliminating poor alternatives. The study provides the opportunity to mould the project to fit its physical and social environment in such a way to maximise the return on the investment.

1.9 Once the feasibility study has indicated which project is likely to be the most worthwhile, detailed planning and analysis can begin. Even though the less promising projects will have been eliminated by this time, the selected project may be redefined and modified as more detailed information becomes available. At this stage, studies of traffic, geotechnics and design will be carried out in order to refine the prediction of costs and benefits and to enable an economic analysis to be carried out.

**Design**

1.10 Preliminary design and feasibility are often simultaneous, but detailed design, which can be very costly (up to 15 per cent of project costs), usually follows provisional commitment to the project. Numerous decisions which will affect economic performance are taken throughout design; and economic appraisal often results in redesign.

**Commitment and negotiation**

1.11 Commitment of funds often takes place in a series of stages. This is followed by invitations to tender and negotiations with contractors, potential financiers and suppliers. At this stage, there are still considerable uncertainties.

**Implementation**

1.12 Detailed recommendations on project implementation are beyond the scope of this Note. However,
several aspects of the earlier stages in the project cycle will affect the success of the implementation.

1.13 The better and more realistic plan, the more likely it is that the plan can actually be carried out and the full benefits be realised. A flexible implementation plan should also be sought. It is almost inevitable that some circumstances will change during the implementation. Technical changes may be required as more detailed soils information becomes available or as the relative prices of construction materials change. Project managers may need to change and replan parts of the project to take account of such variations. The more innovative and novel the project is, the greater is the likelihood that changes will have to be made during implementation.

**Operation**

1.14 This refers to the actual use of the road by traffic; it is during this phase that benefits are realised and maintenance is undertaken.

**Evaluation**

1.15 The final phase of the project cycle is evaluation. This consists of looking back systematically at the successful and unsuccessful elements of the project experience to learn how planning can be improved in the future.

1.16 For evaluation to be successful, it is important that data about the project is collected and recorded in a systematic way throughout all stages of the project cycle. Without this, it is usually impossible to determine details of events and information that were available during periods leading up to the taking of important decisions.

1.17 Evaluation may be carried out by many different people. The sponsoring organisation or external agency may undertake evaluation. In large and innovative projects, a separate unit may be needed to monitor each stage of the project by collecting data for identifying problems that need to be brought to the attention of the project's management. In some cases, outside staff will be used to provide an independent audit and specialist university staff may well be suited to undertake such a task.

1.18 The evaluation should result in specific recommendations about improving aspects of the project design which can be used to improve ongoing and future planning.

**STRUCTURE OF THIS NOTE**

1.19 This Note is concerned primarily with the feasibility stage of the project cycle, but guidance in the Note will also be of use at the identification, design and evaluation stages.

1.20 Technical, financial, social and environmental appraisals should also be undertaken for a project, and these are discussed in this Note where they affect the economic appraisal. Political and strategic considerations are beyond the scope of this Note.

1.21 When carrying out feasibility studies, it is recommended that the following steps are undertaken. References are made to the section of this Note where the various items are covered.

1. **Define objectives**
   (para 1.53-54)

2. **Determine alternative ways of meeting objectives:**
   \(\text{modal choice} \)  
   \(\text{choice between new road or upgrading existing road, etc} \)  
   (para 1.26-51)

3. **Preliminary considerations**
   (para 1.52-57 and Section 2)

4. **Assess traffic demand**
   (Section 3)

5. **Design and cost different options:**
   \(\text{Route location} \)  
   \(\text{Pavement design} \)  
   \(\text{Geometric design} \)  
   \(\text{Design of structures} \)  
   (Sections 4-8)

6. **Determine benefits for each alternative:**
   \(\text{Road user cost savings} \)  
   \(\text{Road maintenance benefits} \)  
   \(\text{Time savings} \)  
   \(\text{Reduction in road accidents} \)  
   \(\text{Developmental and social benefits} \)  
   (Sections 9-14)

7. **Economic analysis and comparison of alternative**
   (Sections 15 and 16)

8. **Recommendations**
   (Section 18)

These steps are not necessarily sequential and iteration between them is usually needed. The analysis undertaken should be used as a project design tool.

1.22 As indicated above, the layout of this Note follows a similar structure. Sections 4-8, on design and costing, are written for a non-engineering audience, but should still be of interest to engineers. Sections 9-14, on the assessment of benefits, are written primarily for administrators, economists and engineers, but should still be of interest to transport planners who are familiar with benefit assessment methods. Section 15, on cost-benefit analysis, will be of interest to economists, although written primarily for an audience who are not familiar with economic analysis techniques. All other chapters are written for a broad audience and should be consulted by all those engaged in feasibility studies.
1.23 Throughout the feasibility study phase, there are a number of underlying issues that need to be borne in mind. These include considerations of:

- uncertainty and risk
- choice of technology
- institutional issues
- socio-economic issues
- environmental aspects.

1.24 Section 19 contains a checklist of key points to be considered during the feasibility study and is designed to assist those submitting and appraising project reports to check quickly whether all of the key issues have been included.

1.25 Case studies have been included as appendices to illustrate different aspects of the feasibility study stage. Further case studies which should be consulted are given by Adler (1987).

### PROJECT TYPES

#### Factors to be considered

1.26 It is rare for a project under consideration to be entirely new. Most projects have a history and have been awaiting the most appropriate time for them to be considered for funding. The decision to carry out a study of a project is not a neutral action. The process of examining a project arouses expectations and creates momentum. Once a decision is taken to carry out a feasibility study, it is sometimes difficult to halt the progress of a project. Rejecting a proposed study on a doubtful-looking project at an early stage is more important than adding sophistication to the appraisal itself to try and obtain a more objective result.

1.27 Occasionally, projects exist which are manifestly viable, such as when a bridge on a major route collapses. Detailed economic feasibility studies are necessary in such cases, although a design study might be appropriate.

1.28 For practical national planning, it is necessary to study a project in the context of the particular needs and problems of the country before proposing solutions. This will help to determine what type of project will be most useful and where the effort should best be applied. A project can normally be considered as a means of converting inputs, such as the cost of a new or improved road, into outputs, such as benefits to vehicle operators or generated traffic. In this context, the following questions should be considered prior to the start of the study to help determine priorities.

1.29 **Is there an effective demand for the project?**

It is vital to differentiate between what people would like, and what they are prepared to pay to use. If forecasts show a spectacular increase in traffic over the present situation, then they should be treated with scepticism and the basis of these forecasts should be re-examined carefully.

1.30 **Will there be enough inputs at the right time and of the right quality to meet the needs for the project?**

It is particularly important for road and transport projects to consider not only the inputs required during the design and construction phases, but also the recurrent inputs required during operation. The maintenance requirements for road projects are particularly important and will be discussed in some detail later.

1.31 **How appropriate and cost-effective is the project for converting inputs into Outputs?**

For example, an alternative to building an all-weather rural access road may be to invest in crop storage facilities so that farmers’ produce can be held until travelling conditions improve.

1.32 **Does the management expertise exist to enable the project to operate efficiently?**

It is necessary to assess the existing numbers of staff, their skills and their availability. There may be some scope for upgrading skills and increasing the numbers of skilled staff by training as part of the project. However, it would be unwise to assume that additional staff will become available to operate the project, or that staff, once trained, will necessarily remain on the project.

1.33 If a satisfactory answer can be given to these four questions, it is likely that the project is worth analysing. The larger and more complex the project, the greater should be the effort put into the feasibility study. For particularly large one-off projects, specialist outside expertise may be required.

1.34 Before any analysis is carried out, decisions must be made about the type of project and the proposed method of construction, etc. All these factors will have an important bearing on the engineering decisions that must be made and on the benefits to be expected.

### Upgrading and new construction

1.35 Upgrading projects aim specifically at providing additional capacity when a road is nearing the end of its design life or because there has been an unforeseen change in use of the road. Typical examples of upgrading projects are the paving of gravel roads, the provision of strengthening overlays for paved roads and the widening of roads. Upgrading projects must not be confused with maintenance, and it is important that they are not undertaken without a proper assessment of maintenance capability as described in para 2.27-34. The appraisal of upgrading projects is similar to that of new projects. In fact most ‘new’ projects are essentially upgrading projects.
because some form of track or lower standard road is usually in existence. Only in the case of bypasses or new roads provided to support other investment are roads likely to be needed where none existed before.

1.36 The most important point about upgrading is that the timing of the project is crucial. For example, in the case of a paved road which requires strengthening to enable it to carry an increased traffic loading, the increased strength can normally be achieved by placing an asphalt overlay on the road. If the placing of this overlay is delayed for any reason, the road may start to deteriorate very rapidly. The cost of appropriate strengthening measures will then escalate and eventually complete rehabilitation will be the only sensible engineering solution costing many times that of a timely overlay and causing greater interruption to traffic.

1.37 Upgrading from a gravel surface to a paved road will be justified principally by savings in vehicle operating costs arising from the smoother running surface, but time savings may also be important. The level of traffic at which this kind of upgrading becomes justified can be determined by manual calculations, but it is easier to use road investment models as described in para 10.5. The availability of such models makes it inappropriate to quote levels of traffic at which upgrading from gravel to paved is justified; each case can and should be studied individually to determine the optimum timing.

Reconstruction and rehabilitation

1.38 Rehabilitation is needed if the road has deteriorated beyond the condition at which overlaying is a satisfactory engineering alternative. This may often be because the road has received insufficient maintenance over its design life. Additionally, rehabilitation may be needed because the original road was not built to the standards of quality required by the original design. Reconstruction to provide a new alignment should be considered as an upgrading project as discussed in the previous sub-section.

1.39 The rehabilitation of gravel roads is usually relatively straightforward. The existing surface will need to be reshaped and the road can then be regravelled. The rehabilitation of bituminous surfaced roads is usually more complicated and much more expensive. Usually, the surface of the road will have deteriorated to such an extent that it must be scarified and a new pavement provided. It is important that rehabilitation projects include remedial works to both the shoulders and the drainage of the road. Without these, the condition of the new pavement, is likely to deteriorate rapidly.

1.40 When rehabilitation work is being proposed, it is important to identify the reasons why the work is needed. If lack of effective maintenance is wholly or partly responsible for the need for rehabilitation, then it is unrealistic to assume that the maintenance of the reconstructed road will be carried out any better than was the case with the original road. This will result in very rapid deterioration and this should be taken into account in the appraisal. Unless the project includes a special component which has a realistic chance of increasing maintenance performance, the feasibility of the new project will be in doubt. The comments made in para 2.27-34 about assessing the capacity of the maintenance organisation are particularly relevant to this situation.

1.41 In order to assess whether a paved road has reached the end of its design life or whether the design specification was actually met at the time of construction, it is necessary to have access to the original design and construction reports and to have reliable traffic and axle load data.

1.42 For paved roads, unfortunately, it is common for design specifications not to be met at the time of construction, particularly with regard to the quality of materials used and the thickness of pavement layers. When assessments are made of roads requiring rehabilitation, it is important that trial pits are dug and cores taken from the road pavement to enable tests to be carried out. A sufficient number of test holes must be dug to enable statistically meaningful results to be obtained and it is recommended that there should be a minimum of one hole every half kilometre on long lengths of road and that a minimum of six holes should be dug in any apparently homogeneous short section of road. More holes than this are preferable, and they should be spread across the road to cover the various wheel tracks and other features. The cores and test pits will provide information on the actual layer thicknesses achieved during construction. Material from the test pits can be tested in the laboratory to compare its characteristics with those specified for the construction. However, it is possible that some of the material properties may have changed with time. If design specifications have not been met, the same construction and supervision teams should not be used again on a project.

1.43 Although design life for economic purposes is expressed in years, for the design of the pavements of bituminous roads, it must be related to the traffic 'loading' that the road is designed to carry. This is explained in para 6.28-30. If the number of vehicles using the road or the axle loads of these vehicles has been higher than was originally forecast at the time of the design, then the road can 'fail' prematurely. Traffic and axle load levels should be checked by examining records for the road and related roads where these exist but, in most cases, new classified traffic counts and axle load surveys should be carried out at the time of the appraisal of the project to provide new and up-to-date information.
**Stage construction**

1.44 Stage construction consists of planned improvements to the pavement standards of a road at fixed stages through the project life. Normally, the road alignment needed at the final stages of the project is provided from the outset. A typical policy will be to construct a gravel road initially which will be paved when traffic flows have reached a given level. Stage construction differs conceptually from upgrading in that any later improvements are planned from the outset, whereas upgrading projects aim specifically at providing additional capacity only when a road is nearing the end of its design life or because there has been an unforeseen change in use of the road.

1.45 When considered purely from the point of view of optimal economic balance, stage construction policies often have much to commend them. However, difficulties can arise in practice, particularly with regard to the future funding of such projects. If a stage construction policy is proposed, its viability will depend crucially on the successful implementation of the upgrading at the correct time in the project life. Experience has shown that budget constraints often prevent the later upgrading phase of stage construction projects from being funded, with the result that anticipated benefits from the project have not materialised. This has resulted in lower rates of return than were originally expected. If stage construction projects are considered, it is important to ensure that full account has been taken of the setting-up and overhead costs at the time of the upgrading as these can represent a substantial part of the contract.

**Maintenance projects**

1.46 The purpose of maintenance is to ensure that the road does not ‘fail’ before the end of its design life. In doing this, maintenance reduces the rate of deterioration of the road, it lowers the cost of operating vehicles on the road by providing a smooth running surface, and it keeps the road open on a continuous basis by preventing it from becoming impassable. It is a relatively low cost activity and specifically excludes those works designed to increase the strength or improve the alignment of the road.

1.47 The form of maintenance projects can be very varied, but there are two principal types of project. The first has the objective of building up the institutional capability of the maintenance organisation to carry out maintenance in an efficient manner. The second form of project has the objective of overcoming a short-term problem and includes such items as the supply of maintenance equipment or spare parts, surface dressing or regravelling a particular length of road by contract, or provision of specialist courses or technical assistance. The second type of project may be one component of the first type.

1.48 Most maintenance projects will be attempting to rectify fundamental institutional problems of a maintenance organisation with the objective of increasing the general capability or, perhaps, the capability in some specific area. Lack of capability will often result from some combination of the particular institutional situation, such as lack of management, technical skills, insufficient resources and lack of foreign exchange. Many problems are likely to be due to basic institutional factors existing outside the roads authority (see para 2.18-21) and which are not susceptible to change, even over a long period. It is vital to identify these factors clearly, and to look for means of carrying out maintenance which will avoid the effects of these factors, or at least minimise them.

1.49 If lack of maintenance has resulted in badly deteriorated roads then, because the cost of construction is already sunk and the possible savings in vehicle operating costs and deferred reconstruction are high, the potential return from road maintenance projects can be extremely large. However, the difficulty of realising these benefits, in practice, is considerable because of the difficulty of overcoming institutional factors.

1.50 The second type of project is usually easier to define and the work is relatively straightforward to execute and monitor. Benefits, and the probability of achieving the benefits, should be relatively easy to predict. However, there is a danger that this type of project will only remedy the symptoms of a problem and will do very little to rectify the cause, which will often be institutional constraints on the general capability to carry out maintenance. Short-term maintenance projects will only be appropriate in a very few cases and proposals in which they are recommended should be vetted very carefully to ensure that a deep-rooted and long-term problem is not being tackled with short-term measures.

1.51 It is important that the two types of maintenance project that have been described are not confused with projects for upgrading, rehabilitation and stage construction as described earlier.

**Network considerations**

1.52 In general, when constructing or improving a road network where economic constraints apply, the most economical solution for one road link may not necessarily be the best solution for the network as a whole. The cost of implementing one project to high standards may consume resources that would be better spent over the whole network, or in filling other gaps in the network with lower standard roads. In those countries where the basic road network is incomplete, it will usually be appropriate to adopt a relatively low level of geometric standards in order to release resources to provide more basic road links. This policy will generally do more to foster economic development than building a smaller number of road links to a higher standard.
PRELIMINARY PROJECT CONSIDERATIONS

Setting objectives

1.53 A road project should, wherever possible, be set against the background of a national or regional transport plan or, at least, a road plan. The feasibility study process involves several steps. Firstly, the project's objectives must be defined to provide the basic framework for the analysis. Within this framework, a range of alternatives should be considered. For each, it is necessary to assess the demand, determine physical resources and costs, and to predict benefits in order to compare alternatives. This should be done in conjunction with the analysis of uncertainty in order to provide a robust recommendation. For appraisal purposes, all costs and prices are expressed in 'economic' as opposed to 'market' terms to reflect the real value of the resource to the economy.

1.54 The project objectives need to be clearly defined from the outset. The objective of providing a new road may be to support some other developmental activity, to provide fundamental links in the national or a district road network, or perhaps to meet a strategic need. Alternatively, a road improvement may be proposed to increase the structural or volumetric capacity of an existing road to cope with higher traffic flows. Often, there will be multiple objectives. Depending on the objectives of the investment, the project will be appraised against different sets of criteria.

Analysis period and design life

1.55 The viability of a road project should not depend on the length of the economic analysis period. Long analysis periods are useful when comparing mutually exclusive projects. Short analysis periods may be appropriate for small projects such as regravelling of rural access roads, where the life of the investment is expected to be limited to a few years.

1.56 Whatever time period is chosen for the economic analysis, the project will usually have some residual value at the end of this period. The residual value can be approximated as the difference in cost between rebuilding the road at the end of the analysis period to satisfy further demand, using the structure remaining from the initial project, and the building cost if the first project were not to take place. The size of this residual value can sometimes be large, especially for structures and concrete roads, and therefore have considerable impact on the choice of project or the feasibility of a project. The problem of determining the residual value can be reduced by extending the period for which the project is appraised, but this causes additional problems of making forecasts, particularly of traffic, for long periods into the future. For most road projects, an analysis period of 15 years from the date of opening is appropriate, but this time period should be tested by the appraisal. Such a period of analysis reduces both the problems of making forecasts for long periods into the future and the impact on the project of the size of the residual value. Choosing the same value for pavement design life in years, and the analysis period, simplifies the calculation of residual values.

1.57 When choosing design standards for a road, a fundamental decision must be made as to whether those design standards should hold only for the analysis period for which a project is being analysed or whether standards should be chosen for a shorter or longer period than this. In the past, geometric standards have effectively been chosen for a life far in excess of the economic analysis period, whereas pavement design standards have been chosen based on the actual analysis period itself, or even for a shorter period when coupled with stage construction. However, there is rarely any economic justification for providing a higher standard of geometric design than is required by the most optimistic traffic forecast for the latter years of the economic analysis period.
2. UNDERLYING ISSUES

2.1 Several issues underly all steps of the feasibility stage of the project cycle and are discussed here.

UNCERTAINTY AND RISK

2.2 All stages of the project cycle involve uncertainty and risk. Projects in developing countries are always set against a background of economic, social and political uncertainty to some degree.

2.3 The appraisal of a project involves the collection of a large amount of data and the forecasting of trends into the future. All data collected in the field are subject to errors and some can be particularly inaccurate. By the time these data have been used to make future projections, any error can be magnified significantly. When this is coupled with the uncertainties which exist in the projection process itself, the appraisal can be subject to substantial errors.

2.4 It is important to recognise that uncertainties exist and to take steps to minimise them. It is also necessary to determine the effect of uncertainty on the robustness of the conclusions reached as this may affect the final recommendations.

2.5 Projects should not only be appraised with a recognition of uncertainty, but they should be designed with it in mind in order to minimise risk. The approach that is necessary to deal with uncertainty should depend on the level of project development. If the project is well defined, 'risk analysis', is likely to be appropriate. This involves formal probability analysis of the likely range of outcomes. If the project is exploratory, with project identification as a component, then 'scenario analysis' is more appropriate.

2.6 Scenario analysis requires the examination of a range of future possibilities that might reasonably be expected to occur. Normally 3 to 5 scenarios would be examined, each reflecting an internally consistent combination of possibilities for the major socio-economic uncertainties relevant to the project. The intention of the set of scenarios is not to act as a forecast of what will occur, but to span a wide but plausible range of possibilities. Projects should be chosen on their ability to deliver a satisfactory level of service across a range of scenarios. In this way, the economic return of a project need not be the sole criterion since social and political realities can also be taken into account.

2.7 Scenario analysis is discussed in the sections on assessing traffic demand and on project design and costing. The general principles are described by Allport et al. (1986). Risk analysis and the role of sensitivity analysis are discussed in Section 17.

CHOICE OF TECHNOLOGY

2.8 When building engineering projects, there is a choice between using technology dominated by mechanical equipment or dominated by labour. Most engineers are familiar with equipment based technology, so emphasis here is on the use of labour based methods.

2.9 Although the use of relatively sophisticated equipment for construction and maintenance can be very effective, it usually has two serious drawbacks for developing countries. Firstly, it has to be paid for in foreign currency and, secondly, it use tends to reduce the employment of local labour. In countries where there are high levels of unemployment or underemployment, there are often good economic, social and political reasons for using labour based methods. However, such methods are very dependent on competent management and organisation at various levels.

2.10 Labour based methods should not be used unless they are competitive from an economic point of view, which may not be identical to the financial viewpoint. Comparison of the economics of labour and equipment should ensure that foreign exchange is properly priced (see para 15.14) and that realistic estimates of equipment availability and output are used (see para 2.29). The introduction of extra cash into the local economy through the utilisation of labour based techniques may well give rise to other effects if large numbers of wage earners are involved and these effects should also be considered.

2.11 The following points should be borne in mind when considering the use of labour based construction methods:

- With certain qualifications and assuming certain improvements over traditional methods, labour based construction can be made competitive with other methods when the average unskilled wage rate is equivalent to about US$4.00 per day (1985) or less; in some circumstances, the competitive wage threshold can be higher than this figure
- It is necessary to check carefully that labour will be available in the actual place where it is wanted, and at the time it is wanted
- Adequate organisation and management are critical considerations for large-scale labour based works
- Design can be modified to suit labour based methods, but any change in benefits from the project that result must be accounted for explicitly
- The health and nutrition of the labour force are very important. Improvement can increase productivity, besides bringing other benefits
- Standardised tools of good quality are vital in order to achieve high levels of outputs
• There are limited prospects for a half-way stage of so-called 'intermediate technology' between the labour based and equipment based methods
• Supervision and management requirements are very different for the two methods of construction.

2.12 Before making direct cost comparisons between the two methods of working, consideration must be given to each of the above factors. It is also particularly important when carrying out feasibility studies to consider the design of the scheme because current construction procurement practices are strongly biased towards the use of equipment based methods. This is largely the result of the influence of the industrial countries where the use of advanced technology, availability of capital and high cost of labour have led to designs, specifications, conditions of contract and methods of finance which take account of these factors. These equipment-biased practices have usually been transferred with little or no modification to labour-abundant countries and have resulted in a failure to consider utilising the natural labour resource which is widely available. A further difficulty is that engineering and training institutions in the industrialised countries expose students from development countries almost exclusively to equipment based construction concepts.

2.13 It is important when projects are being formulated that the aspects of design, specifications and contractual procedures are defined in such a way that any bias is removed and alternative construction methods can be considered on a competitive basis. This process is known as 'neutralisation' and is described in a systematic way by the World Bank in their publication: 'Guide to competitive bidding on construction projects in labour-abundant economies' (International Bank for Reconstruction and Development and Scott Wilson Kirkpatrick & Partners 1978).

2.14 In this World Bank document, it is recommended that a screening process is applied to projects that are being formulated. The object of this is to identify, in two stages, those projects which are likely to benefit from neutralisation and therefore minimise unnecessary effort on projects which for one reason or another must be constructed by mainly labour based or equipment based methods. Even where there are overriding circumstances which determine the method of working, such as government policy towards employment creation, screening should still be carried out to determine the cost of this policy on the economics of the project being considered. Screening must be carried out as early as possible in the project cycle since, once a decision has been made on the broad technology to be followed, it is difficult to change later on in the project preparation process. Most of the factors considered in the two parts of the screening process are the same but, whereas in the first stage they are considered from a country-wide point of view with a long-term perspective, in the second, they are considered with regard to the specific wage levels, labour availabilities, etc, that are applicable in the project area.

2.15 Where appropriate, feasibility studies should include the World Bank type of screening process and demonstrate that the design has been neutralised to ensure that use of the most appropriate technology is being recommended.

INSTITUTIONAL ISSUES

The institutional framework

2.16 The success of many projects will depend upon the institutional framework in which they are set. Aspects that need to be considered are the organisation, staffing, training, procedures, planning, maintenance, funding and controls within the agency responsible for the project, and also within other agencies who may need to make an input to the project. The activities of all agencies responsible for development projects need to be coordinated to ensure that the best use is made of the country's resources and that a project being undertaken by one agency does not undermine the likelihood of success of a project being carried out elsewhere.

2.17 For a project to be a success, it must have full local support and not be undertaken solely because of pressure from a donor or other agency. Such issues should be clarified at the project identification stage. There is also a need for the involvement of the people living in the area of a project in its formulation, and this is particularly important in the case of rural access roads.

Improving institutional development

2.18 There is often a need to strengthen the institutions associated with the implementation of projects. Particular attention should normally be paid to:

• Whether the agency responsible for the project is the most suitable, not only for the implementation of the project, but also for its operation after the project is complete
• The need to develop permanent local training courses which will assist in long term institutional expansion; training should be introduced as soon as possible in the project, rather than at the closing stages and should be aimed at policy makers, managers and technicians; it is essential that counterparts are available to be trained and that there are sufficient incentives for them to wish to be trained
• The agency's ability to hire and fire staff and to provide incentives to reward good performance
• Whether there is effective coordination between agencies involved in the road subsector and the
transport sector as a whole to ensure the optimum use of resources in these areas.

2.19 It is normally to be recommended that institutional development should be carried out as a component of a project rather than as a complementary measure. Technical assistance and training are specific aspects of this and should be treated as subcomponents of the institutional development component.

2.20 The time horizon for institution building projects needs to be long. It is unrealistic to expect to make fundamental changes to the workings of an organisation which are sustained in less than about 10 years. The fundamental problem behind lack of resources may be that the macro economic performance of the country is insufficient to generate the resources that are needed. The lack of trained staff may be due to an insufficient number of students graduating from schools, colleges and universities, or may be due to the lack of a work situation in which training can develop. It may also be due to an inadequate wage structure. Often a combination of several problems will apply simultaneously.

2.21 Proposals for tackling institutional problems should be examined to ensure that they are tackling the root cause. Well-founded projects may be in operation for several years before any measurable improvement can be observed. This must be clearly understood, not only by the people promoting and funding the project, but also by the organisation responsible for its execution. It can be expected that the final benefits from institution building projects may be substantially lower than those predicted, and this should be taken into account when the project is appraised by examining the effects of different scenarios (see para 2.6-7).

Road maintenance organisations

2.22 Although maintenance costs normally only account for a small fraction of the initial investment costs of the road, they are often an important item in the budget. This can lead to particular problems where investment costs are covered by foreign aid donors and maintenance must be financed locally. In addition, because periodic maintenance can sometimes be delayed from one year to another without immediate disastrous consequence, it is tempting for hard-pressed roads ministers to economise on this item rather than on some other element of the budget. The cumulative effect of such skimping is that road maintenance departments are frequently poorly staffed, badly trained and demoralised compared to other departments dealing with new investment. These factors often result in pressures on the financiers and consultants for projects to provide higher standards than are justified in an attempt to reduce the future maintenance burden. The adoption of higher standards than are necessary draw investment funds away from other priority areas and undermine the creation of proper maintenance departments which are essential in the long run.

2.23 On a well maintained road, vehicle operating costs over the project analysis period will typically be four times the size of the construction costs. Maintenance costs over the same period will be only a few per cent of the total. Lack of maintenance, or lack of effective maintenance, which leads to a road pot-holding can lead to a 15 per cent increase in vehicle operating costs. If this situation continues, and the road disintegrates, vehicle operating costs can increase by up to 50 per cent. Similarly, lack of maintenance can lead to the need for premature rehabilitation of a road. Thus, the adequacy of maintenance can have a significant effect on the feasibility of a project.

2.24 Many construction and improvement project appraisals in the past have apparently overlooked the fact that insufficient funds, personnel, equipment, materials and appropriate skills exist to carry out the necessary level of maintenance on the new project, or indeed on any other road. If maintenance fails to reach the planned standard, anticipated benefits will not be achieved which, in most cases, negates the case for the project.

2.25 It is unrealistic to assume that subsequent maintenance of a new project will be carried out any better than maintenance is carried out on the remainder of the road network. Appraisals should therefore be based on measurements of maintenance capability in the existing maintenance organisation. Unless the project includes a special component aimed at improving maintenance performance which has a realistic chance of success, the appraisal and design of a new project should be based firmly on the assumption that it will receive the same level of maintenance as is being applied to comparable roads in the country at the time the appraisal is being carried out.

2.26 For any road development project, it is therefore necessary to assess the institutional capability to carry out effective maintenance in order to appraise the project properly.

Assessment of maintenance capability

2.27 There are several ways of assessing the existing maintenance capacity of a roads organisation. A competent road engineer should be able to make a subjective assessment by simply inspecting a sample of roads. Lack of effective maintenance will be shown up by the level of deterioration of the road network taken as a whole. Watching maintenance gangs working in the field will also give a good indication of the likely productivity and durability of maintenance operations.
2.28 However, appraisals should normally be expected to contain objective assessments of maintenance performance. Field measurements can be taken of several functions and these should be used in conjunction with available records from the road maintenance organisation to enable the assessment of capability to be made. Appropriate maintenance functions that can be included here are the availability and utilisation of specific items of maintenance equipment, the productivity achieved in certain maintenance activities and the frequency of carrying out periodic maintenance. In addition, the record of maintenance funding compared with the estimated amount necessary, with an assessment of work efficiency and the effectiveness of expenditure control will all give indications of maintenance capability. Feasibility studies should include assessments of maintenance capability based on field measurements in these areas.

2.29 Poor availability of maintenance equipment is almost always a sign of an inefficient maintenance organisation. Hence measurements of availability and utilisation, particularly of key times of equipment such as graders and bitumen distributors, gives a good indication as to whether a particular organisation has the capability to carry out maintenance work efficiently. Availability is measured simply as the number of working days that the equipment is in a suitable condition to work. Utilisation is the actual hours that equipment is working as a proportion of the total machine hours in a given period of time. Clearly, the actual utilisation of equipment is constrained by its availability. An efficient organisation would normally expect to have average utilisation of at least 50 per cent. Availabilities and utilisations for the previous years should be obtained from records, if available. Non-availability of records may in itself be a good indicator that equipment availability is low. It is vital that field checks of equipment use are made over as long a period of time as possible. The results from the field checks should be compared with the organisation’s own record as this will highlight systematic errors of recording that might invalidate these records.

2.30 In a similar way, records should be collected and compared with field measurements of productivity rates for selected maintenance activities. These should be compared with the performance standards in Table 8.2 of Overseas Road Note 1 (TRRL Overseas Unit 1987). It is important that field measurements made over a reasonable length of time are used for this assessment, and that the measured productivities take account of any unproductive time, irrespective of the reasons why this arises. It is not sufficient for the appraisal to quote standard productivity rates used by the maintenance organisation as these will normally represent ideal or target values which are unlikely to be achieved in practice. The actual productivities achieved by a reasonably efficient maintenance organisation should lie within the range of outputs quoted in Table 8.2 of Overseas Road Note 1.

2.31 A third check can be made to assess the maintenance capability. On average, paved roads carrying average traffic levels should have been surface dressed every 5-8 years, and all gravel roads carrying about one hundred vehicles per day should have been regravelled every 5-8 years. The surface dressing and regravelling achievements for the last three years should have been checked to see if, on average, between 1/8th and 1/5th of the network has been surface dressed or regravelled in each of those years, and also whether the proportion achieved each year is remaining constant, increasing or declining.

2.32 Inspections should be made of typical lengths of paved roads using the methods and criteria recommended in Overseas Road Note 1. If maintenance has been effective, very few lengths of road should be in need of ‘further investigation’ as defined in Table 7.2 of Overseas Road Note 1. The existence of some corrugated gravel and earth roads is not a good indication of maintenance capability as, even with a high level of maintenance, corrugations can appear within a few days of the maintenance having been carried out.

2.33 The capability to carry out maintenance, as estimated from the above, must be compared with the requirements for the maintenance organisation. Their work programme and budget allocations should be studied, and information obtained from these should be compared with the results of field inspections in order to assess the maintenance requirement. The requirement and the assessment of capability can then be compared.

2.34 Appraisals should use the results of these observations of maintenance capability to estimate a realistic level of maintenance that can be expected to be carried out on the project, and this is the level that should be used in the assessment of feasibility of the project. The sensitivity of the costs and benefits of the project to changes in this predicted level of maintenance should also be examined.

**SOCIO-ECONOMIC CONSIDERATIONS**

2.35 Several socio-economic factors may influence the way that a project should be executed. Projects may produce sudden effects on economic and social activity in the surrounding area of the road, or changing demands on health services and education. Construction camps can introduce populations from outside the project area. Disease problems may arise both from those brought in by the new population, and from their potential exposure to diseases to which they do not have immunity. Depending on how the project is designed, it may increase or decrease the rate of road accidents with the possible
consequences of pain, grief and suffering, in addition to direct costs to the community. A check-list of socioeconomic factors follows.

2.36 **Social changes.** What will be the social consequences of the project and what steps can be taken to deal with these? Socio-economic advice should be sought if the project is likely to introduce sudden changes in the social and economic activity of the surrounding area. If, for instance, the project will result in the enforced movement of people's homes, the advice of a socio-economist and an anthropologist should be sought at an early stage. Effects on health services and education may also be important.

2.37 **Construction consequences.** Has the impact of construction on the indigenous community been considered? What are the implications for the physical environment of the local population and their settlements? What are the implications of the introduction of relatively high earning construction workers into the community? Are there any disease implications? What steps can be taken to mitigate adverse effects?

2.38 **Road accidents.** Has the project been formulated considering the effects on road safety? The recommendations outlined in Section 13 should be followed in order to provide a safer environment surrounding the project.

2.39 **Severance.** Have problems of severance been taken into account? The severance of communities by road projects may not only result in social inconvenience, but may also give rise to an increase in road accidents.

2.40 **Minorities.** Have any special needs of women or minority groups been taken into account in the project formulation?

2.41 **Expertise and resources.** Does the local design organisation and contracting industry have the in-house expertise and resources to mount a project of the nature and scale involved? If not, how can the project strengthen these by institution building or provide additional resources.

2.42 **Data.** Is the information on the local social environment, the site conditions and climate likely to be reliable? If not, what data should be collected under the project to increase this reliability to an acceptable level, or how can the project be formulated to reduce the level of risk?

**ENVIRONMENTAL CONDITIONS**

**Factors to be considered**

2.43 Any road project will have an impact on the environment. In the case of new roads penetrating undisturbed country, this can be profound. The impact of road improvement projects will be less, but should still be considered.

2.44 Particularly in the case of new roads, there will be a direct environmental impact along the line of construction which will encourage the spread of new settlements and agriculture into previously uncultivated areas. These indirect effects are often more potentially damaging than the project itself. Such access may encourage the depletion of forestry resources, the loss of fertile soil through ‘desertification’, the opening of mineral extraction facilities, or the extinction or depletion of species of plants and wildlife. It could be argued that environmental damage of this type resulting from improved access is not the concern of the transport planner, and should be considered at the broader planning level before individual road projects are appraised. In reality, environmental problems are likely to be ignored unless they are raised in connection with specific projects and, if there is likely to be any significant environmental impact, it is recommended that specialist advice from environmentalists and conservationists should be sought.

2.45 Geotechnical damage can often result from projects in the road subsector and steps should be taken to minimise this at an early stage in the project cycle. In hilly environments, considerable attention needs to be given to existing and relic landslide areas. While the former create serious but obvious problems for the road engineer, there are locations where former landslides have become stabilised. Cutting through these sites can reactivate the slides with serious effects for both the road and the slopes above it. Cuttings may also increase the likelihood of soil erosion from slopes above the cutting. Geomorphological mapping of the road line may identify potential risks and allow redesign to reduce the long-term maintenance costs. It is not uncommon for mountain communities to face substantial annual maintenance requirements and these should not be underestimated. Careful planning and design, such as that outlined in Section 5, can do much to avoid or minimise problems of erosion and landslides.

2.46 The future depletion of local roadbuilding and maintenance materials should also be taken into account during the feasibility study and design stages. Most road projects will make heavy demands on gravel, sand, rock, cement and timber resources which will have to be extracted and transported to the construction site. The effects of this extraction can be considerable especially in wetlands and coastal zones.

2.47 Design of bridges and culverts normally takes account of flood discharges, but these can be difficult to estimate when data on rainfall, soil and vegetation are absent or scarce. Furthermore, the effects of land...
clearance may increase run-off and sedimentation in stream channels, so flood peaks become higher and arrive more rapidly after rainfall. It may be necessary in some hilly areas to consider the sensitivity of the design of drainage structures to changes in land use. Roads can impede drainage and may provide suitable habitats for disease vectors. Local water supplies and washing places may be disrupted at bridging points.

2.48 Along the line of construction and around borrow-pits and quarries, there will be direct disturbance of agricultural or natural land. Consideration should be given to the likelihood of damage to wetlands and woodlands in particular, avoiding them where possible, especially when they are isolated elements of the landscape. During feasibility study surveys, it is recommended that an ecological reconnaissance is carried out to provide an initial rapid environmental appraisal which can be accommodated by the initial road design. Particular attention should be given to migration routes, not only for higher animals but for lower animals and amphibians as well. There is often a disturbance corridor along construction routes. Depending upon the terrain and the species, this may extend for about one kilometre on either side. Roads may cut off slower moving species from breeding or feeding grounds. In the latter case, this may cause local overgrazing and land degradation. Roads through existing reserves and national parks should be avoided not only because of the disturbance but also because, unless there is a strong warden system, this can encourage new settlements and more permanent disturbance.

2.49 Borrow-pits often cover large areas and are comparatively shallow. If they receive surface run-off, they may become shallow ponds and habitats for waterborne disease vectors. They may also become fish ponds or provide a new aquatic habitat, in which cases the advice of a fisheries adviser could be sought. Dry pits may also be adopted for farm land, industrial uses or develop as new habitats.

2.50 In coastal areas, roads are often routed across estuaries and mangrove forests upon embankments. These will concentrate tidal flows at bridges and changes will take place in tidal patterns and velocities. This may have 'knock-on' effects on salt-water intrusion into estuaries. Pollutant dispersion and concentration, fisheries, sedimentation and disease vector habitats.

2.51 In industrialised countries, environmental problems of air pollution, noise and vibration, and visual intrusion are often considered to be significant, particularly in urban areas. Knowledge of the costs and benefits of reductions of such environmental damage in developing countries is, at present, inadequate to enable satisfactory policy guidance to be given. Nevertheless, it is always advisable to consider possible environmental effects in qualitative terms during the feasibility studies phase and when considering any subsequent design modifications. Often, low cost changes at the feasibility stage can avoid or minimise problems later.

Environmental assessment

2.52 The general environmental pollution and damage caused by roads is closely associated with the level of economic activity. An increase in GNP is likely to lead to an increase in the environmental cost of transport, although the increased national wealth may also make it possible to raise the level of investment in measures designed to combat pollution. If a nation wishes to reduce the environmental impact of schemes, then it must be realised that there is a definite cost associated with protective measures.

2.53 Environmental benefits do not have infinite value, so it is essential to try and compare the costs and benefits of any change which will reduce the environmental impact, but increase other costs. Maximising the 'general good' or social welfare is commendable, but an impossible quantifiable task because the quality of life as a result of economic changes cannot be measured.

2.54 In view of the high degree of uncertainty about the value of environmental measures, value judgements usually have to be made to determine which measures will yield net benefits to the community. Although it is unrealistic that the 'man-in-the-street' can be involved in the details of environmental decisions, particularly in developing countries, it is important that the impact on the public at large is taken into account when adopting investment policies and plans that will impact on the environment. It is also important that the views of all socio-economic groups are considered and not just those of the affluent or vocal minority.

2.55 In the past, project appraisal in developing countries has either ignored environmental issues or has taken them into account in a very imperfect manner. It is recommended that, when project reports are prepared, they include an environmental impact statement based on an appropriate study of the issues involved. The statement can be presented in the form of a balance sheet where all project costs and benefits are set out using monetary or physical units, where possible, or a points rating where not. The statement should also indicate who are the bearers of costs and the recipients of benefits. For unquantifiable environmental effects, the following general principles for presentation can be considered:

- The population exposed to the effect should be enumerated and described in terms of its level of sensitivity to the effect; the population may need to be classified where levels of sensitivities are different
• The existing level of the effect should be identified and measured, where possible, to show the current degree of exposure of the population.
• The anticipated level of the effect resulting from the project should then be predicted, in the same units as for the existing level, to enable comparisons to be made in terms of population affected.

2.56 The following checklist includes those issues that should be considered in an environmental assessment.

2.57 **Consequential developments.** Will the project stimulate land clearance for agriculture, the development of industry or mineral extraction? What steps can be taken to mitigate long term adverse effects?

2.58 **Geotechnical damage.** Has the project been designed to minimise the possibility of landslides and other geotechnical problems? Have long term maintenance consequences been taken into account?

2.59 **Material resources.** Will the project result in the unacceptable depletion of material resources that may be needed for subsequent maintenance or other construction projects? Will borrow pits be restored and can their effect on the landscape be minimised?

2.60 **Drainage.** Will the project result in increased risks from flooding or landslides as a result of disturbing natural drainage patterns? Will consequential development of agricultural land and other settlements affect hydrological conditions sufficiently to require modification to drainage works and bridges? What will be the effects on coastal habitats and landforms, especially swamps, lagoons and mangroves? Both reclamation and the effects of embankments on estuarine hydrology need consideration, as to disturbance and increased sedimentation during construction. Will any water impoundments create health hazards?

2.61 **Ecology.** Have the effects on animals and plants been considered? Has an ecological reconnaissance been carried out to assess effects?

2.62 **Other factors.** Are the problems of air pollution, noise and vibration, and visual intrusion matters for concern? If so, what can be done to mitigate their effects?

3 ASSESSING TRAFFIC DEMAND

### TYPES OF TRAFFIC

3.1 For the purposes of geometric design and the evaluation of economic benefits, the volume and composition of current and future traffic needs to be known in terms of cars, light goods vehicles, trucks, buses, non-motorised vehicles, etc. For the structural design purposes of paved roads, because the lighter vehicles contribute so little to pavement damage, they can be ignored and only the number and axle loading of the heavier vehicles need be considered.

3.2 In order to assess benefits, it is also necessary to separate traffic into the following three categories:

- **Normal traffic.** Traffic which would pass along the existing road being considered by the project if no investment took place, including normal growth.
- **Diverted traffic.** Traffic that changes from another route (or mode) to the project road, but still travels between the same origin and destination (this is termed 'reassigned' traffic in transport modelling).
- **Generated traffic.** Additional traffic which occurs in response to the provision or improvement of a road (this includes 'redistributed' traffic as defined in transport models).

These categories are each treated separately in an economic appraisal.

### BASELINE TRAFFIC FLOWS

#### Traffic counts

3.3 The first step in assessing demand is to estimate baseline traffic flows. The estimate used should be the Annual Average Daily Traffic (ADT) of traffic currently using the route, classified into vehicle categories such as those described above. This is the total annual traffic in both directions divided by 365, typically obtained by recording actual traffic flows over a specific shorter period from which the ADT is estimated.

3.4 Traffic counts carried out over a short period as a basis for estimating the traffic flow can produce estimates which are subject to large errors because traffic flows can have large daily, weekly, monthly and seasonal variations. The daily variability in traffic flow depends on the volume of traffic, increasing as traffic levels fall, and with high variability on roads carrying less than
1000 vehicles per day. Traffic flows vary more from day-to-day than week-to-week over the year, so that there are large errors associated with estimating annual traffic flows (and subsequently annual average daily traffic) from traffic counts of a few days duration, or excluding the weekend. For the same reason, there is a rapid fall in the likely size of error as the duration of counting period increases up to one week, but there is a marked decrease in the reduction of error for counts of longer duration. Traffic flows also vary from month-to-month, so that a weekly traffic count repeated at intervals during the year provides a better base for estimating the annual volume of traffic than a continuous traffic count of the same length. Traffic also varies considerably through the day, but this is unlikely to affect the estimate of ADT providing sufficient hours are covered by the daily counts.

3.5 In order to reduce the magnitude of errors, it is recommended that traffic counts to establish ADT at a specific site conform to the following practice:

- the counts are for seven consecutive days.
- the counts on some of the days are for a full 24 hours, with preferably one 24 hour count on a weekday and one during a weekend. On the other days, 16 hour counts should be sufficient. These should be grossed up to 24 hour values in the same proportion as the 16 hour/24 hours split on those days when full 24 hour counts have been undertaken.
- counts are avoided on roads at times when travel activity increases abnormally due to the payment of wages and salaries, or at harvest time, public holidays, etc, or on any occasion when traffic is abnormally high or low.
- if possible, the seven day counts should be repeated several times throughout the year.

3.6 Country-wide traffic data must be collected on a systematic basis to enable seasonal trends in traffic flows to be quantified. Unfortunately, many of the counts that are available are unreliable. Therefore, where seasonal adjustment factors are applied to raw traffic data from a traffic survey in order to improve the accuracy of baseline traffic figures, the quality of the statistics on which they are based should be re-checked in the field.

3.7 When determining design flows for bridge or other projects close to urban communities, it is usually appropriate to base the design on peak hourly flows in order to take account of commuter traffic. However, delays must be considered when costs and benefits are assessed, as allowing traffic to queue may be the most economic solution.

### Traffic counters

3.8 Classified traffic counts are normally obtained by counting manually. However, these counts can be supplemented by the use of automatic traffic counters. The commonest types of counter use either a pneumatic tube laid across the carriageway or a loop of wire buried beneath the road surface. Buried loops have a longer life than pneumatic tubes, but can be difficult and expensive to install, especially on a paved road. Pneumatic tubes are easy to install, but require regular maintenance and are subject to vandalism. For short duration counting on a paved road, a loop can be fixed to the carriageway surface (Kember-Smith 1984).

3.9 In their basic form, automatic counters do not distinguish between different types of vehicle, so they cannot provide a classified count. Modern detector systems are now becoming available which can perform classified vehicle counting, but such systems are expensive and not yet considered to be robust enough for most developing country applications.

### Moving observer counts

3.10 In order to obtain a broad impression of the changes in vehicle flows along a length of road, moving observer counts can be carried out. These can be used to guide the number and choice of sites for carrying out the detailed traffic counts.

3.11 A hand-tally can be used to record the number of vehicles. The flow can be estimated from the expression:

\[
q = \frac{(x + y)}{t}
\]

where
- \( q \) = total flow in both directions in time \( t \)
- \( x \) = number of vehicles met (ie travelling in the opposite direction)
- \( y \) = number of vehicles that overtake the observer minus the number he overtakes
- \( t \) = journey time

3.12 This expression assumes that flows in each direction are equal. If the observer can drive so that he passes as many vehicles as pass him in the direction of travel (this can usually be achieved without risk at low traffic volumes) then the expression becomes:

\[
q = \frac{x}{t}
\]

3.13 Counts of this type are also useful as a cross-check on static counts and also to assess the extent of variations in flow from day to day or between one season and another.
TRAFFIC FORECASTING

3.14 Even with a developed economy and stable economic conditions, traffic forecasting is an uncertain process. In a developing economy, the problem becomes more intractable. The economies of developing countries are often very sensitive to world prices of just one or two particular commodities, and fluctuations in world oil price and supply over the last decade have added a new dimension to the difficulties. Despite the uncertainty, the economic viability of a road project is often very sensitive to the forecast traffic levels.

Normal traffic

3.15 The commonest method of forecasting the growth of normal traffic is to extrapolate time series data on traffic levels and assume that growth will either remain constant in absolute terms (a linear extrapolation) or constant in relative terms (a constant elasticity extrapolation) ie traffic growth will be a fixed number of vehicles per year or a fixed percentage increase. Data on fuel sales can often be used as a guide to country-wide growth in traffic levels although improvements in fuel economy over time should be taken into account. As a general rule, it is only safe to extrapolate forward for as many years as reliable traffic data exist from the past, and for as many years forward that the same general economic conditions are expected to continue.

3.16 As an alternative to time, growth can be related linearly to GDP. This is normally preferable, since it explicitly takes into account changes in overall economic activity, but it has the disadvantage that, in order to use the relationship for forecasting, a forecast of GDP is needed. The use of additional variables such as population or fuel price brings with it the same problem. If GDP forecasts are not available, then future traffic growth should be based on time series data.

3.17 If it is thought that a particular component of the traffic will grow at a different rate to the rest, then it should be specifically identified and dealt with separately. For example, there may be a plan to expand a local township or open a local factory during the life of the project, either of which could lead to different growth rates for different types of vehicle, or there may be a plan to allow heavier freight vehicles on the road, in which case the growth rate of truck numbers may be relatively low because each truck is heavier.

3.18 Whatever the forecasting procedure used, it is essential to consider the realism of forecast future levels. Few developing countries are likely to sustain the high rates of growth experienced in the past, even in the short term, and factors such as the high foreign exchange component of fuel costs and vehicle import restrictions could tend to depress future growth rates.

Diverted traffic

3.19 Where parallel routes exist, traffic will usually travel on the quickest and cheapest route, although this may not necessarily be the shortest. Thus, surfacing an existing road may divert traffic from a parallel and shorter route because higher speeds are possible on the surfaced road. Origin and destination surveys should be carried out to provide data which can be used to estimate likely traffic diversions. Assignment of diverted traffic is normally done by an 'all-or-nothing' method in which it is assumed that all vehicles that would save time or money by diverting would do so, and that vehicles that would lose time or increase costs would not transfer. With such a method, it is important that all perceived costs are included. In some of the more developed countries, there may be scope for modelling different scenarios using standard assignment computer programs.

3.20 Diversion from other transport modes, such as rail or water, is not so easy to forecast or deal with. Transport of bulk commodities will normally be by the cheapest mode, though this may not be the quickest. However, quality of service, speed and convenience are valued by intending consignors and, for general goods, diversion from other modes should not be estimated solely on the basis of door-to-door transport charges. Similarly, the choice of mode for passenger transport should not be judged purely on the basis of travel charges. The importance attached to quality of service by users has been a major contributory factor to the worldwide decline in rail transport over recent years.

3.21 Diverted traffic is normally forecast to grow at the same rate as traffic on the road or mode from which it diverted.

Generated traffic

3.22 Generated traffic arises either because a journey becomes more attractive because of a cost or time reduction, or because of the increased development that is brought about by a road investment. It is difficult to forecast accurately and can be easily overestimated. It is only likely to be significant in those cases where the road investment brings about large reductions in transport costs. For example, in the case of a small improvement within an already developed highway system, generated traffic will be small and can normally be ignored. Similarly, for projects involving the improvement of short lengths of rural roads and tracks, there will usually be little generated traffic. However, in the case of a new
road allowing access to a hitherto undeveloped area, there could be large reductions in transport costs as a result of changing mode from headloading to motor vehicle transport and, in this case, generated traffic could be the main component of future traffic flow.

3.23 'Producer surplus' models exist for forecasting generated traffic based on the anticipated response of farmers to road investment. However, the predictive accuracy of these models is poor and a major limitation to their use is that they consider only agricultural freight, which typically accounts for less than ten per cent of road traffic. Road traffic in rural areas is usually dominated by personal travel.

3.24 The recommended approach to forecasting generated traffic is to use demand relationships. The price elasticity of demand for transport measures the responsiveness of traffic to a change in transport costs following a road investment. On inter-urban roads, a distinction is normally drawn between passenger and freight traffic and, on roads providing access to rural areas, a further distinction is usually made between agricultural and non-agricultural freight traffic.

3.25 Evidence from several evaluation studies carried out in developing countries give a range of between -0.6 to -2.0 for the price elasticity of demand for transport, with an average of about 1.0. This means that a one per cent decrease in transport costs leads to a one per cent increase in traffic. Calculations should be based on door-to-door travel costs estimated as a result of origin and destination surveys, and not just on that part of the trip incurred on the road under study. Generally, this implies that the reduction in travel cost and increase in traffic will be smaller than measurements on the road alone suggest.

3.26 The available evidence suggests that the elasticity of demand for passenger travel is usually slightly greater than unity. In general, the elasticity of demand for goods is much lower and depends on the proportion of transport costs in the commodity price. However, the ability to market or process some crops is very dependent on the availability of good road access.

UNCERTAINTY OF TRAFFIC ESTIMATES

3.27 Estimates of baseline traffic flows and traffic growth rates will inevitably be subject to degrees of error. Errors in both of these parameters will have a great impact on the estimated economic rate of return of a road project. It is difficult to estimate baseline traffic flow to within about 20 per cent and, typically, an error this size will give an error of a similar order of magnitude in the net present value (see para 15.19-23). Errors in estimation of traffic growth will increase the uncertainty in the project's economic return even further.

3.28 Particularly bearing in mind the large errors that can be associated with both traffic counting and forecasting, it is vital that considerable attention is paid to the quality and duration of the data collection in this area. In addition, scenario analysis should always be carried out to determine the effects of errors in traffic counts and forecasts on the final recommendations. Projects should normally be analysed using both 'optimistic' (high) and 'pessimistic' (low) levels of future traffic in addition to the scenario of the best estimate.
4. COST ESTIMATION

PURPOSE OF THE ESTIMATE

4.1 The objective of the estimate is to provide the most realistic prediction possible of the total cash expenditure and time that will be necessary to complete the project ready for operation. Cost estimates provided for road projects in developing countries in the past have generally proved to be wildly inaccurate, with two main results:

- Tendered contract bids have often proved to be considerably higher than the engineer's feasibility study estimate
- Considerable cost overruns have occurred during projection execution.

4.2 Traditionally, unit pricing techniques have been used for project costing, but these have been shown to be deficient in several important areas. This section recommends the use of analytical techniques and rigorous procedures of risk management to produce realistic estimates of cost at all stages of the project cycle. Expected values of project costs and construction periods should reflect past experience that actual values achieved have normally been far in excess of those estimated originally, particularly those estimates produced at the early stages of project preparation. It is worth expending considerable effort to produce realistic estimates of cost at all stages of the project.

COST ESTIMATING STAGES

4.3 The stages of a project in which estimates of cost and time may be needed are illustrated in Table 4.1. The result required at each stage and the information normally available are set out. It is appreciated that, in particular projects, some stages may be omitted or be indistinguishable from adjacent stages.

| TABLE 4.1 |
| PROJECT STAGES |

<table>
<thead>
<tr>
<th>Stage</th>
<th>Identification</th>
<th>Feasibility</th>
<th>Design</th>
<th>Commitment</th>
<th>Implementation</th>
<th>Operation/evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activities</td>
<td>Identification of project</td>
<td>Appraisal of the identified project, including basic requirements, alternative schemes, and recommendation of preferred scheme. Normally requires a cost-benefit analysis.</td>
<td>Definition of preferred scheme including basic design data, conceptual design, technical specifications, construction appraisal, contract strategies and estimate of final cash cost.</td>
<td>Consideration of submission for funding</td>
<td>Implementation of approved project including - detailed design - issue of tender enquiries - assessment of tenders - placing of contracts - construction - completion - commissioning</td>
<td>Operation of new asset by client. Evaluation of project.</td>
</tr>
<tr>
<td>Result</td>
<td>Inclusion in forward programme</td>
<td>Recommendation of preferred scheme</td>
<td>Project definition report for use in a submission for funding</td>
<td>Funding approved for defined project. Basis for cost control</td>
<td>Basis for assessment of tenders and ongoing monitoring of costs and progress against approved estimate</td>
<td>Historical cost and productivity data bank</td>
</tr>
<tr>
<td>Available information for estimate</td>
<td>No design capacity/size only</td>
<td>Preliminary designs of alternatives</td>
<td>Conceptual design</td>
<td>Conceptual design</td>
<td>Tender documents</td>
<td>Completed contract</td>
</tr>
</tbody>
</table>
4.4 It is important to strive for the ideal of evolving a cost history of the project from start to finish with an estimated cash total at each stage near to the eventual achieved cost. This ideal can only be approached throughout the life of the project if the rising level of definition is balanced by reducing tolerances and contingency allowances which are effectively the measure of uncertainty. Each estimate should be directly comparable with its predecessor in a form suitable for cost monitoring during implementation.

4.5 The sequence of estimates throughout the life of a typical project is given below.

1. Preliminary

The quick estimate needed at the project identification stage, with no design available, and only the barest statement of capacity or size.

2. Feasibility

Estimates or alternative schemes under consideration in the feasibility study stage of the project. The essential property of these estimates is that they are directly comparable with each other and therefore base estimates could suffice so long as the same estimating technique and price base data are used. The differences between alternatives will not necessarily be absolute and the danger of their use for forward budgeting must be avoided.

3. Design

The cost estimate for the selected scheme using the design (usually conceptual) and specifications resulting from the design study and forming part of the project definition report. This estimate would provide the figures for capital cost, cash flow and currency requirements which would then be used in viability calculations for the project and in the submission for donor aid, where appropriate. It must be a cash estimate.

4. Commitment

The proposal estimate as modified and approved for financing, together with the associated modifications to the project definition and/or the programme. This must be a cash estimate, and will provide the basis for the cost control of the project.

5. Pre-tender

A refinement of the approved estimate in the light of further design work done during the tender period and using the information given in the enquiry documents.

This estimate therefore would use the same information as is available to the tendering contractors and should be a good basis for the assessment of bids.

6. Post contract award

A further refinement of the approved estimate in the light of the contract(s) awarded. It includes redistribution of the monies within the approved total to allow more effective cost monitoring of the project to completion.

7. Achieved cost

A record of the actual costs achieved in order to review the cost performance of the project and for project evaluation. It should include a reconciliation of the actual use of contingencies and of the use of tolerance for dealing with major risks.

THE ESTIMATOR

4.6 The estimator must have relevant experience in the type of project envisaged and, wherever possible, in the costs and productivities of construction work at the proposed construction and main supply locations.

4.7 The estimator must have a close working relationship with the project design organisation and will normally be part of that organisation. It is essential that he is able to appreciate the conception and purpose of the project and the intentions of the design, and can easily investigate and clarify any uncertainties with the designers as they arise during the compilation of the estimate. The estimator must also be able to contact the client, the funding agency, visit the site and have access to any local information relevant to the estimate.

4.8 It is highly desirable that the same estimator is used on all the estimates required during the life of the project and is responsible for the subsequent cost monitoring and control. This clearly depends on the continuity achieved in the design organisation. When a new estimator has to be appointed, for whatever reason, or when a check estimate is required from a separate estimator, then it is important to ensure an orderly transfer to him of all relevant information so that the new estimator is able to become accountable for his estimate and the subsequent cost control against it.

4.9 The estimator should be accountable for his estimate and should be involved in the subsequent monitoring of project costs against it. He should be responsible for employing the estimating technique most appropriate for the type of project and the stage of the project. In reaching this decision, he should note the advice on the various techniques, their strengths and weaknesses and their sources of data.
INFORMATION IN THE ESTIMATE

4.10 The information required by the estimator should include the following:

- The latest description of the intended project including all available drawings, specifications, job descriptions and the site location
- The intended/required start and completion dates and latest programmes
- Latest ideas on method of construction
- Sources of project funding with dates of availability
- Latest ideas on contract strategy and availability of resources together with any prescribed restrictions of choice
- Any papers or reports describing performance and problems encountered on similar projects in similar locations
- Any cost/productivity data relating to the project or current construction projects in the host country.

4.11 The essential documents to be submitted by the estimator will be:

- Summary of estimate, together with any further documents necessary for explanation
- A list of documents and drawings used in compiling the estimate
- A programme for the project showing key dates.

In all cases the estimator should also be required to submit:

- A method of construction
- A contract strategy report.

4.12 Each section of the estimate should be compiled in the working currency envisaged for that section at prices current at a stated price base date. The consequent base estimates will be converted to cash estimates by the use of inflation indices, selected by the estimator, in conjunction with the project programme. Where a funding agency is involved, all cash estimates should be converted to the currency used by that agency using a stated exchange rate.

ESTIMATING TECHNIQUES

The techniques available

4.13 The four basic estimating techniques available to meet the project needs outlined above are summarised, together with the data required for their application, in Table 4.2.

4.14 The global and unit rate techniques rely on historical data of various kinds. Comments on this aspect of each technique are given under the respective headings, but the associated dangers are so critical that it is worth making the following general warning points about the use of historical data in estimating.

4.15 Sample size The data must be from a sufficiently large sample of similar work in a similar location and constructed in similar circumstances.

4.16 Base date Cost data needs to be related to a specific historical date, chosen with care. In the case of construction work carried out over a period of time, an appropriate ‘mean’ date has to be chosen e.g. two-thirds through the period.

4.17 Price indices Having selected the relevant price base date, there remains the problem of updating the price to the base date for the estimate. The only practical method is to use an inflation index, but there may not be a sufficiently specific index for the work in question. If there is not, recourse to general indices is usually made. In any event, there is a limited length of time, which probably does not exceed five years, over which such updating has any credibility, particularly in times of high inflation.

4.18 Market effects Overlying the general effect of inflation, is the influence of the ‘Market Place’. This will vary with the type of project being undertaken, with the host country and also with the supplying countries. The state of the world economy at the price base date will require careful consideration before historical data can be credibly applied to a later or future date.

Global

4.19 This term describes the ‘broadest brush’ category of technique which relies on libraries of achieved costs of similar projects related to the overall size or capacity of the asset provided. This technique may also be known as ‘rule of thumb’ or ‘ballpark’ estimating. Examples are:

- cost per metre or km of roads
- cost per square metre of bridge deck areas or per cubic metre of mass concrete.

4.20 The technique relies entirely on historical data and therefore must be used in conjunction with inflation indices and a judgement of the market place influence to allow for the envisaged location and timing of the project.

4.21 The use of this type of rolled up historical data for estimating is beset with dangers, especially inflation, as outlined generally above. The following specific dangers apply.

4.22 Varying definitions of what costs are included

- engineering fees and expenses by consultants/contractors/client, including design, construction supervision, procurement and commissioning
### TABLE 4.2

**ESTIMATING COSTS**

<table>
<thead>
<tr>
<th>Project Data required</th>
<th>Global</th>
<th>Man hours</th>
<th>Unit rate</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Size/capacity</td>
<td>- Size/capacity</td>
<td>- Quantities</td>
<td>- Bill of quantities</td>
<td>- Materials quantities</td>
</tr>
<tr>
<td>- Location</td>
<td>- Location</td>
<td>- Location</td>
<td>- Location</td>
<td>- Method statement</td>
</tr>
<tr>
<td>- Completion date</td>
<td>- Completion date</td>
<td>- Key dates</td>
<td>- Completion date</td>
<td>- Programme</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Simple method statement</td>
<td></td>
<td>- Key dates</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>- Completion date</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Basic estimating data required</th>
<th>Global</th>
<th>Man hours</th>
<th>Unit rate</th>
<th>Operation</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Achieved overall costs of similar projects (adequately defined)</td>
<td>- Achieved overall costs of similar projects (adequately defined)</td>
<td>- Hourly rates</td>
<td>- Historical unit rates for similar work items</td>
<td>- Labour rates and productivities</td>
</tr>
<tr>
<td>- Inflation indices</td>
<td>- Inflation indices</td>
<td>- Hourly rates forecasts</td>
<td>- Inflation indices</td>
<td>- Labour rate forecasts</td>
</tr>
<tr>
<td>- General inflation forecasts</td>
<td>- General inflation forecasts</td>
<td>- Materials costs forecasts</td>
<td>- General inflation forecasts</td>
<td>- Plant capital and operating costs forecast</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

List of potential problems, risks, uncertainties and peculiarities of the project

- final accounts of all contracts including settlements of claims and any other payments
- land acquisition costs
- transport costs of materials
- financing costs
- taxes, duties etc.

**4.23 Varying definitions of measurement of the unit of capacity**

- is a metre/kilometre of road an overall average including pro rata costs of bridges or should these be estimated separately?
- square metre of bridge deck area: including or excluding the cost of abutments?: cubic metre of mass concrete in bridges: height measured from top of ground or top of foundations?

**4.24 Not comparing like with like**

- differing levels of quality such as different pavement thicknesses for different levels of traffic
- different terrain and ground conditions such as roads across flat plains compared with mountainous regions
- different logistics depending on site location
- item prices taken out of total contract prices may be distorted by front end loading eg fob prices for hard currency items.

**4.25 Inflation**

- different cost base dates - it is essential to record the 'mean' base date for the achieved cost and use appropriate indices to adjust to the forecast date required.

**4.26** A scrutiny of all these dangers, especially the effects of inflation, must be made before any reliance can be placed on a collection of data of this type. It follows that the most reliable data banks are those maintained for a specific organisation where there is confidence in the management of the data. The wider the source of the data, the greater is the risk of differences in definition.

**4.27** However, so long as care is taken in the choice of data, the global technique is probably as reliable as an over-hasty estimate assembled from more detailed unit rates drawn from separate unrelated sources and applied to 'guesstimates' of quantities.

**Man hours**

**4.28** This is most suitable for labour based construction and erection work where there exist reliable records of productivity of different trades per man hour. The total man hours estimated for a given operation are then costed at the current labour rates and added to the costs of materials and equipment. The advantages of working in current costs are obtained.

**4.29** The technique is often used without a detailed programme on the assumption that the methods of construction will not vary from project to project. Experience has shown, however, that where they do vary (eg due to the capacity of heavy lifting equipment available), labour productivities and consequently the total
cost can be affected significantly. It is recommended that a
detailed programme is prepared when using this technique.
The prediction of cash flow requires such a programme.

Unit rates

4.30 This technique is based on the traditional bill of
quantity approach to pricing construction work. In its most
detailed form, a bill will be available containing the quantities
of work to be constructed, measured in accordance with an
appropriate method of measurement. The estimator selects
historical rates or prices for each item in the bill using either
information from recent similar contracts or published
information (eg price books for civil engineering), or 'built-up'
rates from his own analysis of the operations, plant and
materials required for the measured item. As the technique
relies on historical data, it is subject to the general dangers
outlined earlier.

4.31 When a detailed bill is not available, quantities will be
required for the main items of work and these will be priced
using 'rolled up' rates which take account of the associated
minor items. Taken to an extreme, the cruder unit rate
estimates come into the area of global estimates as described
above (eg unit rate per metre of road).

4.32 The technique is most appropriate to repetitive work
where the allocation of costs to specific operations is
reasonably well defined and operational risks are easily
manageable. It is less appropriate for civil engineering works
where the method of construction is variable and where the
uncertainties of ground conditions are significant. It is also
likely to be less than successful for engineering projects in
locations where few similar schemes have been completed in
the past. In these cases, success depends much more on the
experience of the estimator and his access to a well
understood data bank of relevant 'rolled up' rates.

4.33 Unit rates quoted by contractors in their tenders are
not necessarily related directly to the items of work they are
pricing. It is common practice for a tenderer to distribute the
monies included in his tender across the items in the bill to
meet objectives such as cash flow and anticipated changes in
volume of work. It is likely that similar weighting is carried
out by all tenderers in an enquiry and therefore it is not easily
detected. It follows that tendered bill unit rates are not
necessarily reliable guides to prices for the work described.

4.34 The technique does not demand an examination of the
programme and method of construction and the estimate is
compiled by the direct application of historical 'prices'. It
therefore does not provide an analysis of the real costs of
work, of the kind that would need to be
carried out by a tendering contractor, for any but the simplest
of jobs. Neither does it encourage consideration of the
particular peculiarities, requirements, constraints and risks
affecting the project.

4.35 There is a real danger that the precision and detail of
the individual rates can generate a misplaced level of
certainty in the figures. It must not be assumed that the
previous work was of the same nature, carried out in identical
conditions and with the same duration. The duration of the
work will have a significant effect on the cost. Many
construction costs are time related, as are the fees of
supervisory staff and all are affected by inflation.

4.36 It is therefore recommended that a programme
embracing mobilisation and construction is prepared. This
should be used to produce a check estimate in simplified
operational form where there is any doubt about the realism of
the unit rates available.

4.37 Nevertheless, unit rate estimating can result in reliable
estimates when practised by experienced estimators with
good, intuitive judgement and the ability to assess the realistic
programme and circumstances of the work.

Operational (resource-cost)

4.38 This is the fundamental estimating technique since the
total cost of the work is compiled from consideration of the
constituent operations or activities revealed by the method
statement and programme, and from the accumulated demand
for resources. The advantages of working in current costs are
obtained because labour, plant and materials are costed at
current rates.

4.39 The most difficult data to obtain are the productivities
of labour and construction plant in the geographical location
of the project and especially in the circumstances of the
specific activity under consideration. Claimed outputs of plant
are obtainable from suppliers, but these need to be reviewed
in the light of actual experience. Labour productivities will
vary from site to site depending on management, organisation,
industrial relations, site conditions, etc and also from country
to country. Productivity information is a significant part of the
'know how' of a contractor and will naturally be jealously
guarded.

4.40 The operational technique is particularly valuable
where there are significant uncertainties and risks. Because
the technique exposes the basic sources of costs, the
sensitivities of the estimate to alternative
assumptions/methods can be investigated and the reasons for
variations in cost appreciated. It also provides a detailed
current cost/time basis for the application of inflation
forecasts and hence the compilation of a project cash flow.
4.41 In particular, the operational technique for estimating holds the best chance of identifying risks of delay as it involves the preparation of a method of construction and a sequential programme including an appreciation of productivities. Sensitivity analyses can be carried out to determine the most vulnerable operations and appropriate allowances included. Action to reduce the effect of risks should be taken where possible.

Suitability of individual techniques

4.42 At the identification stage, the absence of all but the simplest definition of the project means that only the global technique can be applied. However, estimating organisations which regularly use operational techniques state that even their crudest overall data are recorded in such a way that the effects of the more obvious uncertainties can be allowed for at this early stage. Clearly the availability of a reliable, well managed, global cost data bank together with associated 'broad brush' analyses is an essential requirement for any organisation involved in the early identification of projects for inclusion in a forward financial programme.

4.43 The essential activity in the feasibility stage of a project is the consideration of many alternatives. The most important characteristic of the estimating technique employed is, therefore, reliable comparability between the alternative schemes, which may be numerous. The technique must also be usable with only preliminary data for the schemes, as the conceptual design will normally be in its very early stages. The most appropriate techniques would be:

- Global
- Unit rate, using 'rolled up' unit rates for the main items of work.

4.44 However, if the state of information is good enough and time and funds are available, then the operational technique should be considered even at this stage, especially for plant intensive construction, where the key requirement is to identify the major resources and cost them over their period of required availability.

4.45 As soon as sufficient design detail is available at the appraisal stage, the first preference should be to use the operational technique. Exceptions may be labour based projects, where the man hours technique would be appropriate. In cases where, for whatever reason, there is insufficient time, funds or data available for the operational method, the unit rate technique may have to be resorted to.

4.46 When considering estimating techniques, the following factors should be kept firmly in the foreground:

- For all 'one-off' jobs, there is no credible alternative to operational estimating
- Accuracy in all estimates depends heavily on a clear definition of scope, the extent of use of local information and on the definition of uncertainties and potential problems
- There is considerable merit in using an alternative approach to prepare a 'validation' estimate; any differences between the main and validation estimates must be satisfactorily reconciled.
- An estimate submitted at any stage of a project should be subject to review
- It is recommended that all submitted estimates should include a carefully considered programme for the work; if this is omitted, there is a reduced likelihood that the effects of risk, delay and inflation will be properly considered
- It is vital that any modifications to the estimate are backed up by a depth of study not less than the depth of the original estimator's own investigations.

SOURCES OF DATA

Principal sources

4.47 Estimating data are normally obtained from three principal sources:

- Project-specific data collected for a particular project and therefore related to a specific location and time
- Data banks of previous or current projects collected by an individual estimator or estimating organisation
- Published data.

4.48 It is important that the estimator is directly involved in the collection of these data. This involvement should include visits to the project location and any other appropriate sites. It should also include a search for any significant risks, peculiarities or constraints to which the project may be subject and any factors which might affect the method of construction.

Project specific data

4.49 These data are in two forms:

- current costs of basic inputs to the work
- productivity outputs relevant to the type of work, its location and the particular circumstances surrounding it.

4.50 The basic inputs for which the estimator must collect current cost data include:

- hour wage rates
- other labour costs and overheads
- construction plant purchase prices and/or hire rates
- management, supervisory and administrative salary rates
- prices of materials
- prices of services and utilities
- transport, shipping and freight charges
- import duties
- taxes
- insurances
- interest rates.

4.51 Current cost data should be obtained from the sources closest to the initiation of potential price changes. The estimator must have accurate information on the prices and costs ruling in the market place at the base date assumed for the estimate. The sources must be local to the activity in question and will include:

- Government institutions
- Public works departments
- Contracting organisations (both local and experienced offshore)
- Consultants (both local and experienced offshore)
- Aid or development agencies
- Trade missions
- Shipping agencies
- Construction plant and materials manufacturers or importers
- Transport companies, etc.

All these sources are subject to error and the estimator must continually and critically assess their relevance to the specific project.

4.52 Credible productivity data and current cost data of basic inputs are essential information for the compilation of operational and man-hours estimates. They may also be used, with care, to revalidate data for global and unit rate techniques.

4.53 The translation of the base estimate to a cash estimate requires information on inflation and exchange rates which will be normally available from government sources, financial institutions and publications.

### Data banks

4.54 Each estimating organisation can be expected to maintain a record of the costs and times achieved in the projects in which it has been involved. In-house data banks are more reliable than data banks collected by others as the management and interpretation of the information is within the control of the organisation and therefore consistency in its application should be assured. However, the reliability of any data bank depends on:

- The size of the sample available
- The acceptance throughout the organisation of standard methods of measurement and definitions of terms
- The recording of any special factors and circumstances which affected the performance of the recorded project

4.55 Wherever it is necessary to access data banks collected by others, the credibility of the information obtained should be assessed using the same criteria.

4.56 The data recorded should be considered in two basic categories: cost data and productivity data.

4.57 Cost data The majority of these data will be historical, derived from compiled prices, and will include, in increasing order of detail:

- global unit costs related to size of project; eg cost per kilometre of roads
- 'rolled up' unit rates for main items of work
- rates for standard bill of quantity items.

4.58 All types of historical cost data must be related to a date from which the subsequent inflation can be estimated, normally using published indices. In addition, historical data must be assessed against changes in the market place over time. It follows that greater weight should be given to the most recent data available, such as that from current projects.

4.59 These data are for use in the global and unit rate estimating techniques.

4.60 **Productivity data** These data cover outputs and possibly utilisation figures for labour and construction plant. They will be related to specific operations in a known location and in defined circumstances. It is recommended that data are collected in the form of:

- output of work achieved in unit paid time by production units
- utilisation figures for the production units.

4.61 Such data can be collected at several levels, examples of which are given below in increasing order of detail:

a. a histogram of major resources available, coupled with the main quantities of work achieved
b. information of the form ‘x number of machines of y capacity were employed for z weeks to remove V m³ of clay material’, together with utilisation figures for the period
c. the output of work achieved on a specific task by a labour gang or item of equipment, together with overall utilisation figures for the production unit.

4.62 As the level of detail increases, so does the importance of clear definition and consistent use of the terms used for productivity measurement. In particular, the distinction and relation between output and utilisation must be recognised.
4.63 It is recommended that levels (a) and (b) are the most appropriate for the initial collection of productivity data. They are the most readily usable for client estimates, since they allow for downtime over a significant period of time. As data are collected from an increasing number of projects, it should become possible to reconcile differences between them. This will be facilitated if a record is kept of the major factors affecting output and utilisation.

4.64 Such productivity data are unaffected by inflation and therefore can be applied in the operational and man-hours estimating techniques, wherever similar circumstances for the operation are foreseen.

**Published data**

4.65 Wherever required data are not available from in-house resources, or from specific resources related to the project, the estimator may have to resort to published data. Such data must be used with caution and thorough inquiry made into its basis and the circumstances of its achievement. For instance, the unit rates quoted for a common building activity in the United Kingdom in a range of established publications have been found to vary by -50% to +150% from the mean. Other studies have shown that equipment outputs as low as 20% to 30% of the manufacturer's published data might be expected, particularly in developing countries. The estimator is responsible for judging the credibility of any published data he may decide to use.

4.66 Some relevant sources of published data are given below, although there are many other useful publications:

- 'Civil Engineering and Public Works Review' publish a quarterly selection of unit rates for items of civil engineering construction in the UK.

**CONTRACT STRATEGY**

4.67 The choice of construction contract strategy could have a major bearing on the cost and therefore the feasibility of the project. It is therefore appropriate to consider this choice at an early stage.

4.68 The following four types of contract can be used:

- **Lump sum** payment based on a single price for the total work
- **Admeasure** payment for quantities of completed work, valued at tendered rates in a bill of quantities
- **Cost-reimbursable** payment for actual cost (requires 'open book' accounting) plus fee for overheads and profit
- **Target cost** payment based on actual cost plus fee plus incentive.

Choice of one or other type will be largely dictated by the perception of financial risk.

4.69 **Price based contracts** In lump sum and admeasure contracts, the contractor bears much of the risk and has to price his tender accordingly. When, as may frequently be the case in developing countries, the risks are high, this results in extremely high prices or in offshore contractors being reluctant to tender at all.

4.70 **Cost based contracts** In a cost-reimbursable contract, the client and donor will bear the main risks, whereas the intention of a target cost contract is to price the work excluding risk, the cost of which is borne by the client. Target cost contracts introduce an incentive for the contractor to work efficiently, aligning his objectives with that of the client to achieve the construction cost-effectively. Flexibility is desirable under the uncertain conditions found in many developing countries. Where the contract is managed with 'open book' accounting, this provides the opportunity, in theory, for client, consultant and contractor to discuss design modifications when these may be desirable. However, such methods of contract are very demanding of senior site staff for both consultant and contractor.

4.71 Where there is an active construction industry, tendering mobilises competition to good advantage. However, to be truly successful, the tender procedure also depends on there being a precise, comprehensive specification and a thorough design. Where the above conditions are not met, it is likely that negotiation of a cost-plus form of contract is more likely to be practical. A mixed approach is often adopted with initial tendering followed by negotiation on some aspects of the contract.

4.72 There are strong developmental arguments for using local construction capacity where this is available. Not only will this capacity usually be much less costly to mobilise, but the experience gained will strengthen the industry and help the country to be self-sufficient. There will also often be multiplier effects on other sectors of the economy. Some donors treat local contractors preferentially. For instance, the World Bank will consider local bids acceptable even if they are 15 per cent more expensive than those from offshore contractors.
THE DESIGN PROCESS AND PROJECT COSTS

4.73 For anything other than 'global' cost estimating, it will be necessary to base costs on a design which has been carried out to an appropriate level of detail. The road design process consists of four distinct phases: route location, the structural design of the pavement, the geometric design, and the design of structures including bridges, culverts and earth retaining works.

4.74 Route location applies only to new roads and is discussed in Section 5. It is that stage of the design process where the general positioning of the route or its 'corridor' is determined. The corridor should be chosen to meet the objectives of the project which normally implies a balance between maintaining user benefits by providing the shortest route consistent with engineering constraints of topography, ground conditions, drainage, structures and the location of road building materials.

4.75 The structural design of the road is the process in which the various layers of the pavement are selected so that they are capable of supporting the traffic for as long as required. The principal elements in this process are the choice of materials and their thickness for each pavement layer. This is dealt with in Section 6, where the basic principles of structural design are described and key features pertinent to the appraisal process are highlighted.

4.76 Section 7 covers the topic of geometric design which is the process whereby the detailed layout of the road in the terrain is designed to meet the needs of the road user. The principal elements of this process are the selection of suitable horizontal and vertical alignments and road widths.

4.77 Finally, the design of bridges and structures is concerned with a variety of topics, which include structures which allow the road to cross or be crossed by rivers, water courses, railways and other roads: it is concerned with earth retaining systems, drainage systems and special provisions for erosion control. These issues are discussed in Section 8.

4.78 In general, the four elements of design can be considered separately although, in some areas, there are overlaps and particular subjects need to be considered under more than one heading. For example, the width of road shoulders has implications for both geometric design and structural design. Other important examples are the consideration of road maintenance and the provision of adequate drainage which affect all three elements of design. Where overlap exists, the requirements can sometimes conflict and compromises are necessary. Topics of this kind are specifically mentioned in the text.

4.79 The relative contribution that each aspect of design makes to the total costs of the project depends mainly on the various design standards adopted and on the type of terrain through which the road passes. To provide a particular geometric standard in hilly terrain requires the construction of cuts and fills involving the movement of earth or rock, much of which would be unnecessary in flat terrain. On the other hand, the quantity of high quality road making material required to provide the necessary structural strength in the pavement will not usually depend on the terrain. The choice of design standards should be based on an economic analysis, but can only be made within practical limits of design, construction and consistency. It is an iterative process and it is not possible to provide general guidelines or rules of thumb on the relative costs associated with each aspect of design. Each case will need to be assessed on its merits with the objective of optimising the relationship between costs and benefits.

4.80 It is expected that road engineers will already have detailed knowledge of the methods used to design and cost projects at the various stages of their development and implementation. The following four sections on geotechnics, pavement design, geometric design, and drainage and structures are therefore written primarily for transport planners, economists and administrators, and others who may not have experience of practical road engineering.
5 GEOTECHNICS

OBJECT OF GEOTECHNICAL SURVEYS

5.1 Geotechnical surveys are required principally for projects for new roads, although they still have some application for projects concerned with existing roads. They are usually carried out at three stages in the project preparation process: identification (also called 'reconnaissance' by geotechnical engineers), feasibility, and design. As the project proceeds through these stages, geotechnical information needs to be collected at greater levels of detail.

5.2 The amount of geotechnical work that needs to be carried out will depend on whether the road is new and the alignment has to be selected, or whether the project is only concerned with upgrading or reconstruction of an existing road. In projects for new roads, the geotechnical surveys are usually carried out to select and compare alternative routes for the road and general 'corridor' studies will be required. Information on the supporting ground for the road, earthworks, bridge sites, drainage and materials (including water) for construction are some of the important features which have to be considered. For upgrading and reconstruction projects, geotechnical information is needed to determine the choice and properties of materials that are available for use in pavement construction. Where existing roads have been damaged or are threatened by ground instability, geotechnical information is needed to effect the necessary repairs or provide suitable protection.

5.3 For all projects, information from geotechnical surveys provides the basis for much of the costing of the engineering works. The level of information should be appropriate to the level of accuracy required to estimate costs at the different project stages. It is important that any factors which could have a major impact on engineering costs during or after construction should be identified at an early stage. The actual costs of geotechnical surveys varies depending on the standard of road to be built, the complexity of the conditions encountered, and many other factors, but sums between 0.5 and 3 per cent of the total project cost are typical.

INFORMATION NEEDED

Route location

5.4 Route location consists of selecting the best compromise between 'demand' factors and 'terrain' factors. Demand factors determine the areas to be served and the road standard, and terrain factors influence the engineering cost. The principal terrain factors are:

- ground conditions as they influence the strength of the soil beneath the road (the subgrade) or present instability problems or natural hazards
- materials used in construction, including quarried rock
- earthworks (the volume and stability of cuttings and embankments)
- surface and sub-surface drainage, including erosion
- the need for structures.

5.5 The emphasis placed on these different factors will vary with the stage of the survey. The choice of route is normally associated with the identification and feasibility stages. One of the major objectives of these stages is to identify critical factors which could have a major impact on engineering costs and therefore deserve extra study at the early stages of the project. Changes to the design that must be made during the course of a construction contract often involve considerable disruption, delay and expense, and are normally the result of insufficient preliminary survey work.

Subgrade strength

5.6 Predictions have to be made about the strength of the subgrade after construction. Areas of very weak soil such as swamps should be identified at early stages of survey and avoided wherever possible. Having rejected the obvious areas, the next decision is to assess the relative subgrade strengths of alternative alignments and their implication on the pavement design. Details of the pavement design process are described in Section 6.

5.7 For route alignment, a method of construction should be suggested that provides an appropriate structure for the design life of the project in relation to subgrade strength and available construction materials. At the early stages of survey, any factors which might have a major influence on route alignment should be identified to guide the more detailed design surveys that will be carried out later. In some areas, construction materials may be abundant, but there may be considerable variation in the strength of the soil. In other areas, soil conditions may be fairly uniform, but known sources of materials are scarce, and so the emphasis should be on finding alternative sources to minimise the cost of haulage.

5.8 The subgrade strength depends on the soil type and moisture condition and its importance depends to some extent on the standard of the road. For a low volume road, it may be economic to lengthen the route to avoid difficult soils and thus to minimise construction costs. On a heavily trafficked road, where the shortest route will produce the highest user benefits, it may be economic to import material to the road line to blanket areas of weak soil. The surveys at the feasibility stage should identify the alternatives and the design stage should quantify the costs. The types of feature that need to be investigated
are areas of unstable Soil, such as expansive black clays, or areas liable to flooding where the road embankment may need to be raised. Problems such as these may give rise to maintenance problems if they are not catered for at the design stage. Other problems that need to be identified are erodible soils which may require expensive anti-scout structures, spring lines and perched water tables that may cause local recurrent failures, or features associated with particular terrain, such as the need for protection against sand dunes covering the road, or corrosive water which attacks concrete.

Materials

5.9 Having decided the strength of the foundation, the pavement design process defines the thickness and properties of the separate layers. Before this can be done, information must be obtained on the nature and engineering properties of the road building materials available in the area. Previous experience in the area may assist with this, but often a survey will be necessary. The materials required include rocks suitable for crushing and natural aggregates such as gravels and sands. The specifications for these materials depend on the type of road being constructed and are discussed more fully in Section 6. The purpose of the geotechnical survey is to identify sources of the materials within an economic haulage distance and to ensure that they exist in sufficient quantity and are of sufficient quality for the purposes intended. This process often requires an extensive programme of site and laboratory testing, especially if materials are of marginal quality or occur in small quantities. However, it is important that the answers to these two questions should be very reliable before the contract for the road construction is awarded. Two of the most common reasons for construction costs to escalate is that, once construction has started and material sources fully explored, the material is found to be deficient in quality or quantity leading to expensive delays whilst new sources are investigated, or the road is redesigned to take account of the actual materials available. It is not possible to give general guidelines on the level of detail required for such surveys and specialist advice should be obtained.

5.10 A reconnaissance survey at the project identification stage should indicate the main types of construction materials and estimate if they are likely to be in short supply. A feasibility study can then identify the sources of material with estimates of quantities. It should be borne in mind that different parts of the road structure require materials of different quality. Sufficient testing must be carried out to identify substandard or variable materials. If problems do exist, then extra effort will be needed in the final design when all sources should be identified and proved by digging pits to the full depth of the gravel layer or drilling rock to the full depth of the proposed working. The siting and frequency of such excavations will be decided by an engineer according to site conditions and existing knowledge of material variability. Where good construction materials are scarce, soil stabilisation may sometimes be used to improve the quality of local materials.

5.11 Soils and aggregates are the most important materials in construction, but water can also be vital. Many construction jobs have been delayed because of an underestimate of the supply of water conveniently available for construction. Construction can be phased to make best use of natural moisture in the materials. In arid areas near the coast, sea water can sometimes be used for compaction, but care must be taken to ensure that levels of salt contamination do not rise above acceptable limits. Dry compaction methods should always be considered in arid areas.

5.12 Regravelling of gravel roads is normally needed about every five to eight years to replace material lost from the surface. The effect of this could be to exhaust sources of material or to increase haul distances if the better materials are used first. Good quality material may be required at a later stage in the road's life if the standard is improved to meet increased traffic demands. Increased costs for regravelling may result in it becoming economic to pave roads at lower traffic levels than would otherwise be the case.

Earthworks

5.13 Earthworks always form a significant part in the cost of road construction, as even a simple road in flat terrain involves the excavation of ditches, and the formation of a small embankment. When the terrain is not flat, cuttings are required, and their design can greatly affect the cost of earthworks. In tropical areas, shallow cuttings of less than about 3 metres with a steep slope are normally preferred to minimise earthworks and to reduce the area exposed to erosion by rain water. In certain areas, such cuttings are unstable and will need to be set back to a flatter slope. The increase in land acquisition costs is not normally a significant factor.

5.14 In areas of steeper terrain, the expense of earthworks increases and the design engineer has to select the best combination of vertical alignment, horizontal alignment and earthworks costs. Shortening of the road and increasing earthworks can be offset by shorter construction time, and taken in conjunction with reduced operating costs, this can sometimes provide a better solution. The transport planner should be able to provide the engineer with an estimate of the likely benefits in road user cost savings of shortening the road on a per metre basis (Sections 10, 12 and 13) to help guide the design. However, increased earthworks can lead to increased risk of landsliding and the higher standard of road leads not only to a higher cost of repairing such damage, but also a higher cost of delay to traffic if the road is cut completely.

5.15 In deep cuttings, it is likely that rock will be encountered, although in tropical environments a much deeper zone of weathered material may occur in comparison
with temperate climates. Information from the desk study or site investigation at identification or feasibility stage should indicate the general geology of the area and the type of rock that will be present. Rock usually requires blasting and this will be more costly than soil excavation. On the other hand, rock can be cut to steeper slopes than soil, thus reducing the volume of excavation needed and often providing aggregate for use in building the road. When exposed in steep cuttings, metamorphic and sedimentary rocks, are often more prone to instability and failure along joint planes and faults than igneous rocks. The presence of discontinuities or faults should be noted at an early stage as this could be a key feature affecting route alignment. Certain types of rocks may be very hard and apparently durable when first opened up in a cutting but, after being exposed to tropical weathering for a few months, become extremely soft and unstable. The angle of this cut face may need to be reduced to take account of this. Fine-grained sedimentary rocks are very prone to rapid weathering, as can be igneous and metamorphic rocks. Local enquiry and observation of existing road cuttings should be made to identify such rocks.

5.16 An important factor in any earthworks operation, especially in steep terrain or areas where there is evidence of former landslide activity, is that the construction work could upset a delicate equilibrium in terms of ground stability. Rainfall can trigger landslips either by draining into the slope or by causing erosion and it may be necessary at the design stage to take preventative measures to avoid the occurrence of failures. The heterogeneous nature of soils and rocks, as well as a shortage of time available to monitor slope conditions, often makes it difficult to apply theoretical design measures for cut slopes and full advantage should be taken of the observed performance of other slopes in similar conditions in the region.

**Drainage**

5.17 Drainage is vital to the successful performance of a road. The choice of a ridge route will minimise the number of culverts needed and also lead to better foundation conditions. Allied with drainage is the problem of erosion and, depending on soil type, climate and site conditions, anti-erosion measures may be needed on embankment faces, cuttings, culverts, side drains and stream crossings. Some of these may only be temporary measures after construction until vegetation grows and establishes stability, or it may be necessary to install permanent solutions to long term problems.

5.18 A particular hazard in steep terrain is the indiscriminate dumping of spoil on the hillslope below the road or into a convenient stream. The spoil can erode, or may wet up and slide in a mass. Material is carried downslope and may cause scour of watercourses or bury stable vegetated or agricultural land. Material choking stream beds causes the stream to meander from side to side, undercutting the banks and creating further instability.

**Structures**

5.19 One of the first factors to consider in route alignment is the need for major structures such as bridges or large culverts. The very high cost of such structures is reduced by siting the structure at the most favourable point in the terrain. The cost saving thereby produced may be sufficient to justify shifting the alignment away from the most desirable course for many kilometers on each side of the structure. These 'nodal' points on the route will be located at the identification stage and may affect costings of the whole project.

5.20 A road diverts considerable quantities of water from one part of a slope to another. Care must be taken not to overload a stream with excess water. Stream courses in mountainous areas are often only marginally stable, and the addition of water, poured in from a road drainage system during a tropical thunderstorm, can cause grave erosion from which the watercourse may never recover.

**SOURCES OF INFORMATION**

5.21 Much of the geotechnical information needed will be obtained from field studies and site investigations, but existing information may be available locally in the country concerned or from international documentation centres. Information that should be sought includes topography, geology, soils, hydrology, vegetation, land-use, earthquake activity and climate in the region. Any constraints which may affect the engineering appraisal such as political, economic, environmental or timing restrictions should also be noted. More specific engineering information may be available from other reports on road projects in similar areas.

5.22 Often in developing countries, there is a scarcity of published information and the desk study should reveal where deficiencies occur. Information from maps can be considerably enhanced by the use of aerial photography and satellite imagery. The use of such remote sensing techniques should never be overlooked in road planning studies as they provide the facility to study the project from a broad to a detailed level. They may also show developments that have taken place after the publication of a map. The main benefit from using aerial photographs and satellite imagery is that unmapped and remote areas can be studied in detail and considerable savings in time in the field can be made. Expensive oversights of advantageous terrain conditions or unsuspected natural hazards can be avoided. A skilled interpreter with geological training should be a member of the survey team, but engineers without formal training in photo interpretation are still able to obtain valuable information.

5.23 Landsat satellite imagery is available for the whole world apart from persistently cloudy regions. The images,
in colour, depict terrain and drainage systems over very large areas (185 x 185 km per image). They are commonly studied at scales of 1:100 000 to 1:1 000 000 and, as such, are most useful at desk study and project identification stages of investigation. They also show changes in surface features dating back to 1972, by repeated coverage of the same area. Change in major river flow patterns, retreating coastlines, or deforestation can be observed in this way. Since early 1986, the French satellite 'SPOT' has also been collecting images of the earth's surface. These are similar to Landsat images but have the advantage of higher resolution, nominally 25 m in colour or 10 m in black and white, depending on availability.

5.24 Aerial photographs are generally flown at scales ranging from 1:20 000 to 1:60 000, in black and white. Their chief advantage is in giving a highly detailed view of the terrain. When studied with the aid of a stereoscope, the ground surface is seen in full three-dimensional relief. Even sub-surface features, such as tilted or folded rock strata, solution hollows in limestone, or buried gravel deposits, can be interpreted from aerial photographs by the effect they have on surface features.

5.25 As an extension of air photo and satellite image interpretation, terrain evaluation methods have been developed which enable all types of engineering information to be incorporated into a systematic mapping scheme describing the terrain and its attributes (TRRL 1978).

**STEPS IN THE SURVEY PROCESS**

5.26 The steps required to provide geotechnical information at each stage of a road project are described in Appendix 2 of 'Terrain evaluation for highway engineering and transport planning' (TRRL 1978). The way that these steps can be augmented by the use of widely-available remote sensing techniques is summarised in Table 9.2 of 'Remote sensing for highway engineering projects in developing countries' (Lawrance and Beaven 1985). The steps in the survey process are summarised in the following sub-sections.

**Project identification**

5.27 The purpose of this reconnaissance stage of the survey process is to identify possible alternative routes in terms of the 'corridors' within which they lie.

5.28 Possible routes should be examined on maps, satellite images and air photo mosaics, where available, and a broad terrain classification should be made for collation of the regional information, possibly on a data storage system. Visits should be made to site to check interpretations and findings should be summarised to assist in planning the next stage.

5.29 Air photo mosaics at a scale of approximately 1:100 000 and Landsat images at 1:500 000-1:250 000 should be used to interpret boundaries between terrain types, where changes in topography, geology, drainage pattern or vegetation (land use) occur. A change in any of these will give rise to different engineering conditions, which could affect the design of the road. Such items as the following should be considered:

- changing course of major rivers
- catchment areas of major river systems
- extent of flooding of low-lying areas
- possible sources of water for construction
- possible sources of construction materials
- pattern of regional instability
- extent of erosion
- spread of deforestation
- assessment of land acquisition/site clearance problems
- location of all possible bridge sites.

**Feasibility**

5.30 At this stage, the corridors are appraised to select the best route. This should be carried out mainly using air photos for all detailed interpretations, ideally at a scale of 1:20 000-1:60 000, as available. These can be supplemented by colour information from Landsat images.

5.31 Detailed interpretations should be made of conditions on all routes and, if necessary, a more detailed terrain classification of the area should be made. The following items should be investigated:

- foundation conditions
- catchment areas and the location of culverts
- location of spoil areas and possible borrow areas
- possible sources of construction materials
- identification of most favourable bridge sites
- possible major hazard areas such as poorly drained soils, spring lines, unstable areas, erosion in river courses.

5.32 Site investigations should be carried out of alternative routes, guided by the terrain evaluation. These should note key physical and geotechnical features. Selected laboratory and field testing should also be carried out, again guided by the terrain evaluation. If more detailed information is required, specialised air photography may need to be commissioned at a scale appropriate to the size of the task and degree of ground complexity (approximately 1:10 000-1:30 000).

5.33 Finally, cost comparisons should be made of alternative alignments to assist in the recommendation of the best route.

**Design for project implementation**

5.34 The final stage of the geotechnical survey process is to make detailed field studies of the selected route to enable a design to be carried out to engineering standards.
5.35 A further land classification should be carried out at a more detailed level on the selected route corridor, commissioning special photography, if required. Detailed air photo interpretation should be continued in support of all field activities to help plan a comprehensive site investigation of the selected route, which should be carried out with a full sampling and testing programme. This should examine:

- construction materials
- subgrade conditions
- cuttings and embankments
- areas of instability
- erosion and soft ground
- requirements for frequency and size of culverts
- bridge sites

5.36 The geotechnical survey phase of the appraisal process concludes by preparing detailed designs and cost estimates.

COSTS AND ACCURACIES OF GEOTECHNICAL SURVEYS

5.37 Table 5.1 indicates the approximate amount of effort in man-days required to carry out geotechnical investigations at each of the principal stages of road survey. Because of the extreme variety of conditions under which geotechnical surveys are carried out, it is impossible to specify the costs of such surveys. The table represents a range of 'typical' conditions, which have been simplified into two types of project: one covering an area such as might be demarcated for a network of rural access roads, and one linear which is more appropriate for surveys along a single road alignment. The table also shows the difference between effort required in easy terrain and in difficult terrain as defined below.

5.38 Time is allocated both to field work, and to interpretation of aerial photographs and satellite images in advance of field work. Time spent on interpretation is considered essential for economic use of field time.

The following assumptions are made about the time allocations in the table:

- Time taken to collect together maps and photographs, including photographic processing and computer processing, is excluded.
- Remote sensing imagery is used at all stages. Thus, time spent on interpreting images at the second and third stages is assumed to be minimal because of experience during the earlier stages of the surveys.

Definitions

The following terms are defined to represent the extremes of a range, with continuous intergrading between. Allowance must be made for combinations of factors when interpreting the table.

### TABLE 5.1

Approximate man-days of effort required to accomplish a geotechnical survey

<table>
<thead>
<tr>
<th>Stage of survey</th>
<th>Easy terrain</th>
<th>Difficult terrain</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area (per 100 km²)</td>
<td>1 interpretation</td>
<td>1 interpretation</td>
</tr>
<tr>
<td>Line (per 25 km)</td>
<td>1 interpretation</td>
<td>1 interpretation</td>
</tr>
<tr>
<td>Feasibility study</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>1 interpretation</td>
<td>1 interpretation</td>
</tr>
<tr>
<td>Line</td>
<td>1 interpretation</td>
<td>1 interpretation</td>
</tr>
<tr>
<td>Design</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Area</td>
<td>2 interpretation</td>
<td>3 interpretation</td>
</tr>
<tr>
<td>Line</td>
<td>2 interpretation</td>
<td>4 interpretation</td>
</tr>
</tbody>
</table>

- **Terrain**
  - EASY. Easy to moderate access by vehicle; good visibility on the ground; flat to rolling topography; simple geology and geomorphology (arrangement of surface land forms such as slopes and drainage patterns).
  - DIFFICULT. Difficult or no access by car; poor visibility on the ground; hilly topography; complex geology and geomorphology. In mountainous areas, or areas covered by jungle, conditions tend to be extremely arduous and field work is very slow. Remote sensing is of value only at a coarse level in jungle terrain.

- **Project type**
  - AREA. A unit area of 100 km² has been taken. The time taken to cover larger areas increases in linear proportion.
  - LINE. A unit length of 25 km has been taken. 'Line' applies to projects such as single road projects that are essentially linear in nature. The principles of survey, as far as a geotechnical engineer is concerned, do not differ from area surveys, but a linear unit of measurement is more appropriate. Note that an effective geotechnical survey is never restricted to the centreline of the road, but always includes excursions of possibly several kilometres into the country on either side to check on sources of construction material, alternative alignments, off-road hazards etc.
6 PAVEMENT DESIGN

STRUCTURAL CLASSIFICATION

6.1 The structural or pavement design of the road is the process in which the various layers of the pavement are selected so that they are capable of supporting the traffic for as long as required. The principal elements in this process are the choice of materials and their thickness for each pavement layer.

For structural design, roads can be classified as follows:

- Unimproved earth roads and tracks
- Gravel surfaced roads
- Roads incorporating pavement quality concrete or 'rigid' pavements
- Roads incorporating bituminous materials or 'flexible' pavements.

6.2 The aims in designing a pavement are to protect the natural ground, or subgrade, from the high and concentrated load stresses which would be applied to the subgrade by the wheels of vehicles, whilst at the same time ensuring that the pavement layers are strong enough to support the traffic loads. Since the imposed load stresses are higher nearer to the wheel and the road surface, the traditional type of construction consists of various layers of material with the weakest layer at the bottom and the strongest layer at the top.

6.3 There are various ways of describing the pavement layers and this has often led to confusion. Figure 6.1 illustrates the most common method. The most important layers are the surface layers and the road base since these need to be the strongest.

EARTH ROADS

6.4 Earth roads have no added pavement and layers are therefore not structurally designed. Their performance depends very strongly on their cross-sectional shape (see Section 7), material properties, location in the terrain (see Section 5) and the drainage facilities incorporated in the design (see Section 8). With very low traffic roads, the most important consideration is whether or not the road is passable, since very high costs may be associated with the road being closed. Consideration should be given to the provision of simple drainage structures and local graveling and improvements to provide all weather access where appropriate. The engineering aspects of earth roads will not be discussed further.

GRAVEL ROADS

6.5 Roads may be surfaced with gravel to provide traction for vehicles in wet weather at relatively low cost. Surfacing with gravel also retards the increase in deformation of the surface, but regular reshaping is needed as part of recurrent maintenance activities. Even when badly deformed, gravel roads can normally carry traffic successfully as drivers try to avoid deformed areas by choosing different wheelpaths, but vehicle operating costs will be increased considerably as gravel roads deteriorate. Gravel roads normally have properly designed and built drainage structures compared with earth roads and provide all-weather instead of seasonal access.

6.6 Gravel roads are rarely designed in the structural sense. Within the normal range of conditions, differences in performance which can be attributed to gravel thickness are not pronounced except on very weak subgrades. Usually a fixed thickness of gravel (150 mm or
200 mm) is used irrespective of climate, subgrade strength or traffic loading conditions, and this is replenished periodically as it is worn away. Rates of gravel loss are of the order of 20-30 mm thickness a year per 100 vehicles per day, but this will vary depending on local materials and conditions. The gravel itself should be selected on the basis of its material properties and its expected behaviour under the climatic conditions prevailing. Recommended specifications are given in Tables 3 and 4 of Overseas Road Note 2 (TRRL Overseas Unit 1985).

6.7 If traffic volumes are high, total vehicle operating costs will rise rapidly as the road deteriorates and rates of gravel loss will be correspondingly large. Under these circumstances, there may be some justification for increasing the gravel thickness, but it is often cheaper to provide a surface dressed road. Considerable information has been gained in recent years on the performance of gravel roads under a variety of conditions. It is now possible to estimate the total transport costs associated with a gravel road including vehicle operating costs, maintenance costs and regraveling costs under a variety of traffic, climatic and maintenance conditions using road investment models. Their use is described in Section 10. The traffic level at which a bituminous surface is justified will depend on many factors including the expected rate of gravel loss and the cost of hauling gravel, and can range from 50-800 vehicles per day. It is not possible to give general guidelines for this and each case must be studied individually on its merits using an investment model.

6.8 As with earth roads, the performance of gravel roads depends very strongly on their positioning in the terrain (see Section 5), their cross-sectional shape (see Section 7) and the adequacy of drainage facilities (see Section 8). The engineering aspects of gravel roads will not be discussed further.

**CHOICE OF PAVED ROAD CONSTRUCTION TYPE**

6.9 Where a paved road is necessary, there are two basic types of construction that can be used. In the past, flexible pavements with an asphalt surfacing have normally been used in most tropical countries because they have provided a more economic solution. However, with variations in oil prices affecting the cost of using bitumen, the cost of using rigid pavements constructed with portland cement concrete has become more competitive, particularly in those countries having their own cement manufacturing capability.

6.10 The choice between flexible and rigid pavements should be made on considerations of the likely cost of both construction and maintenance, the pavement life and effect on road user costs.

**RIGID PAVEMENTS**

6.11 Feasibility studies for paved roads should normally consider the potential for building in concrete. Particularly in those countries which manufacture their own cement, but import bitumen, the initial costs of construction are likely to be comparable. Even where the initial cost of construction is higher than for a comparable bituminous surfaced road, the reduced maintenance requirement over the design life may make this type of construction more economic in the long term. This should be considered particularly in those countries experiencing difficulties maintaining their road network to an economic standard (see para 2.22-26). It is also probable that the riding quality of concrete, although initially rougher than on bituminous roads, will deteriorate much less, so that future vehicle operating costs will not increase so rapidly.

6.12 A further advantage of concrete roads is that they can be built by labour based methods using skills and technology learned in the building trade. The introduction of concrete technology in the road building sector can also do much to develop local skills and offers scope for the fostering of local contracting industries.

6.13 However, the benefits associated with concrete roads will only be obtained if they are well constructed; if not, remedial works are much more costly than for bituminous roads and vehicle operating costs on a very deteriorated concrete road are likely to be high. Attempts should be made to quantify these longer term effects when comparing the lifetime costs of bituminous and concrete roads. These issues are discussed in Sections 10 and 11.

6.14 No design methods have been produced specifically for concrete roads in developing countries in the tropics. Until such time as a specific method is available, designs should be based on either the ASSHTO (1974), CPCA (1984) or the TRRL (Mayhew and Harding 1987) methods.

**FLEXIBLE PAVEMENT MATERIALS**

**Surfacings**

6.15 The essential requirement of all bituminous surfacings is that they should be waterproof. They should also provide a skid resistant surface. Surfacings do not necessarily have to perform a load spreading function because this can often be done by the underlying structural layers.

6.16 The surfacing is the most expensive of all the layers and therefore needs to be kept as thin as possible commensurate with the stresses that it can withstand and the tolerances on thickness which can be achieved with
the construction methods and materials chosen. The following list of surfacing materials is not complete, but it includes the principal types that are met in practice.

6.17 **Surface treatments.** The simplest type of surfacing is a surface dressing consisting of a thin layer of bitumen into which single sized stone chippings are rolled. This type of surfacing is very flexible and provides a reasonably waterproof seal. Depending on traffic and climatic conditions a single, double or even triple surface dressing may be used. A surface dressing is too thin to provide any structural strength. Other similar surfacings whose main function is to waterproof the road surface are sand seals (sand plus bitumen), slurry seals (graded fine aggregate or sand plus bitumen emulsion) and a combination of slurry seal and surface dressing, often called a cape seal.

6.18 **Structural surfacings.** There are many types of surfacings which provide substantial structural strength to a pavement. These consist of precisely defined mixtures of bitumen, coarse and fine aggregate, sand and fine material called filler. In order to make them properly, it is usually necessary to mix the constituents in specialised plant and hence the materials are generally known as premix or plant mix. However, in some countries, lower quality materials are often made by mixing on the road itself or by the side of the road, usually by a more labour intensive method. Such methods can be useful for producing patching material, but are rarely practicable for surfacing or resurfacing. The principal types of premixed structural surfacings are as follows:

- **Hot rolled asphalt (HRA).** This type of mix has been used extensively in the United Kingdom. It derives its strength from the properties of a mortar of bitumen, sand and filler. Larger stones are added to the mix mainly to act as an extender. HBA is easier to make successfully than some of the other mixes but has not been used extensively in hot countries because of fears that under hot conditions and heavy traffic it will deform more easily than other mixes. However the deformation properties of HRA can be controlled in the mix design process and can be verified by simple laboratory tests at elevated temperatures. Provided that suitable sand is available, the use of HlT should be encouraged since it is resistant to cracking and therefore provides a more resilient water proof surfacing than other mix types.

- **Asphaltic concrete (AC).** Asphaltic concrete is the most common surfacing material in use on heavily trafficked roads in developing countries. Asphaltic concrete was developed in the USA and derives much of its strength from the interlocking of angular particles within the particle/bitumen matrix. All sizes of particle need to be present in precisely the right proportions to ensure a satisfactory mix. It is more difficult to make than HRA because the proportions of each sized particle need to be more accurately controlled. It can be made very stiff or strong to reduce the risk of deformation occurring at high temperatures, but it is intrinsically rather brittle and thus liable to crack under heavy traffic loads, allowing water to penetrate the road base.

- **Bitumen macadams.** These mixes are similar to AC, deriving much of their strength from the interlocking of angular particles. Dense bitumen macadam (DBM) is suitable as a wearing course. Open textured mixes are suitable as the base course of a surfacing or as road bases (see Figure 6.1) and in other situations where their permeability is of no consequence, such as regulating courses under strengthening overlays on roads which have deformed excessively.

6.19 **Mix-in-place surfacings.** In some countries, mix-in-place and hand mixed surfacings are constructed for use both on trunk roads as well as more minor roads. The results are not easy to control and the methods are often wasteful in their use of bitumen. Their use is not recommended.

### Road bases

6.20 The road base is generally the main structural element of a road. Base materials are conveniently divided into three categories.

- **Unbound bases.** Unbound materials are the most common in developing countries. The materials should be a mechanically stable mixture of angular particles of different sizes ranging from about 50 mm in diameter down to dust. Usually rock or gravel needs to be crushed for this purpose although some natural gravels are suitable. It is important that the fine particles should not cause too much weakening of the base when wet, hence they should have little or no clay present. The most common type of unbound base is graded crushed stone, or 'wet mix', but other types, such as dry bound macadam and water bound macadam which, despite their names, are two types of unbound aggregate base are frequently encountered.

- **Cement or lime stabilised bases.** If unbound material of suitable strength is not available, use can be made of material which is inadequate in some way. To do this, the material is strengthened and improved by the addition of cement or lime. Not all materials are suitable for lime stabilisation as clay minerals are necessary in the soil for the stabilisation reaction to occur. For both cement and lime stabilisation to be effective, the material to be stabilised should not be too uniform in size and should be free from organic matter.
• Bitumen stabilised bases. Bitumen stabilisation is rarely used for lower grade aggregates in road bases because other alternatives are usually cheaper and more reliable. If bitumen is used in bases at all, it is usually because a high strength, high quality pavement is justified and, in such a situation, good quality aggregates will be used to make a premix. One exception to this general rule occurs in areas where there are no aggregates available. Here bitumen stabilised sand is an alternative which can be used successfully for moderate traffic.

Sub-bases and other pavement layers

6.21 The quality of material used for sub-base does not need to be as high as for bases. Usually the material is required to meet few selection criteria. The most common materials for use as sub-bases are naturally occurring (unmodified) gravels and gravel-sand-clay mixtures. Sometimes cement or lime stabilised soils are used. Selected fill material and 'capping' layers are of still lower quality and are usually selected on the basis of a simple strength test to ensure a platform of minimum guaranteed strength on which to build the pavement proper.

Use of marginal materials

6.22 Specifications for pavement materials used in developing countries have normally been copied from those used in the more industrialised countries. These original specifications have usually been evolved to overcome different climatic and loading conditions to those found in developing countries, such as the need to reduce frost damage. Local experience sometimes suggests that standard specifications can be relaxed to make use of materials that are marginal in quality, but are abundant and relatively cheap to use. The need to do this will be dictated by a lack of conventional materials or a need to build a lower cost road.

6.23 Consulting engineers are often reluctant to allow the use of marginal materials and, in many countries, they are discouraged from trying new techniques. There is often little incentive to propose the use of non-standard techniques under normal contractual arrangements since any benefits are accepted with little acknowledgement, but the results of failure are remembered for a long time. The result is that unnecessarily expensive designs are sometimes recommended.

6.24 The use of marginal materials needs a greater degree of control during construction and may lead to an increased rate of deterioration. However, these materials should always be considered when carrying out pavement design in situations where their use is economic.

FACTORS AFFECTING FLEXIBLE PAVEMENT DESIGN

6.25 The structural design of road pavements depends primarily on the following factors:

• strength of the subgrade
• traffic loading
• materials
• variability and uncertainty in the above three items and in the quality control of the construction process.

6.26 In addition, the structural performance of the road will depend on the adequacy of drainage measures within the road structure, the design of the shoulders and the level of maintenance.

Subgrade strength

6.27 The most important factor which controls the pavement thickness is the strength of the subgrade soil. This, in turn, depends on the type of soil, its moisture content and the level of compaction (density) achieved during construction. The thickness of pavement required to carry a particular traffic level is very sensitive to subgrade strength when the subgrade is weak, but insensitive to subgrade strength when the subgrade is very strong. The strength of the subgrade can change with time as a result of moisture changes in the soil. Such changes are often associated with poor maintenance and are therefore unpredictable. Designers often include substantial safety factors at this stage of the design process. It is important to estimate the strength of the subgrade under the most likely adverse conditions and guidance on how this can be done is given in Road Note 31 (Transport and Road Research Laboratory 1977 -currently under revision).

Traffic loading

6.28 The second important factor to influence pavement thickness is traffic loading. The damage that vehicles do to a road depends very strongly on the axle loads of the vehicles. The exact relationship is influenced by the type of road structure and the way the road deteriorates but a 'fourth power' damage law gives a good approximation for most practical applications. All axle loads are converted to an equivalent number of 80 kN (8.157 tonne) axles, referred to as standard axles, using Figure 6.2. Multiple axles are treated as separate axles for this purpose.

6.29 Figure 6.2 illustrates the importance of axle load surveys for structural design. An increase in axle load of 60 per cent increases the number of standard axles by 700 per cent and the passage of one 13 tonne axle causes as much damage as the passage of eight 8.2 tonne axles.
One of the most common causes of premature pavement failure in third world countries is incorrect estimates of traffic loading. In most developing countries, overloading is common and it is also unwise to assume that axle loads on all roads in a country are similar. It is essential to carry out independent axle load surveys when planning paved road projects. Guidance on how to carry out such surveys is given in Road Note 40 (Transport and Road Research Laboratory 1978). It is important to ensure that traffic cannot bypass the weighing site and that axle loads do not decrease as drivers and vehicle operators become aware of the survey and temporarily reduce the vehicle loads.

6.30 Although traffic induced damage is sensitive to axle loads, once the traffic has been expressed in terms of equivalent standard axles it is found that pavement design thicknesses are much less dependent on traffic load than on subgrade strength. For example, an increase in pavement thickness of ten per cent should enable several hundred per cent more traffic to be carried. Conversely, if the thickness is too low, very rapid failure can be expected.

Materials

6.31 The third factor which influences thickness is the choice of materials for the construction of the pavement layers themselves. This becomes most significant for the design of very heavily trafficked roads and depends on the detailed mechanisms of deterioration for each type of material. The better design methods available take this into account, but the subject is complex and specialist engineering advice should be sought.

Variability and uncertainty

6.32 The design must take account of inherent variability in the materials, variability in the quality control, uncertainties associated with climate, in particular rainfall and depth of water table and uncertainties in future maintenance, future vehicle axle loadings and traffic flow levels.

6.33 Subgrade strength. The subgrade strength normally varies both along the road alignment, from season to season and from year to year. Soil properties can change within a few metres, but it is quite impractical to change the structural design over short distances, hence a representative value must be chosen for the subgrade strength for design purposes which reduces the risk of early localised pavement failures to acceptable levels. The more soil testing that is done beforehand, the easier it is to reduce the risk in the design and to produce a cheaper pavement. It is recommended that the value of subgrade strength chosen for design purposes should be the lower ten percentile value for each nominally uniform section of subgrade.

6.34 The variation of subgrade strength with time is more difficult to assess. Underneath the centre of an impermeable road the strength remains reasonably constant and its value can be estimated from knowledge of the depth of water table and easily measured properties of the soil. Problems arise when road maintenance cannot be guaranteed to ensure that the surface is always impermeable. The ingress of water through damaged or aged surfaces and shoulders, and the retention of this water through poor maintenance of the drainage systems has a drastic effect on material strength and road performance.
It is not possible to compensate adequately for such effects by means of more conservative designs.

6.35 **Materials.** Additional problems of variability arise with the aggregates chosen for road bases and, to a lesser extent, sub-bases. There are numerous ways in which the aggregates can fall outside specification and unless sufficient testing of potential quarry sources is done at the feasibility study stage of a project to ensure that all materials are within specification, problems are inevitable. There are so many factors which affect the performance of a road that it is extremely difficult to evaluate the effects of deviations from the specifications for many of the material properties specified. Lack of sufficient testing is likely to give rise to disputes during the construction phase, often with serious financial consequences.

6.36 However, selection of pavement materials is probably one aspect of structural design where large financial savings can be made in road construction, especially for low and intermediate levels of traffic, by using marginal materials as discussed in para 6.22-24, particularly on more lightly trafficked roads.

6.37 **Construction control.** The construction process itself is seldom as well controlled as expected or desired. Sources of variability arise in all aspects of the work such as the mix proportions of premixed bituminous materials and the degree of road base compaction achieved transversely across the road. Variation in the thickness of the pavement layers is often a major cause for concern because of the extreme sensitivity of traffic carrying capacity to structural thickness. This sensitivity means that small increases in thickness should ensure that the road carries the traffic satisfactorily despite large uncertainties in traffic forecasts providing that the natural variations in thickness arising from the construction process are properly accounted for in the design.

**Shoulders**

6.38 Shoulders are an essential element of the structural design of a road, providing lateral support for the pavement layers. They are especially important when unbound materials are used in the pavement and, for this type of construction, shoulders should be at least two metres wide. Narrower shoulders are acceptable for roads with bound bases (see Section 7). In order to exclude water from the road, at least one metre of the shoulder nearest the road should be impermeable and a surface dressing or other seal should be applied. Unsealed shoulders are not recommended as they often require considerable maintenance if satisfactory performance is to be guaranteed.

**Drainage of pavement layers**

6.39 Drainage within the pavement layers themselves is an essential element of structural design as the strength of the subgrade used for design purposes depends on the moisture content during the most likely adverse conditions. It is impossible to guarantee that roads will remain waterproof throughout their lives, hence it is important to ensure that if any layer of the pavement, including the subgrade, consists of material which is seriously weakened by the presence of water, the water must be able to drain away quickly. To facilitate this, correct camber should be maintained on all layers that are impermeable and a suitable path for water to escape must be provided.

---

![Fig.6.3 Drainage of pavement layers](image-url)
be provided, either by extending a permeable pavement layer right through the shoulder as indicated in Figure 6.3, or by including a permeable layer within the shoulder.

**PREPARATION AND CHECKING OF FLEXIBLE PAVEMENT DESIGNS**

**Collection of information**

6.40 In order to estimate pavement costs for a feasibility study, it is necessary to carry out a preliminary pavement design. This task should be carried out by a road engineer. If a paved road is being considered, the cost of the pavement will represent a significant proportion of the construction cost, so comparable effort should be put into the design study.

6.41 For most projects, a pavement design life equivalent to 15 years should normally be used to match that of the project analysis period. This not only simplifies the calculation of the residual value at the end of the analysis period, but reduces the problem of forecasting uncertain traffic trends for long periods into the future. However, shorter design periods do increase the accuracy of the assessment.

6.42 Information from the traffic and axle load surveys should be used to determine the cumulative equivalent standard axle loading that the road is forecast to carry over the design life. Information from the geotechnical surveys should indicate the likely availability of materials and the unit costs for using them in pavement construction. All of this information should be used together to prepare several alternative designs. The alternatives should contain different types of pavement construction and should reflect the uncertainties in traffic forecasts.

**Choice of design method**

6.43 Most pavement design methods in current use are derived primarily from empirical studies in Europe and North America. These methods have proved reasonably satisfactory, provided the materials, environment and traffic loading conditions do not differ significantly from those which pertained during the original studies on which the design methods were based. However, the extension of these empirical design methods to the different materials, different weights and volumes of traffic and different environmental conditions found in developing countries can pose serious problems. During the last decade, considerable advances have been made in the theoretical understanding of pavement behaviour. It is now claimed by proponents of the theoretical techniques that cheaper and better roads can be designed using these methods. Whilst this is somewhat overstating the case, it is from this area that future improvements in designs will come, and some developing countries are beginning to introduce some of these ideas into their pavement design methods.

6.44 There is an increasing body of evidence that suggests that the mechanism of deterioration of flexible pavements in tropical countries are often quite different to those in temperate climates. In addition, considerably different structural designs are obtained by using different design charts. Total thickness variations exceeding 100 per cent are not uncommon and, for heavily trafficked roads, even larger differences can occur. There are various reasons for this. Each type of structure behaves differently and therefore the same thickness design would not be expected to apply. Furthermore, criteria for determining terminal conditions, which are inherent in each design method, are often quite different. The result of this is that the designs to carry a particular traffic vary quite significantly from method to method. Inbuilt assumptions in the design methods are not normally described in the published manuals and it is often quite difficult to find them described at all. Technical comparisons between structural designs are therefore always difficult and economic comparisons often impossible.

6.45 Road Note 31 (Transport and Road Research Laboratory 1977—currently under revision) is a general design guide for bituminous surfaced roads in developing countries and emphasises good engineering practice which applies universally. It is based on research by the Overseas Unit of TRRL, but it cannot encompass all of the conditions likely to be encountered in all countries. In particular, extreme conditions of climate and axle loading are not dealt with. This design guide can be used to prepare or to check the pavement design being put forward as part of a project analysis to ensure that the design being proposed is of the correct order of magnitude.

**STRENGTHENING FLEXIBLE PAVEMENTS**

6.46 Strengthening overlays are designed using similar empirical or theoretical techniques as for the design of new roads. Usually some method of non-destructive testing, such as dynamic cone pentrometer or benkelman beam deflection testing, is used to assess the 'strength' of the existing road and to determine how much additional strengthening is required. No proven method of overlay design exists for tropical condition so, until one is developed, the method described in the Appendix of TRRL Laboratory Report 1043 (Smith and Jones 1982) is recommended. This method should be used either to prepare overlay designs or to check those submitted as part of project reports.
6.47 Problems arise if the road is in poor condition. Under these circumstances, the decision to strengthen the existing road or to rebuild the whole or parts of the road can be difficult. No easy guidelines exist. Conditions along the road will vary so much from place to place that the quantity of pavement layer testing required to assess the structural condition, and the degree of risk attached tooverlaying under these circumstances, often mitigates against strengthening in favour of reconstruction. In this situation, engineering judgement plays a major role and risk analysis may be used to help quantify the likely consequences of error. When assessments are made of roads requiring rehabilitation, it is important that sufficient testing is done to enable statistically meaningful results to be obtained. The results will need to be assessed by an experienced road engineer to determine the best remedies.

COSTING

6.48 Costing the design of the new pavement or overlay should be based on final achieved costs in other contracts, as described in Section 4, rather than on current contract rates. Costs are normally specified on a square metre basis for surfacings and on a cubic metre basis for all other layers. However, it is important to ensure that differences in haulage distances and other variables are taken into account, and that realistic prices are allocated for the use of new or modified materials. Local advice should always be sought.

7. GEOMETRIC DESIGN

PURPOSE OF GEOMETRIC DESIGN

7.1 Geometric design is the process whereby the layout of the road in the terrain is designed to meet the needs of the road user. The principal elements of this process are the selection of suitable horizontal and vertical alignments and road widths. The geometric design standards provide the link between the cost of building the road and the costs of the road users. Usually, but by no means always, the higher the geometric standard, the higher the construction cost and the lower the road user costs. Geometric standards are not more than a first approximation to design needs, since it is now accepted that design must be site-specific. The optimal design for a given traffic flow will depend on terrain and other characteristics. Appropriate geometric design standards for use in developing countries are given in Overseas Road Note 6 (TRRL Overseas Unit 1988).

7.2 One of the principal objectives of a feasibility study should be to make recommendations about the geometric design standards for a project such that the optimum balance between road construction cost and road user cost is obtained over the project analysis period. It is vital that decisions are not taken before this is carried out which prejudice the choice of geometric design standard. In the past, insufficient attention has been given to the choice of design standards with the result that roads have been built to standards well in excess of those that are justified by the traffic levels over the life of the project.

7.3 There are few developing countries who have carried out basic research on traffic economics and safety in order to develop their own geometric standards which have therefore been adapted from standards used in industrialised countries. However, the needs of road users in the industrialised countries are usually very different from those in developing countries. In developing countries pedestrians, animal-drawn carts, bicycles, autorickshaws etc are often an important component of traffic mix, even on major highways. In Europe and North America, traffic composition is dominated by the motor car, whilst, in developing countries, lorries and buses often represent the largest proportion of the motorised traffic. As a result, it may be necessary to adapt conventional geometric design standards to meet the needs of all road users by, for example, widening the shoulders of the road to allow their use by slow-moving traffic.

ELEMENTS OF GEOMETRIC DESIGN

7.4 Geometric design covers horizontal and vertical alignments, road width and sight lines. ‘Sight distance’ is the distance ahead that can be seen by the driver. The sight distance needed for safe stopping from travelling
speed is the 'stopping sight distance' and the sight distance needed to see ahead for safe overtaking is known as the 'passing sight distance'. In detail, the specification may include the following.

7.5 **Horizontal alignment** (see Fig.7.1):
- Minimum radius of curvature
- Minimum stopping sight distance
- Minimum passing sight distance.

7.6 **Vertical alignment** (see Fig.7.2):
- Maximum gradient
- Length of maximum gradient
- Minimum stopping sight distance or passing sight distance on summit curves
- Length of valley curves.

7.7 **Cross-section** (see Fig.7.3):
- Width of carriageway (running surface)
- Width of shoulders
- Crossfall, camber and superelevation
- Width of structures
- Width of road reserve.
RATIONAL BASIS FOR GEOMETRIC DESIGN

7.8 Traditionally, the first step in choosing geometric standards is to fix the 'design speed' for the road. However, when choosing geometric design standards for a particular situation, it is more important to consider the purpose for which the road is being provided. For geometric design purposes, it is most convenient to consider road projects under one of the following three categories.

7.9 **Access roads** (lightly trafficked roads carrying up to a few hundred vehicles per day) These provide a basic means of communication between minor centres of population, or between a centre of population and an existing road. The geometric standards of such a road have much less importance than whether a road link exists at all or, if a link exists, whether it is 'passable' at all times.

7.10 **Collector roads** (traffic volume likely to be in the range of 100 to 1000 vehicles per day) Projects for these roads normally have the purpose of providing additional capacity for low-volume roads in the network. Geometric standards contribute to these projects in the areas of road width and gradient but, for most developing countries, more important factors are whether or not a road is paved or whether it has sufficient structural strength to carry the traffic using it.

7.11 **Arterial roads** (traffic volume normally greater than about 400 vehicles per day) These will normally carry relatively high levels of traffic and, because of this, the operational efficiency of the traffic on the road becomes a significant factor with the result that geometric design standards assume their greatest importance for this type of project.

7.12 This Section of the Note gives guidelines on the range of geometric standard which are appropriate for road projects in each of these categories based on concepts of both economics and road safety.

DESIGN RELATED TO TERRAIN

7.13 In flat undeveloped terrain, the cost of a road is almost entirely independent of its alignment, so a high design standard can often be adopted with no cost penalty. Only when the road is in hilly or mountainous terrain will there be any significant costs which are attributable to the alignment chosen. A higher standard of alignment will mean that more cuts and fills are needed resulting in a higher earthworks cost. However, a shorter alignment will result in lower pavement and maintenance costs, and cost savings for road users. The objective should be to produce a design such that any marginal increase in earthworks costs is more than offset by potential savings in user costs over the analysis period for the project. Feasibility studies for roads in hilly terrain should always consider alternative alignments before recommendations are made.

7.14 Consistency of design standards over relatively short lengths of route of say 5 to 15 km will improve road safety by reducing sudden and unexpected changes in road standard. However, when the road passes through...
### TABLE 7.1
GUIDELINES FOR GEOMETRIC DESIGN STANDARDS

<table>
<thead>
<tr>
<th>Road type</th>
<th>Access road</th>
<th>Collector road</th>
<th>Arterial road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal surface type</td>
<td>Unpaved/paved</td>
<td>Gravel/paved</td>
<td>Paved</td>
</tr>
<tr>
<td>Approximate range of traffic levels (vehicles per day)</td>
<td>&lt; 400</td>
<td>100 - 1000</td>
<td>400 - 15000&lt;sup&gt;(2)&lt;/sup&gt;</td>
</tr>
<tr>
<td>Carriageway width (metres)</td>
<td>2.5 - 5.0</td>
<td>5.0 - 5.5</td>
<td>6.0 - 7.0</td>
</tr>
<tr>
<td>Shoulder width (metres)</td>
<td>0&lt;sup&gt;(3)&lt;/sup&gt; - 1.5&lt;sup&gt;(4)&lt;/sup&gt;</td>
<td>1.0</td>
<td>1.0 - 2.5</td>
</tr>
<tr>
<td>Crossfall (per cent)</td>
<td>(5)</td>
<td>(5)</td>
<td>(5)</td>
</tr>
<tr>
<td>Stopping sight distance (metres)</td>
<td>25&lt;sup&gt;(6)&lt;/sup&gt; - 85</td>
<td>50 - 120</td>
<td>65 - 230</td>
</tr>
<tr>
<td>Overtaking sight distance (metres)&lt;sup&gt;(7)&lt;/sup&gt;</td>
<td>140&lt;sup&gt;(8)&lt;/sup&gt; - 240</td>
<td>140 - 320</td>
<td>180 - 590</td>
</tr>
<tr>
<td>Minimum horizontal curve radius (metres)</td>
<td>0&lt;sup&gt;(9)&lt;/sup&gt; - 190</td>
<td>60 - 210</td>
<td>85 - 450</td>
</tr>
<tr>
<td>Minimum crest curve K values&lt;sup&gt;(10)&lt;/sup&gt;</td>
<td>0&lt;sup&gt;(9)&lt;/sup&gt; - 16</td>
<td>5 - 30</td>
<td>10 - 120</td>
</tr>
<tr>
<td>Maximum percentage gradient</td>
<td>15 - 20&lt;sup&gt;(11)&lt;/sup&gt;</td>
<td>10</td>
<td>8&lt;sup&gt;(12)&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

**Notes**

1. Values are based on those recommended in Overseas Road Note 6 (TRRL Overseas Unit 1988).
2. For higher traffic volumes, use latest British (Department of Transport 1981) or Australian (NAASRA 1980) standards.
3. On 2.5-3.0 metre carriageways with no shoulders, passing places should be provided.
4. 1.5 metre shoulders are needed on carriageways with widths of 3.0 metres or less.
5. Crossfall = 5.0 per cent on unpaved roads; 3.0 per cent on paved roads.
6. Longer stopping sight distances will be needed on single track roads.
7. It will normally be uneconomic to design roads for full overtaking sight distance.
8. Overtaking sight distances are inappropriate on access roads built to minimum standards.
9. Minimum standard access roads need not have designed horizontal and vertical curves.
10. Where design is for animal-drawn carts, gradients may need to be restricted to a maximum of 4 per cent; slippery soils may also restrict the practical maximum value to as low as 5 per cent.
11. Climbing lanes should be considered when the length of road at maximum gradient exceeds about 500 metres. In very hilly country, short lengths of climbing lane of about 200 metres may be helpful.

significant changes in topographic type, it will usually be cost-effective to lower the alignment standards in the more rugged terrain.

7.15 The alignment should be chosen carefully to provide good drainage and to minimise earthworks. When locating roads in erosion-prone regions or areas where instability of slopes is a problem, careful attention must be given to minimising the disturbance of the terrain caused by the road. The location of the road will also be affected by the availability of road-making materials.

**HORIZONTAL ALIGNMENT**

7.16 Suitable ranges of horizontal alignment standard are given in Table 7.1. There will normally be little difficulty in producing cost-effective designs with horizontal curve radii well above the minimum values in the range. The absolute minimum values should only be required in severe terrain.

7.17 For access roads, it is assumed that any new roads will carry low traffic volumes and therefore should be built to minimum standards. In steep ground, it is important that all of the vehicle types likely to operate on a road can negotiate curves. The minimum radius should be chosen to be adequate for all likely vehicles to use the road, including 4-wheel drive tipper lorries which tend to have very poor turning circles, but excluding large heavy goods vehicles. Where it is known that the road...
requirement will only be for say light 4-wheel drive jeeps, this figure can be reduced. However, consideration would need to be given to other special users of the road, such as the Roads Department to allow access during road maintenance. It is most desirable to flatten the gradient at any tight corner.

7.18 For collector and arterial roads, projects will often be for improvement works rather than new construction. In such cases, it is seldom economic to improve individual horizontal curves. Proposals to do this to remove safety hazards may be considered, but should be looked at very critically in terms of benefits and costs. A completely new alignment may be justified where there is a physical constraint to widening the road, where a higher speed road is economic, or where safety and congestion factors arise when the road passes through a settlement.

7.19 It is preferable that lengths of horizontal curves should be close to desirable minimum radius and as short as possible. This type of design provides the maximum length of road where sight distances are not reduced and where overtaking can be carried out. Previous design methods used longer curves to produce 'flowing alignments' and more gentle bends. However, such designs, sight distances will be restricted on the longer curves and a shorter length of alignment will be available where overtaking is safe.

VERTICAL ALIGNMENT

7.20 The vertical alignment of a road has a strong influence upon the construction cost, the operating cost of vehicles using the road, and the number of accidents. The vertical alignment should provide adequate sight distances over crests and should not present any sudden hidden changes in alignment to the driver. Gradients need to be considered from the standpoint of both length and steepness, and the speed at which heavy vehicles enter the gradient. They should be chosen such that any marginal increase in construction cost is more than offset by the savings in operating costs of the heavy vehicles ascending them over the project analysis period.

7.21 For access roads, the cost of earthworks is often a substantial part of the cost of total construction, so it is best to consider the maximum gradient that particular types of vehicle can climb safely, rather than to adopt a gradient that can be negotiated by all kinds of vehicles. The basic determinant for maximum gradient is whether vehicles are to be 2-wheel-drive, 4-wheel-drive or animal drawn trailers. The absolute maximum gradients given in Table 7.1 should then apply. These gradients are extremely steep and, if possible, all gradients should be much less severe than these. On access roads with an earth surface, particular soil types may give rise to slippery conditions in the wet and even moderate gradients can be very difficult to negotiate. On hairpin bends, it is important to keep the gradient on the bend itself as flat as possible.

7.22 Collector road projects will often involve improvement rather than new construction. If recommendations are made to bypass a steep gradient, the proposal should compare the benefits and costs of this course of action and the alternative of providing a climbing lane on the existing alignment. This comparison should be looked at very critically. Steep gradients can bring problems of potentially dangerous downhill speeds for heavy vehicles and can also lead to difficulties climbing hills for old or poorly maintained vehicles such as often found in developing countries. It may be economic to pave steep gradients on a gravel road to reduce maintenance problems.

7.23 For arterial roads, the choice of vertical alignment for the road has a significant effect on both the construction cost and the road user cost. The maximum gradient should be chosen to minimise the sum of these costs. Proposals should support their recommendation for choice of vertical alignment by comparing costs with alternative standard alignments. Road investment models should be used for carrying out such an analysis, and these are described in Section 10. Minimum values for the radii of vertical curves should be based on safety criteria, and the standards in Table 7.1 are based on limits of stopping sight distance which are appropriate. Where traffic flows will lead to congestion on steep gradients, the relative costs of building climbing lanes and flatter gradients should be evaluated. If climbing lanes are adopted, road markings should be used to indicate clearly that two lanes are 'up' and one is 'down'.

7.24 The length of summit curves should be as close to the minimum radius and as short as possible to reduce the length of road where minimum sight distance applies. This is for the same reason as was recommended for horizontal curves.

CROSS-SECTION

7.25 Road capacity is a measure of the number of vehicles that are able to use the road at any time and is chiefly a function of road width. As traffic levels approach the capacity of the road, vehicle speeds will fall.

7.26 For access roads where traffic flows are so low that vehicles meet only occasionally, a single track width road with intermittent passing places is the cheapest road to construct. For higher traffic flows, single track roads cause considerable inconvenience to traffic and it is only to be recommended for short roads or in hilly terrain where the cost of construction in side cut and the subsequent haulage cost of materials is high. Most rural
access road programmes have provided roads that are sufficiently wide for two vehicles to pass safely. It should be noted that, if the new road is to be constructed by machine, the extra construction cost of building a wider road will often be quite small. If there is a large amount of pedestrian, animal or bicycle traffic, both shoulders should be increased in width. Where visibility is reduced on bends and on summit curves, the carriageway width should also be increased.

7.27 For collector roads, research has shown that, for relatively low traffic volumes, carriageway widths in excess of the minimum values in Table 7.1 cannot be justified in terms of accidents or traffic operation. Further work has shown that there is benefit in widening from this value on bends and summit curves. If there is a large amount of pedestrian, animal or bicycle traffic, shoulder widths should be increased, or it may be appropriate to segregate this entirely from the vehicular traffic. The edges of paved carriageways can be delineated by sealing shoulders with different coloured aggregates, or painted edge marking should be provided.

7.28 One of the objectives of arterial roads is to provide efficient operation of the road network and roads at this level will normally be paved. This has an influence on the appropriate road width, and the width and type of shoulders. For roads expected to carry very high volumes of traffic, multi-lane roads may need to be considered from both a capacity and safety point of view. Proposals for such designs should be supported by good technical justifications and may be based on the latest British (Department of Transport 1981) or Australian (NAASRA 1980) practice. Shoulders should normally be at least partly sealed and should be differentiated from the carriageway by the use of different coloured aggregate or edge markings. Where large amounts of pedestrian, animal and bicycle transport is expected, shoulder widths should be increased. Arterial roads should normally carry centre line markings.

7.29 Crossfall is needed on all roads in order to assist the shedding of water into the side drains. Suitable values are given in Table 7.1. Shoulders should be at the same crossfall as the carriageway.

ROAD RESERVE

7.30 For new road construction, most countries already have standards of the amount of land that they will buy or acquire for the road. Often this is much wider than in industrialised countries since the pressure on land space is not as great. The total width of the road reserve may be from 10 to in excess of 50 metres. Its purpose is to provide land for future road widening and to provide the fill material for the road construction. There are two problems with having too wide a reserve: first, it implies a loss of land to agriculture or other use; and, secondly, the road authority is sometimes obliged to cut the grass in the road reserve. A third problem may be that, if people graze their cattle in the road reserve, then this can be a traffic hazard. On the whole, the road reserve only needs to be sufficient for the road, its drainage, services, for future widening to dual carriageway, and to control erosion and ribbon development. A wider road reserve will improve sight distance.

JUNCTION DESIGN

7.31 Conflicting vehicle movements at junctions are the largest cause of accidents in many developing countries. A small number of well designed junctions on a route is preferable to a large number of low standard junctions. Simple cross-roads have the worst accident record. Staggered cross-roads or two separated T-junctions will reduce the accident rate. The use of roundabouts, traffic lights and channelisation may be appropriate to improve vehicle flow and safety. Local widening at T-junctions combined with painted channelisation (ghost islands) has proved highly cost effective in industrialised countries, as has the use of low cost traffic engineering devices, such as yellow bar markings on the approach to junctions. Conflicts can be largely eliminated by the expensive solution of grade separation, but it is not normally necessary to design for free-flow conditions at intersections, and their use will not be appropriate in most cases.

SIGNS AND ROAD MARKINGS

7.32 Warning signs should be used to inform the motorist that there is a change in design standard on the road and to reduce approach speeds. On new projects, signs will be needed where the project joins on to the existing road or where standards have been changed on passing into a different terrain type. Road markings will be needed on summit curves on paved roads where overtaking sight distance is not provided. Warning signs should also be erected to inform of other hazards such as road junctions. Mandatory signs indicate where action by the driver is necessary which is enforceable by law, and direction signs help to direct traffic along a route to a destination. If these three types of signs are used properly, they will form an information system which will reduce accidents and minimise confusion and delay.

7.33 Ideally, signs should be reflectorised, but ordinary paint is better than nothing. The use of marker posts and chevron board on bends is also strongly recommended, particularly for roads being designed at the minimum standards being recommended here. As has been mentioned earlier, the use of road markings on the edge of roads, on the centre line and on climbing lanes is also recommended. However, in many countries, maintenance of road markings can be a problem.
COSTING EARTHWORKS

7.34 Standard engineering methods should be used to prepare preliminary alignment designs based on the range or geometric standards recommended here. Computer programs are available to assist with this process from a variety of sources including:

Highways Directorate
Department of Transport
2 Marsham Street
London SW1P 3BB
United Kingdom

7.35 For feasibility study purposes, alignments designed on the basis of available contour maps are adequate to provide the level of detail required to make cost estimates to an acceptable order of accuracy. For design studies, more detailed terrain information is needed as described in Section 5.

7.36 A significant proportion of the cost of building or realigning a road is the cost of earthworks. This is made up principally of the cost of excavating cuttings, building embankments and hauling material between the two. Additional material may also need to be brought in from pits, and any surplus or unsuitable material will need to be dumped. Standard engineering methods should be used for determining earthworks quantities and costs. Computer programs are available to assist with these calculations including the construction cost submodel of micro-RTIM2 which has been developed specifically for use in feasibility studies in developing countries. Details of how to obtain copies of this program can be obtained from:

Overseas Unit
Transport and Road Research Laboratory
Crowthorne Berkshire RG45 6AU
United Kingdom

7.37 Methods of costing based on those in Section 4 should be used.

8. DRAINAGE AND STRUCTURES

8.1 Consideration of drainage is important in a road project analysis because the cost of providing structures can represent a significant proportion of the construction cost of a new road.

THE DRAINAGE SYSTEM

8.2 One of the most important aspects of the design of a road is the provision made for protecting the road from surface water or ground water. If water is allowed to enter the structure of the road, the pavement will be weakened and it will be much more susceptible to damage by traffic. Water can enter the road as a result of rain penetrating the surface or as a result of the infiltration of ground water. The road surface must be constructed with a sufficient camber or crossfall to shed rainwater quickly and the formation of the road must be raised above the level of the local water table to prevent it being affected by ground water.

8.3 Water can also have a harmful effect on shoulders, slopes, ditches and other features. High water velocities can cause erosion which, when severe, can lead to the road being cut. Alternatively, low velocities in drainage facilities can lead to silt being deposited which, in turn, can lead to a blockage. Blockages often result in further erosion.

8.4 A good road drainage system, which is properly maintained, is vital to the successful operation of a road. It has four main functions:

- to convey rainwater from the surface of the carriageway to outfalls
- to control the level of the water table in the subgrade beneath the carriageway
- to intercept ground and surface water flowing towards the road
- to convey water across the line of the road in a controlled fashion.

The first three functions are performed by side drains and the fourth by culverts, drifts and bridges.

SIDE DRAINS

8.5 The cost of side drains will normally be calculated as part of the cost of earthworks (see Figs 6.3 and 7.3, and Section 7). Side drains should be flat-bottomed if they are to be maintained by hand (Fig 7.3), or V-shaped if they are to be maintained by machine (Fig 6.3). Wide flat drains, known as 'meadow drains', can be used with advantage if there is room. The longitudinal gradient of
side drains should always exceed 0.5 per cent to reduce the possibility of silting up. In hilly terrain, providing side drains with the same gradient as the road may result in water velocities that are too high. It may therefore be necessary to reduce the maximum gradient to an acceptable level by the provision of shallow dams or scour checks. These are often constructed of masonry, but can also be constructed in concrete or even timber. Wide drains are preferred to reduce the velocity and so minimise erosion. The provision of turnouts or cut-off drains should also be considered to reduce or control the amount of water in the side drains. Costing may need to take account of these and the need to line drains with masonry or concrete in highly erodible soils.

8.7 The following types of structure should be considered:

- **Ford.** This utilises a suitable existing river bed and is appropriate for shallow, slow moving watercourses with little probability of flash floods: traffic volumes up to about 100 vehicles per day.
- **Drift.** This is sometimes known as an 'Irish bridge' and consists of a concrete slab constructed in the river bed which would otherwise be unable to carry vehicles and is suitable as a crossing for rivers that are normally fordable but are prone to flash floods; where the river is running most of the year, culverts can be placed in the drift to reduce the frequency and depth of overtopping during flash floods: traffic volumes up to about 100 vehicles per day.
- **Culvert.** This usually consists of a concrete or steel pipe, or a reinforced concrete box, placed under the road within an embankment to provide a suitable means of conveying streams, or the contents of side drains, under the road with no restrictions on traffic.
- **Bridge.** This may have a superstructure of timber, concrete and/or steel on masonry, concrete, or timber abutments and will be required for crossing streams or rivers where culverts would provide insufficient capacity, or where the road crosses an obstruction such as a railway or canal. There is no restriction to traffic unless the width of the structure is less than the road width.

8.8 Traffic requirements should be determined using the methods described in Section 3.

8.9 In order to determine the maximum likely flow of water to be accommodated by the chosen structure, information may be needed on:

- water catchment area
- rainfall characteristics
- topography
- vegetation and soils
- catchment shape
- available storage in lakes and swamps
- urban development (if any).

Peak flood volumes can then be estimated using standard hydrological techniques such as those described by Watkins and Fiddes (1984).

8.10 In order to determine the type of structure, consideration may need to be given to the cost of delays to traffic if, for example, a concrete drift is impassable for several days or if a single lane bridge is being considered instead of a two lane structure. Thus, the choice of structure may need to be determined by appraisal. The value of time is discussed in Section 12.

**FORDS AND DRIFTS**

8.11 The simplest river crossing is a ford. Large stones with flat tops can be placed at the upstream and downstream sides of the ford so that pedestrians can use them as stepping stones rather than having to wade across the river. Gravel or stones can be used to line the bottom of the ford to provide a firm footing for vehicles. Fords should normally only be used for rivers that do not flood as this may cause the ford to be washed away. However, repair or replacement is cheap and this may still provide an acceptable solution. The cost of providing fords is small and can usually be ignored for project analysis purposes, although some additional earthworks costs may be incurred to ensure that the road gradient on either side is acceptable to traffic.

8.12 An improvement on a ford is a concrete drift. This provides a permanent running surface for traffic, although delays may still occur when stream levels are above the level of the carriageway. The gradient of the road on either side of the drift should be not more than about 10 per cent, or 4 per cent where animal drawn traffic is expected. It may be necessary to surface the road where such gradients are unavoidable, even where a gravel surface is otherwise adequate. The width of the drift need be no more than 3.5 to 4 metres, but should be delineated by graduated marker posts to show both the edge of the road and the depth of the water during floods. Culverted drifts may be used to cross perennial streams. Culverts should normally be at least one metre in diameter to reduce the likelihood of blockage and to make them easier to maintain. The cost of drifts can be
estimated from the volume of concrete required for construction, but allowances must be made for engineering work required to ensure that the pavement is not eroded or undermined. These costs may be significant. Cost estimates for culvert pipes are made on the basis of the length of pipe required. Unit prices for concrete and for culvert pipes of various diameters which are appropriate to the road being analysed should be readily available.

CULVERTS

8.13 The use of culvert pipes to convey surface water under a road alignment is common, and provides a relatively cheap and durable solution. Most countries make concrete pipes of up to one metre diameter and these may be cost effective provided that they can be transported and handled. Corrugated galvanised steel pipes, often known by the trade name 'Armco', are available in larger diameters and are usually more expensive, but lighter and easier to handle. There should be little maintenance required for either material other than an annual inspection and clearing of accumulated silt or debris, although corrosion may occur to metal pipes in some circumstances. Culvert pipes require headwalls to protect the ends of the pipe and to direct water either towards or away from the culvert. The outfall of the culvert must be protected against scour and environmental damage downstream.

8.14 For larger volumes of water, it is possible to use several pipes in parallel under the road. Multiple pipes can also be used where the planned embankment height is insufficient to cover a single pipe of sufficient diameter adequately. However, pipes of less than one metre diameter are not recommended since they are difficult to maintain.

8.15 Reinforced concrete box culverts may also be used either singly or in parallel where relatively large volumes of water must be carried. These are normally cast in place, although smaller sizes may be precast.

8.16 Costs for culverts and for mass and reinforced concrete should be based on final achieved contract costs rather than current contract rates (see Section 4). Culvert pipes are normally costed per unit length, depending on diameter, whereas headwalls and box culverts are normally costed on the basis of volume of concrete used. Local advice on costs should always be sought to ensure that all reasons for cost differences are taken into account.

BRIDGES

8.17 Bridges will be needed over rivers where high level crossings are essential, where several culverts in parallel do not have sufficient capacity to carry the flow, or where drifts are not suitable because of safety considerations, or because resulting traffic delays are unacceptable. The following gives a brief survey of the main issues and choices. Specialist engineering advice should be sought whenever possible.

Bridge design

8.18 Most countries have established bridge design codes which specify the size, type and configuration of loads which the structure must be able to carry safely. Such codes are usually based on, or similar to, codes adopted in the USA (AASHTO 1983) or the United Kingdom (BSI 1972, 1978). It is normally advisable that new structures are designed to the code adopted by the country concerned. This avoids the need to impose weight restrictions, which may be difficult to enforce or, conversely, the provision of a structure which will safely carry loads which cannot be permitted elsewhere on the network. An exception may be made where:

• A temporary structure is envisaged
• Provision must be made for known exceptional loads, eg access to a power station or other structures known to require exceptionally heavy plant or equipment.

8.19 The width of a proposed bridge can significantly affect the cost of construction. If two lanes are provided instead of one, material costs will more than double as heavier construction will be required to accommodate the additional traffic loads. Particularly where a long bridge is required, careful consideration should be given to the relative cost of the provision of two lanes and the delays to traffic that would otherwise occur over the life of the structure. The proportion of pedestrians, bicycles, and animal-drawn vehicles should also be considered. In such cases, it may only be necessary to widen the carriageway sufficiently to ensure that motor traffic is unimpeded rather than provide two standard traffic lanes. A cheaper solution may be to provide light footways cantilevered out from the main structure. It is very unlikely that more than two lanes will be required in rural areas in developing countries.

8.20 A significant reason for bridge failure and high maintenance costs in tropical countries is erosion and scour leading to foundation failure. Even at the analysis stage, it is worthwhile to make sure that these aspects have been considered and appropriate protection provided.

Site conditions

8.21 Temporary structures apart, bridges are normally designed to operate without major structural alteration for very long periods, typically fifty years. It is therefore
particularly important that the design takes into account all factors that can reasonably be foreseen and that may affect performance. Such factors must include the characteristics of the river, which will determine the location and design of abutments and piers, and the elevation of the deck or superstructure. Other factors include the extent of river training and scour protection measures that are needed. Of equal importance, will be a knowledge of ground conditions at the selected site. No reasonable estimate of cost can be made without this information and a site investigation should always be undertaken to determine the strength and other characteristics of the soils on which the structure will be founded.

8.22 The cost of providing river training works is often high and, where there is evidence of the river changing its course, it may be preferable to reduce the design life and the cost, and accept the need to rebuild the bridge at a later date. It is also important to consider what the cost of disruption or damage would be if the river were to overtop the bridge. An understanding of the river characteristics, the construction cost and the risk of structural failure is crucially important in deciding the optimum choice of materials and design for the structure.

Abutments and piers

8.23 Abutments and intermediate piers distribute the vertical and horizontal loads on the bridge to the foundations. Abutments must also resist the horizontal forces of the soil which is constrained.

8.24 Where the ground conditions at a reasonable depth are adequate to support the bridge and traffic loads, it is normal to support abutments on narrow reinforced concrete slabs or footings. Where the soil is too weak to support this type of foundation, piles will be needed to support the abutments and piers. Normally piles are more expensive than concrete footings and require specialist design and construction skills.

8.25 Abutments and piers are usually constructed of reinforced or mass concrete, masonry, brick or timber. The choice between concrete, masonry or brick will be determined by the cost and availability of materials and the skill and experience of the available labour force. Timber should be considered with care because, although accommodating considerable movement without distress, it is prone to rot and insect attack, particularly when used in abutments and retaining soil. Careful selection of species and treatment will help, but maintenance costs may be high and regular monitoring of condition essential.

Timber decks

8.26 In many rural areas which are close to forests, the cheapest construction option for the superstructure of bridges may be parallel timber logs. Cutting and squaring timber for such crossings is expensive and not normally worthwhile. Ideally, timber should only be used where there is little or no problem with wood-boring insects and a naturally durable species should be selected, or else some form of chemical treatment, such as creosote, applied. To be effective, timber preservation must be done thoroughly and may significantly increase costs. On top of the logs, cross beams should be used to support longitudinal running boards.

8.27 The maximum span that can be used will depend on the species and height of available trees, but spans of up to about 15 metres are feasible.

8.28 Modular timber bridges have been developed for use in developing countries (Parry 1981, UNIDO and TRADA undated). These are suitable for spans of 12 to 24 metres and have the following advantages:

- relatively cheap to build
- the materials and skills required to build the bridge are available locally in most developing countries
- the modular design permits prefabrication of the frames in local workshops
- the frames may be stored for emergency use, and can be assembled to make a bridge on prepared abutments very quickly
- the bridge components are small enough and light enough to be transported to a remote site if a bridge is required urgently.

Although such bridges have some disadvantages, they should be considered for use in appropriate situations.

Concrete decks

8.29 Concrete superstructures are now common practice in most developing countries. Local contractors may be capable and experienced in some of the simpler forms of reinforced concrete. Where cement is locally produced, it may be economic to set up a precasting factory for standard bridge beams. Where these are available, they will often be cheaper and more suitable than steel. Alternatively, the beams may be cast in-situ but, in either case, a concrete slab needs to be cast to provide a running surface. A bituminous wearing course may also be added. An alternative to a beam and slab design would be either a solid concrete slab without beams, or a slab cast with voids to reduce the weight, also without beams. The most cost-effective configuration will depend on the span, width, available reinforcement, concrete strength achievable, and many other factors which the bridge designer should take into account.

8.30 Other, more sophisticated techniques of pre-stressing may be considered.
8.31 **Post tensioned beams and slab.** The deck is constructed in-situ in a similar way to above, but incorporating accurately located steel ducts to accommodate separate wires, strands, or high strength steel bars. When the concrete has hardened, the wires or strands are tensioned by jacks bearing against the concrete faces. The tensile force in the wires imposes a compressive force on the concrete. This condition is maintained by specially designed anchors attached to the ends of the wires.

8.32 **Pretensioned beams.** This method is applicable mainly to precast elements. Prior to casting the concrete, wires, strands or high strength steel bars are located in the mould and loaded to the required tensile stress. After the concrete has hardened, the load is removed and the tensile stress in the reinforcement applies an equal compressive stress in the concrete through the bond between the materials.

8.33 Both forms of pre-stressing offer advantages over conventional reinforced concrete. A pre-stressed beam or slab is generally free from cracks and is therefore more durable. Much less steel is required, since the weight of high-strength steel in the tendons is only a fraction of the weight of the reinforcement it supersedes. The cross-section is smaller since the concrete is used more efficiently and resistance to shear stress is substantially increased. However, pre-stressing demands high quality concrete, special steels, specialist equipment, and experienced and knowledgeable contractors and designers. Pre-stressing should not be considered if any of these requirements cannot be met.

8.34 **Segmental box girder units.** This is a technique for use on longer spans. Each separate unit is manufactured using industrial processes either at site or in a factory. High quality concrete is therefore achievable, but specialist construction skills and equipment are required and, in general, this design is unlikely to be appropriate where local contractors are employed.

**Steel decks**

8.35 Steel superstructures are of three types.

8.36 **Rolled steel beams** provide the simplest design consisting of a number of parallel 'I' beams spanning from one fixed abutment to the other, or to intermediate piers. The length is usually limited by handling and transport constraints to about 18 metres but, in many countries, the size of beam available limits the span to about 8 or 10 metres. A timber or reinforced concrete deck is constructed on top of the beams. If a concrete deck is used, this can be more efficient if the steel beam and concrete are designed to act compositely, i.e. are effectively bonded together.

8.37 **Panel bridges** are made of steel sections fabricated at a factory to form trusses and may be either part or fully assembled before delivery to site. In the UK, these are fabricated and designed by Callender-Hamilton and Mabey, who produce both their own 'Universal' design and the 'Bailey' type. Bailey bridges are also available from Messrs Thomas Storey. By varying the number of panels, various spans can be constructed. Although relatively expensive, the panel system is also excellent for the quick erection of bridging at temporary sites. Pontoon type crossings have also been effective on many rivers using standard panel units.

8.38 **Box girder bridges** are sophisticated structures used for long spans. They require specialist design and construction skills, but are technically very efficient in that they have a high strength to weight ratio. Suspension bridges often incorporate prefabricated box girders.

**Arch bridges**

8.39 Masonry and brick arch bridges are a traditional form of construction in some countries and may well be competitive where skilled bricklayers or masons are plentiful, and where appropriate materials are available. Despite this, the use of this type of structure is often overlooked in road projects where design is done by engineers from countries where there is little experience of their construction because labour costs make them uncompetitive. Structural analysis of this type of structure is less precise than that possible for steel or concrete, but arch bridge are capable of carrying exceptionally high loads without distress. There is thus more scope for the use of arch bridges in road projects and they should be considered as an alternative to steel and concrete structures in appropriate situations.

**Replacement of existing bridges**

8.40 If the project is to replace an existing bridge, a technical appraisal should be carried out to ascertain the need. If load restrictions are in force, the benefits of replacing or strengthening will be derived from more efficient freight operations. The age of a bridge should not be the sole criterion for replacement. Replacement should be based on a technical assessment of the bridge's ability to carry the required loads in the future. In many cases, deck reconstruction will be more cost-effective than replacement, particularly where piers and abutments are sound. However, the costs of disruption to traffic should be included in the analysis. In many cases, old bridges, especially stone or brick arches, will carry legally permitted traffic loads even though they were not originally designed for them. A sub-standard bridge located in an important route can have a considerable effect on goods throughout the network and thus reconstruction/replacement may have benefits beyond the immediate vicinity of the bridge which should be considered in the analysis of a project.
8.41 Another common problem arises where a two lane road includes a series of narrow single lane bridges. Often these have short spans and are of adequate strength, but because of their width, they represent a safety hazard and traffic is delayed by giving way to oncoming vehicles. A widening or replacement programme may be appropriate, but should be tested by the economic analysis.

8.42 Many large rivers in developing countries have an existing railway bridge but no equivalent road crossing. Where both rail and road traffic is light (say up to 10 trains and 250 vehicles per day), the economic feasibility of converting the rail bridge into a rail/road bridge should also be considered.

Costing bridges

8.43 There are many factors which affect the design choice and the cost of the structure, and these will vary at each site. In general, the simpler designs will be easier to construct, and hence cheaper, for short span bridges.

8.44 The availability of materials and local expertise will tend to govern the choice between concrete and steel structures. Local contractors may construct reinforced concrete competently; pre-stressed or post-tensioned concrete may be beyond their capability. The cost of concrete bridges, in general, will be relatively insensitive to the load carried whereas, for steel panel bridges, the load at certain span lengths determines the number of units that are needed and hence the cost. For some timber bridges, the load carried may be extremely critical on particular spans as this will determine whether locally available timber is strong enough.

8.45 The choice of optimum span for a large bridge is an important decision since the longer the span, the more expensive and difficult construction becomes, but there is a corresponding saving in cost of foundations and piers. Where the river is permanent, fast flowing, and carrying considerable debris in flood, then the cost of building adequate intermediate supports for the bridge is likely to be high. There will be physical limits on the maximum length of span for a given design that can be constructed, and these will have to be carefully balanced with the river conditions and foundation problems.

8.46 The alignment of a structure is usually determined by the geometry of the approach road. This may result in the bridge being ‘skewed’ in relation to the river. Both design and construction costs will be higher for a skewed structure than for one at right angles to the river. Local realignment of the approach road should be considered as an alternative to a skewed structure if adequate sight distances can be maintained.

8.47 A major cost may be the transport of materials to the bridge site. In inaccessible areas where existing roads or tracks are non existent, this problem becomes more acute and the use of construction materials near to the site becomes very economic. On low volume roads, the use of whole timber logs may be appropriate as the timber can normally be obtained virtually ‘free’ whilst cement and other conventional materials are expensive or unobtainable.

8.48 Costs do not rise gradually, but in a series of steps at particular loadings and spans. Single lane bridges can still be suitable for main roads if the capital cost advantage of doing this is substantial. This will usually be the case on long span bridges where the traffic flow is less than about 250 vehicles per day.

8.49 It is not possible to give definitive rules on which design is ‘best’ for a particular situation since much will depend on the terrain, river regime, materials, local skills and available plant.

8.50 Bridges can represent a significant proportion of the cost of a construction project and, if large structures are needed, they can outweigh other costs. Thus, even at the project feasibility stage, considerable attention must be paid to bridge costs and this cannot be done unless preliminary designs and a site investigation have been carried out. This design and costing should always be carried out by a structural engineer on the basis of prices obtained locally.

MAINTENANCE

8.51 If a structure is to perform adequately over its design life, it must be regularly inspected and maintained. The resources and capabilities of the department responsible for upkeep of the structure should be considered at the design stage if a truly cost-effective solution is to be found. Care taken to ensure that such critical details as bridge bearings and expansion joints are both maintenance-free as possible, and easily accessible, will ensure that expensive repairs are less likely to be required later. Steel components will require regular painting and the performance of timber will be radically affected by both the quality of the initial treatment and the avoidance of traps for moisture and debris in the design.

8.52 A cost-effective design will be that which most successfully takes account of local skills, materials, location, safety and maintenance capabilities.

FERRIES

8.53 Rivers do not have to be crossed by bridges. Another option is to improve or provide a ferry service. These are particularly applicable where the river channel is constantly changing. Where traffic levels are low and the river wide and slow-moving, they can be a cost-effective alternative and several designs of flat bottomed ferry are available. However, appraisals should take account of the delay to traffic introduced by the utilisation of ferries and both their capital and maintenance cost.
9. INTRODUCTION TO THE ASSESSMENT OF BENEFITS

9.1 In order to analyse a project, estimates need to be made, not only of the costs associated with the project, but also of the benefits that are expected to occur. Benefits normally considered are:

- direct savings on the costs of operating vehicles
- economies in road maintenance
- time savings by travellers and freight
- reduction in road accidents
- wider effects on the economic development of the region.

9.2 All types of benefits should be considered for all projects although, depending on the type of project, different benefits will predominate. It is possible for some benefits to be negative. Direct savings in vehicle operating costs will normally be the most significant benefit of inter-urban road projects in situations where the value of time is low. These roads carry relatively high traffic flows and their role is mainly to provide for the carriage of goods and people over long distances. Time and accident savings may also be significant for inter-urban projects. At the other extreme, rural access roads represent the grass roots of the road network which feed traffic onto the primary roads linking rural areas to the main network. They are generally short in length, have low traffic volumes and are usually constructed with earth or gravel surfaces. For these roads, economic justification for the investment rests mainly on the expected impact on rural and agricultural development. This benefit often manifests itself as generated traffic (see para 3.22-26) and, if development benefits and generated traffic are both being evaluated, it is important to ensure that 'double counting' of benefits does not take place in the appraisal.

9.3 Many developing countries are experiencing increasing pressure from their agricultural populations for rural road development and rural access roads can assist in the production of real wealth. Although criteria have been established whereby rural access road investment can be justified on grounds other than savings in vehicle operating costs, it should be recognised that the diversion of scarce resources to this sector can be at the expense of the standard and upkeep of the primary network. Interurban routes carry vastly higher traffic flows than the rural access road network and their upkeep is a high priority component of the roads budget. Furthermore, without a properly maintained primary road system, it may not be possible to realise all the potential benefits from rural access road improvements.

9.4 The assessment and valuation of benefits is discussed in more detail in the following sections which consider vehicle operating cost savings, road maintenance benefits, time savings, reduction in road accidents and economic development benefits. It is expected that transport planners will already have detailed knowledge of the methods used to assess these benefits. The following five sections are therefore written primarily for engineers, economists and administrators who may not have the practical experience of assessing the benefits of road projects.
10. VEHICLE OPERATING COST SAVINGS

Factors affecting vehicle operating costs

10.1 When a road improvement is undertaken, the owners and users of vehicles profit from reduced costs of transport. Higher average speeds can be maintained, and the more even running, with fewer gear changes and braking, may lead to savings in fuel consumption. Tyres last longer on improved road surfaces and there is less wear and tear on the suspension and body. These savings are perceived by road users in the form of lower expenditures.

10.2 Vehicle operating costs depend on the number and types of vehicles using the road, the geometric design standards of the road, particularly the curvature, gradient and road width, the condition of the surface of the road, primarily its unevenness or 'roughness', and driver behaviour. Changes in any of these parameters as a result of a project will result in a change in vehicle operating costs.

10.3 The components of vehicle operating cost with their approximate respective contribution to the total are given in Table 10.1.

<table>
<thead>
<tr>
<th>Component</th>
<th>Percentage contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Private cars</td>
</tr>
<tr>
<td>Fuel consumption</td>
<td>10-35</td>
</tr>
<tr>
<td>Lubricating oil consumption</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>Spare parts consumption</td>
<td>10-40</td>
</tr>
<tr>
<td>Vehicle maintenance labour hours</td>
<td>&lt; 6</td>
</tr>
<tr>
<td>Tyre consumption</td>
<td>5-10</td>
</tr>
<tr>
<td>Vehicle depreciation</td>
<td>15-40</td>
</tr>
<tr>
<td>Crew costs</td>
<td>0</td>
</tr>
<tr>
<td>Other costs and overheads</td>
<td>10-15</td>
</tr>
</tbody>
</table>

10.4 In feasibility studies, all costs and prices should be expressed in 'economic' as opposed to 'market' terms to reflect the use of real resources of the country's economy (see para 15.12-17).

ROAD INVESTMENT MODELS

10.5 Computer models are available for assisting in the calculation of vehicle operating costs under a range of conditions and of estimating vehicle operating cost savings as a result of road projects. The most well-known of these are 'micro-RTIM2' and HDM-II'. Micro-RTIM2 was developed for ODA by the TRRL Overseas Unit and is designed to be simple to use with a user-friendly input facility. HDM-II has been developed by the World Bank and is more comprehensive than the TRRL model. Both models run on a micro-computer. The models simulate the performance of a road over time and under traffic. Costs and benefits are determined by applying unit rates to quantities that are calculated; since these unit rates are supplied by the user, the models are applicable to a wide range of economic and financial environments. The effect on vehicle operating cost of the changing condition of the road surface is taken into account in the determination of costs and benefits.

10.6 The micro-RTIM2 model is normally run first for a 'do nothing' or 'do minimum case. A series of project options may then be run and, as each is completed, the results are compared with those of the 'do nothing' case to determine benefits. Net present values (see para 15.19-23) are then calculated over a range of discount rates (see para 15.9-11) chosen by the user, and the internal rate of return and first year rate of return are determined (para 15.25-27). The relationships in the model allow it to be used to study many aspects of a road investment project such as the optimum maintenance standards for the road, the choice of a gravel or bituminous pavement, and the benefits of adopting any number of different stage construction options. The model will also enable the study of uncertainties in traffic forecasts, in the selected discount rate or in any other variables.

10.7 Copies of the micro-RTIM2 program to run on a range of microcomputers may be obtained on application to:

Overseas Unit
Transport and Road Research Laboratory
Crowthorne, Berkshire RG45 6AU
United Kingdom

Copies of HDM-II for mainframe or IBM-compatible micros may be obtained from:

Transportation Department
The World Bank
1818 H Street NW
Washington DC 20433
United States of America

VEHICLE OPERATING COST TABLES

10.8 Tables for estimating vehicle operating costs can be obtained on written application from both TRRL Overseas Unit and the World Bank. These provide
convenient tools for estimating vehicle operating costs on low volume rural roads with free-flowing traffic. Costs have been divided into various components, for different classes of vehicle and for road surface types. The tables are given in terms of physical quantities or non-dimensional ratios and costs are obtained by applying the appropriate unit price to these. They can be applied to any monetary system or used in any appropriate environment and are useful where no computer or microcomputer facility is available.

DATA REQUIREMENTS

Measured values

10.9 In the TRRL investment model and vehicle operating cost tables, vehicle speed and operating cost have been related to the physical condition of the road and the characteristics of the vehicle, using relationships based on the results of empirical research. The following variables and units are used, and measurements of these should be made for existing roads and estimates made for road projects that are being appraised.

10.10 Road characteristics
- Rise (m/km)
- Fall (m/km)
- Curvature (degrees/km)
- Roughness (m/km)
- Road width (metres)
- Surface moisture content for gravel and earth roads (per cent)
- Rut depth (mm).

10.11 Vehicle characteristics
- Free speed in the environment under consideration (km/h)
- Vehicle weight (tonnes)
- Power to weight ratio (bhp/tonne)
- Vehicle age (km, yr)
- Annual utilisation (km, hr)
- Vehicle price
- Tyre price
- Price of fuel and lubricants per litre
- Price of maintenance labour per hr
- Vehicle crew cost per hr
- Overheads.

10.12 Climate
- Rainfall (mm/year).

10.13 It is essential that the user applies the best available estimates of the relevant physical quantities and vehicle descriptors in order to arrive at valid cost estimates whether using the tables or one of the investment models.

Relative importance of data items

10.14 In order to determine vehicle operating costs, it is necessary to obtain several items of data. The ease of collection of these items varies as does the relative impact that they have on the final value. The collection of data should be viewed against the background of the accuracy of the relationships used in the investment models and tables which is only of the order of plus or minus 25 per cent.

10.15 Data should be relatively easy to collect for rise and fall, curvature, road width, vehicle weight, power to weight ratio, vehicle and tyre prices, and prices for fuel for existing roads. Good estimates of these should therefore be obtained in all cases. For new roads, estimates must be made based on information collected on related roads and predictions made about any changes in the parameters that are likely to result from the project. Although data on surface moisture content, rut depth and lubricating oil are easy to collect, their effect on total vehicle operating costs is relatively small (see Table 10.1) and, when resources for data collection are severely limited, these values can be ignored or replaced by simple estimates.

10.16 If a change in vehicle operating cost following a road improvement is being determined, then the key variables will be the change in roughness, annual utilisation and vehicle age. These are all difficult items for which to obtain reliable estimates and considerable effort should be made to collect good data in these areas.

10.17 The input parameters are discussed further in the following sub-sections which contain suggestions and, where necessary, guidelines, for their use.

Physical parameters of the road

10.18 Rise and fall. The average rise and average fall per kilometre should be estimated separately. The accuracy of the estimates of rise and fall provided by the user will depend on the amount of information available for the study. In the absence of detailed engineering plans, reasonably accurate estimates can be extracted from large scale contour maps. Also, simple measurements of an existing road can be made using an abney level to measure the amount of rise and fall.

10.19 Horizontal curvature. Horizontal curvature is usually related to gradient, and sections of road which are similar with respect to rise and fall can be expected to have broadly similar horizontal curvature characteristics. The average value of curvature should be expressed in degrees of curvature per kilometre of road. The degree of curvature can be extracted from engineering plans or large scale maps. It can also be measured on an existing road using a prismatic compass.
10.20 **Roughness.** Many of the operating cost components are influenced by the surface condition of the road, measured primarily in terms of roughness. The measurement of roughness will normally be made with a ‘response-type’ instrument such as:

- TRRL integrator unit
- NAASRA meter
- Mays ride meter

The TRRL integrator unit is relatively cheap and easy to install and use but, whatever type of instrument is used for measuring roughness, it will be necessary to calibrate this to ensure that the results obtained are consistent with the standardised values used for vehicle operating cost calculations in the road investment models and vehicle operating cost tables. Equations now exist (Sayers et al 1986) for relating standard roughness values to the absolute longitudinal profile of the road. The response-type instruments used can be calibrated by running them over roads with various levels of roughness. The longitudinal profile can be determined by measuring the road with an engineer’s rod and level. However, this method is laborious and the calculations needed to determine the calibrated values are time consuming. An instrument has been developed at TRRL for calibrating response-type roughness measuring devices more easily and this is known as the ‘Abay beam’. This contains an on-board microprocessor and, when the machine is used on the road, an automatic readout of calibration roughness is obtained.

10.21 In the past, roughness has been measured in units of ‘mm/km’ based on a BI trailer towed at 32 km/h. These units can be converted to international standard (IRI) values using the following equation:

\[
m/km \text{ IRI} = 0.0032 \times (\text{mm/km BI})^{0.89}
\]

10.22 In the absence of any information for assessing the surface condition of the road, the user will require some guidance on estimating the roughness of the road under study. A range of roughness values are given in Table 10.2 below. These values provide very broad guidelines by basically demarcating different pavement types in terms of a range of roughness.

10.23 The value of roughness used should be the average value experienced by vehicles over the period for which operating costs are being calculated. Although estimates need only be made to the nearest 0.5 m/km, the value used will have a significant effect on the magnitude of the operating costs and some effort needs to be made to determine the appropriate value.

10.24 Road width. As noted in Section 7, for free-flow traffic conditions, width has little effect on speed for wide roads but, on narrower roads, the speeds are reduced. Therefore, an estimate of road width is required. On existing roads, a reasonable estimate can be obtained by making a few sample measurements with a tape measure.

10.25 **Surface moisture content.** On unpaved roads, the moisture content of the road surface affects its slipperiness and hence the speeds of vehicles, but its effect on cost is small. The use of values of zero for dry zones (annual rainfall less than 750 mm) ranging up to six per cent for very wet zones (annual rainfall greater than 1750 mm) is recommended.

10.26 **Rut depth.** The rutting of unpaved road surfaces reduces the speeds of vehicles to a small extent. Rut depth is measured under a two metre straight edge placed across the wheel track. Average values varying from 10 mm for unpaved roads in good condition to 50 mm for roads in very poor condition are common.

**Vehicle descriptions**

10.27 **Free-speed of vehicles.** In order to estimate the average speed of vehicles on the road under investigation, it is necessary to determine the free-speed of each class of vehicle in the environment under investigation. This is defined as the average speed at which vehicles of different classes will travel on uncongested, flat, straight, smooth and wide sections of road in the particular environment. These speeds have been found to be affected by the general layout of the roads in the area through differences in driver behaviour and vehicle performance. For example, vehicles operating in a hilly or mountainous region are found to have considerably lower free-speeds than those of vehicles operating in flat or rolling open terrain. Similarly, the free speeds of vehicles operating in countries where straying animals are common, or that tend to have slow-moving animal-drawn carts, are found to be lower than in countries where this tends not to happen.

10.28 The user should conduct a vehicle speed survey where the speeds of the various classes of vehicles are recorded on a flat, straight, smooth and wide section of road. The average speed for each class of vehicle will be the free speed for that class for the environment under investigation.

10.29 **Vehicle weight.** Fuel and tyre consumption are influenced by the weight of light vehicles, trucks and buses. The best estimates of vehicle weights for different classes of commercial vehicle can be found from axle-load surveys conducted on the route under study (see Section 6). In the absence of information from such surveys, a knowledge of the nature and type of goods transported on the route together with the size distribution by carrying capacity of commercial vehicles will help to provide reasonable estimates of the average vehicle weight.
<table>
<thead>
<tr>
<th>Serviceability description</th>
<th>m/km</th>
<th>mm/km</th>
<th>Serviceability description</th>
<th>m/km</th>
<th>mm/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ride comfortable over 120 km/h. Undulation barely perceptible at 80 km/h in range 1.3 to 1.8. No depressions, pot-holes or corrugations are noticeable: depressions &lt;2 mm/3 m. Typical high quality asphalt 1.4 to 2.3. High quality surface treatment 2.0 to 3.0.</td>
<td>1.5–2.5</td>
<td>1000–2000</td>
<td>Recently bladed surface of fine gravel, or soil surface with excellent longitudinal and transverse profile (usually found only in short lengths).</td>
<td>1.5–2.5</td>
<td>1000–2000</td>
</tr>
<tr>
<td>Ride comfortable up to 100 - 120 km/h. At 80 km/h, moderately perceptible movements or large undulations may be felt. Defective surface: occasional depressions, patches or pot-holes (eg 5-15 mm/3m or 10-20 mm/5m with frequency 1-2 per 50 m or many shallow pot holes (eg on surface treatment showing extensive ravelling). Surface without defects: moderate corrugations or large undulations.</td>
<td>4.0–5.5</td>
<td>3000–4000</td>
<td>Ride comfortable up to 70-80 km/h but aware of sharp movements and some wheel bounce. Frequent shallow-moderate depressions or shallow pot-holes (eg 6–30 mm/3 m with frequency 5–10 per 50 m). Moderate corrugations (eg 6–20 mm/0.7–1.5 m).</td>
<td>3.5–4.5</td>
<td>2500–3500</td>
</tr>
<tr>
<td>Ride comfortable up to 70–90 km/h, strongly perceptible movements and swaying. Usually associated with defects: frequent moderate and uneven depressions or patches (eg 15–20 mm/3 m or 20–40 mm/5 m with frequency 5–3 per 50 m) or occasionally pot-holes (eg 1–3 per 50 m). Surface without defects: strong undulations or corrugations.</td>
<td>7.0–8.0</td>
<td>5500–6500</td>
<td>Ride comfortable at 50 km/h (or 40–70 km/h on specific sections). Frequent moderate transverse depressions (eg 20–40 mm/3–5 m at frequency 10–20 per 50 m) or occasional deep depressions or pot-holes (eg 40–80 mm/3 m with frequency less than 5 per 50 m). Strong corrugations (eg &lt;20 mm/0.7–1.5 m).</td>
<td>7.5–9.0</td>
<td>6000–7000</td>
</tr>
<tr>
<td>Ride comfortable up to 50–60 km/h, frequent sharp movements or swaying. Associated with severe defects: frequent deep and uneven depressions and patches (eg 20–40 mm/3 m or 40–80 mm/5 m with frequency 5–3 per 50 m) or frequent pot-holes (eg 4–6 per 50 m).</td>
<td>9.0–10.0</td>
<td>7000–8000</td>
<td>Ride comfortable at 30–40 km/h. Frequent deep transverse depressions and/or pot-holes (eg 40–80 mm/1–5 m with frequency less than 5 per 50 m) with other shallow depressions. Not possible to avoid all the depressions except the worst.</td>
<td>11.5–13.5</td>
<td>9500–11500</td>
</tr>
<tr>
<td>Necessary to reduce velocity below 50 km/h. Many deep depressions pot-holes and severe disintegration (eg 40–80 mm deep with frequency 8–16 per 50 m).</td>
<td>11.0–12.0</td>
<td>9000–10000</td>
<td>Ride comfortable at 20–30 km/h. Speeds higher than 40–50 km/h would cause extreme discomfort, and possible damage to the car. On a good general profile: frequent deep depressions and/or pot-holes (eg 40–80 mm/1–5 m at frequency 10–15 per 50 m) and occasional very deep depressions (eg &lt;80 mm/0.6–2 m). On a poor general profile: frequent moderate defects and depressions (eg poor earth surface).</td>
<td>20.0–22.0</td>
<td>18000–20000</td>
</tr>
</tbody>
</table>
of the different classes of vehicle. The value used should be the total weight of the vehicle over the period for which the operating costs are being determined. This involves making an estimate of the loads carried by the vehicles and the amount of unladen running.

10.30 **Power to weight ratio.** The power to weight ratio is the net brake horse power per tonne of the gross vehicle weight. If an axle-load survey is carried out this could also be used to provide information on the brake horse power of the various classes of commercial vehicle using the route, and so enable the average brake horse power per tonne of vehicle weight to be calculated. Table 10.3 gives examples of commercial vehicles by type and average brake horse power and the power to weight ratios for different conditions of load. They are representative of the type of vehicles operating in most developing countries.

10.31 **Vehicle age.** In order to determine vehicle operating costs, vehicle age needs to be determined as the total distance run since new as well as in years. The age in kilometres is a significant factor in determining average vehicle repair costs and the age in years is used to determine depreciation. Normally average values for vehicle classes will be used in the calculation of the vehicle operating cost components. Vehicle age spectra, both in terms of kilometres and years, vary widely from country to country, and it is vital that good information is collected in the field in all cases. This is emphasised because the components of depreciation and repairs normally form a significant proportion of total vehicle operating costs (see Table 10.1). The value of age in kilometres used should be that at the end of the year for which the operating cost is being evaluated, whereas the age in years should be the mid year value.

10.32 **Annual utilisation.** Vehicle utilisation in hours per year is used directly to determine annual crew costs and to apportion annually accruing costs such as depreciation and overheads on to a kilometre basis so that they can be related to usage on particular roads. Utilisation in kilometres per year is important because, when multiplied by vehicle age, is used to determine spare parts costs. These costs are normally some of the largest components of vehicle operating cost (see Table 10.1), so the need to collect good local data on utilisation is emphasised.

10.33 **Vehicle price.** Average vehicle price is used to determine depreciation costs and, in the TRRL investment model and operating cost tables, is also used to determine spare parts costs. Both these costs are a significant proportion of the total cost (Table 10.1) and are highly sensitive to the initial vehicle price. Good local data should be collected and this is normally easy to do. Price values should be obtained for the mid point of the year for which costs are being evaluated.

10.34 **Tyre price.** This obviously affects the cost of tyre wear and local data is easily obtainable. Mid year values should be used.

10.35 **Price of fuel and lubricants.** Information on prices of these commodities is easy to collect locally. Again, mid year values should be used.

10.36 **Price of maintenance labour.** This is needed to determine the labour component of fitting spare parts and

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Unladen weight</th>
<th>Half laden weight</th>
<th>Fully laden weight</th>
<th>Average bhp</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>p/w</td>
<td>p/w</td>
<td>p/w</td>
<td></td>
</tr>
<tr>
<td>Two axle, petrol engine</td>
<td>2</td>
<td>2.5</td>
<td>3</td>
<td>76</td>
</tr>
<tr>
<td>Three axle (rigid)</td>
<td>9</td>
<td>16</td>
<td>24</td>
<td>150</td>
</tr>
<tr>
<td>Three axle (articulated)</td>
<td>9</td>
<td>16</td>
<td>11</td>
<td>165</td>
</tr>
<tr>
<td>Four axle draw-bar trailer</td>
<td>12</td>
<td>15</td>
<td>8</td>
<td>177</td>
</tr>
<tr>
<td>Six axle draw-bar trailer</td>
<td>14</td>
<td>13</td>
<td>7</td>
<td>177</td>
</tr>
</tbody>
</table>
repairing vehicles, although its contribution to vehicle operating cost is relatively small (Table 10.1). It is important that prices include all supervision and overhead costs otherwise underestimates will be made. Prices will vary between countries and also within a country depending on the size and type of workshop carrying out repairs. A weighted average of unit prices should be used between large and small repair workshops depending on the proportion of vehicles on the project road that are repaired in each. This proportion is easily estimated from information collected in origin and destination surveys (see Section 3).

10.37 **Vehicle crew cost.** Crew cost is normally included as a vehicle operating cost rather than as a time cost. It is determined by the number of crew that a vehicle carries, their wages and the overheads of employing them. As in the case of maintenance labour prices, the crew cost will depend on the size and type of organisation operating the vehicle, and unit values should be based on weighted averages in a similar way. Crew costs can be a significant proportion of the total cost for commercial vehicles (Table 10.1).

10.38 **Overheads.** This component of vehicle operating cost includes such items as interest on capital and garaging. Insurance costs may also be included as a surrogate for accident costs. Maintenance labour costs should not be included here to avoid double counting. The costs will vary from country to country and, depending on the size of the transport operator, will vary from company to company. A weighted average of costs should be used to represent typical vehicles on the road under study. Overheads can represent a significant proportion of operating costs and, although good data is sometimes difficult to collect, considerable effort should be made.

**DETERMINING COSTS**

10.39 The vehicle operating cost relationships included in the road investment models and tables are appropriate for use in most developing countries with the exception of those for vehicle depreciation which may differ in countries where import policies influence the age spectrum of vehicles. This does not mean that the relationships are ‘perfect’, but that it is unlikely that economists, planners and engineers carrying out feasibility studies can produce better relationships in the time available during an appraisal mission. However, it is vital that the project report provides evidence of having collected data from vehicle operators to check that the size of the operating costs predicted by the investment models or tables is correct for the country and the projects in question. If the size differs considerably, the appraisals should determine why this has occurred and vehicle operating costs should be computed manually purely from local information. In this case, the tables of vehicle operating cost may prove useful to determine the change in vehicle operating costs with road geometry, surface condition, etc.

10.40 Road improvements do not necessarily lead to reductions in all components of vehicle operating costs. When a gravel road is paved, lower values of roughness reduce fuel consumption, but increases in speed have the opposite effect, with the result that fuel consumption is often virtually unchanged. Spare parts requirements depend on roughness values and vehicle age in kilometres, hence road improvements that result in increased vehicle utilisation will tend to increase costs whereas roughness reductions will lower costs. Depending on the relative effect of these parameters, the cost of the spare parts replacement component can either increase or decrease. Nevertheless, when all components are considered, road improvements normally reduce vehicle operating costs, but these examples emphasise the need to collect data and determine costs specifically for each individual project.

10.41 For road upgrading projects, vehicle operating costs should be estimated for the existing road and the new project. Savings in vehicle operating cost for normal traffic represent a direct benefit of the project. Where the project results in traffic diversion taking place, all vehicle operating costs on both the road from which the diversion has taken place and on the project road should be considered when determining benefits. Benefits accruing to any traffic generated by the project are discussed in para 14.7-11. For upgrading projects for arterial and collector roads, vehicle operating cost savings for normal traffic will usually be the largest project benefit. For rural access roads, where traffic flows are low, vehicle operating cost savings may be insignificant. Road maintenance projects usually reduce roughness values and, hence, affect vehicle operating costs.
11. ROAD MAINTENANCE BENEFITS

11.1 Despite the difficulties experienced by many developing countries in carrying out adequate maintenance (see para 2.22-26), savings in road maintenance cost are a potential benefit from many types of project and are particularly welcome because they release scarce resources for maintenance of other roads.

11.2 Maintenance savings can normally be obtained with the following types of project:

- Paving a gravel road where traffic levels have increased
- Strengthening or reconstructing a road which has deteriorated badly.

PAVING GRAVEL ROADS

11.3 In order to keep gravel roads in an acceptable and economic condition, their surface will normally need grading several times a year and regravelling every few years. The frequency at which these activities are needed depends on the level of traffic, the type of gravel material and the climate. As traffic levels increase, the frequency of the maintenance activity needs to be increased and eventually the cost of maintenance is so high, that it becomes cheaper to provide a paved road.

11.4 The actual traffic level at which paving becomes economic should normally be determined using one of the investment models described in Section 10. It is not possible to give recommended traffic levels, because these values will depend on the relative costs of grading, regravelling and paving which, in turn, will depend on local circumstances. The higher the relative cost of grading and regravelling, the lower will be the traffic level at which paving becomes justified.

11.5 A further difficulty is that sources of good road building gravel are becoming scarce in many developing countries with the result that haul distances and costs are increasing. It may therefore be appropriate in appraisal studies to re-estimate the unit cost of regravelling during the life of the project to take account of this. A consequence of this will be that, in some cases, it may be appropriate to pave a road earlier and at a lower traffic level than was previously the case.

11.6 In arid areas, unpaved roads are often affected by dust. Dust is a maintenance problem because it results in the loss of material from the road surface which has to be replaced. It is a contributory factor to road accidents because of the reduction in visibility and it also pollutes the atmosphere close to the road and may reduce the value of crops. Hence, road safety and environmental benefits and agricultural benefits may arise as a result of paving gravel roads, but these are difficult to quantify in an economic analysis.

11.7 Where economies in maintenance are made as a result of paving gravel roads, vehicle operating cost savings will also normally be made. These two benefits are linked closely together and road investment models are therefore very appropriate for carrying out the analysis.

STRENGTHENING AND RECONSTRUCTION

11.8 A bitumen road with a rapidly deteriorating surface needs increasing amounts of maintenance if it is to continue serving its intended purpose. A bitumen road may require the patching of pot-holes, repair of eroded edges, and the sealing and repairing of cracked areas. Compared to this, the overlaying or reconstruction of the road can produce immediate savings by eliminating the need for continuous recurrent maintenance, although future periodic maintenance will still be needed. It is, however, important to strengthen pavements before they deteriorate to the extent that their structural integrity is lost.

11.9 Road investment models can be used to assess maintenance benefits in these cases, but their use is limited because the modelling of badly maintained pavements that are in poor condition is not very accurate. Thus, any assessments of maintenance benefits for this situation which have been derived using investment models should be treated with caution.

11.10 The cost of strengthening and reconstructing paved roads is considerably greater than the annual cost of routine, recurrent and periodic maintenance, so it will be unusual for projects of this nature to be justified solely on the grounds of economies in maintenance. Projects will normally be justified principally on vehicle operating cost savings and any maintenance savings will increase the benefits and lead to a higher rate of return.

CONCRETE ROADS

11.11 Where traffic levels are rising rapidly, and particularly when large increases in goods vehicles can be expected, the provision of a concrete surfacing to an existing gravel road may prove to be economically justified. Similarly, concrete overlays to existing bituminous surfacings are likely to reduce future maintenance costs. Experience of the construction of concrete pavements is limited at present to very few developing countries and experience of concrete overlays is almost entirely limited to Europe and North America. The use of these techniques should therefore be treated
with caution, particularly as the investment models currently available cannot assess their viability.

DIVERTED TRAFFIC

11.12 If significant traffic diversion from other roads is expected to take place as a result of a new project (see para 3.19-21), then the changing maintenance needs on the road from which the diversion took place should be considered in the assessment of benefits. Reduced maintenance needs on the existing network will normally result in a small benefit to the project, although this may be offset by an increased cost of maintenance on the project itself.

TRAFFIC DELAYS DURING MAINTENANCE WORKS

11.13 When large scale maintenance and renewal works take place on heavily trafficked roads, delays to traffic and increased accidents are likely to occur. For project appraisal purposes, where future strengthening or stage construction is being planned, these additional costs should ideally be taken into consideration as part of the appraisal. However, where these works are taking place in the later years of the project's life, the effect of additional costs of delay and accidents on the outcome of the project are likely to be small in present value terms on all but the most heavily trafficked roads because of the effect of discounting (see para 15.2-11). In these cases, lump sum estimates should be made of the additional costs for heavily trafficked roads; additional costs can be ignored on lightly trafficked roads.

11.14 However, where the project is for the upgrading of an existing paved road to provide additional capacity or structural strength, the additional costs will occur early in the project's life and are therefore more likely to influence the choice or timing of the capital investment. The costs of traffic delays will increase if projects are delayed, because traffic levels will be higher. For very heavily trafficked roads, a more rigorous estimate may be appropriate.

DETERMINING COSTS

11.15 Maintenance costing systems that are implemented in organisations are often not accurate enough for determining maintenance cost savings. Typically, costing systems undervalue the costs of owning and operating plant and equipment by a significant amount by failing to include interest charges or even the replacement cost of the equipment. Costing systems seldom include realistic overheads for employing personnel and providing buildings and other facilities. The result is that real costs are commonly more than 100 per cent greater than those quoted by roads departments. The quality of field recording of activities and expenditures is usually very poor with the result that the usefulness of the data collected is very doubtful. Many costing systems in use only attempt to provide details of total expenditure for budgetary purposes and it is not possible to identify in detail the activities on which expenditures have taken place.

11.16 Against this background, it is difficult to obtain realistic unit costs which can be used to determine maintenance savings for many countries. However, in most cases, projects will not be justified solely on the grounds of maintenance savings as these will be small in comparison with savings in vehicle operating costs. Nevertheless, maintenance cost estimates are a necessary part of appraisal, including cases where they are a negative benefit, and an attempt to collect good local cost information must be made. Available records in maintenance organisations must be examined to provide the basis of cost estimates, but these should be reviewed in the light of knowledge of how the records are obtained. In all cases, the sensitivity of benefits to large potential errors in the cost estimates should be determined.
12. TIMESAVINGS

GENERAL CONSIDERATIONS

12.1 Journey time savings can represent a large proportion of a project's benefits. The benefits of shorter journey times will accrue to the vehicle fleet, in that greater vehicle productivity can be achieved, and to the passengers and freight being carried. A general discussion of some of the principles involved in the valuation of time savings is given below, together with a suggested approach to their quantification and incorporation in a feasibility study.

VEHICLE FLEET

12.2 Consider first vehicles which are used exclusively for commercial purposes such as buses and lorries. When travel time is reduced, the time saving can in principle be used to make further journeys, and hence productivity per vehicle rises and the size of fleet necessary to support the current demand for transport can be reduced. This reduction in fleet size means a reduction in those elements of the fleet operating costs which are classed as standing costs, notably crew wages, vehicle depreciation and interest on capital. By using appropriate values of vehicle utilisation in the 'with' and 'without' project cases, these cost savings will be determined directly.

12.3 It is often argued that, in practice, time savings cannot be properly utilised and, as a result, will not lead to pro-rata reductions in fleet size. The reasoning for this is that currently most journeys are 'quantised' as round trips, such as a complete circuit of a bus route, or a delivery made by road where the lorry both starts and ends its journey at its base. If travel time on any of these journeys were saved, the chances are that it would be insufficient to permit another round trip during the same working day and, as completion of only part of the trip within a working day is not acceptable, the time saved could not be usefully employed. One of the problems with this kind of argument is that, in some instances, the time saving might just be adequate to allow another round trip and, in these cases, the benefits could be far more than simply pro-rata. Overall, one has to try and visualise a pattern of use which fairly represents the whole of the current pattern. Unfortunately, it has to allow, for example, for the possibility, in the case of buses, of extending the route, having additional stops, etc and, in the case of lorries, of loading the night before, staying out overnight, etc. Additionally the demand for transport is subject to fluctuations and long-terms trends, and travel times themselves may also be subject to fluctuations and trends for reasons not associated with the project under review. Clearly, providing a long-term realistic and representative picture is overwhelmingly difficult in all but the very simplest of situations.

12.4 Looking at the problem from an overall point of view, because of the discrete nature of most activities, the vehicle fleet cannot be productively employed for 100 per cent of the working day. If, after the project is completed, vehicles on average are working for the same proportion of the working day as in the before situation, this is equivalent to saying that time savings are fully used. To assume that, in the long term, time savings should not be costed as if the time were fully used is to imply that there is some special feature of the before situation which gives rise to an efficient use of time which will never be matched in the after situation.

12.5 It may well be that adaptation of current transport activity to take full benefit of the reduction in travel time brought about by the project will not be immediate. However, it would be difficult to judge the true form of the lag between change and benefit on the basis of detailed examination of the activities of individual operators. On the whole, unless other reliable information is available, it is safest to assume that all time benefits are available at once.

12.6 In the case of privately owned cars, then the above discussions are less appropriate. The demand for transport by a car owner is not shared between a number of vehicles but falls just on his own vehicle. If his travel time on a particular journey were to fall, this is unlikely to reduce directly the number of vehicles owned. It may well encourage the car owner to make more journeys, but the treatment of this is separately dealt with in the discussion on traffic generation benefits (para 14.7-11). Taxis should be considered in the same way as other commercial vehicles.

VEHICLE OCCUPANTS

12.7 Travel time savings for passengers in buses and the occupants of private cars may occur either during working or non-working time. Time savings during working hours can be used for productive purposes to increase the GNP. Non-working time savings do not increase national production but, since there is evidence that people are prepared to pay for time savings that occur in non-working time, such savings must be perceived as increasing their welfare.

12.8 If working time is spent travelling, the value of that travelling time is clearly equal to the wage rate plus those costs to the employer which are directly associated with the costs of employment. In practice, the situation is not so straightforward. There are imperfections in the labour market, especially where minimum wage legislation exists, where there are high rates of unemployment, or significant levels of under employment. Despite these problems, it is usually assumed that working time savings should be equated to the average wage rate plus
overheads associated with employment, such as pensions, insurance, etc, shadowed priced if appropriate (see para 15.12-17).

12.9 The value of non-working time is usually based on perceived cost studies. Most of the research into perceived costs has taken place in the developed world, but similar results have been found in studies undertaken in developing countries. The studies show that the value put by individuals on journey time savings accruing outside working hours is between 25-45 per cent of their earnings and that higher unit values of time saving should be ascribed to higher income groups than to lower income groups. In practice this is rarely done because it is considered inequitable. In the United Kingdom, for example, a flat rate equivalent to 43 per cent of the average hourly earnings is used in the evaluation of non-working time travel savings for full time adult employees. This value is an average of both commuting and leisure time. Where governments wish to adopt a policy that maximises GDP rather than leisure time preferences, a zero value should be used for leisure time whilst maintaining working time values. To use a percentage of the average wage may lead to an underestimate of time costs in developing countries because only the comparatively wealthy can afford to travel, even by bus, and certainly by car.

12.10 Other problems occur in the valuation of passenger time savings. The distinction between working and non-working time is not always clear cut, especially when many trips are multi-purpose. Marginal values of time may vary for the same individual, depending on the activities for which the time saved is used. The value of time is normally a function of factors other than a tradeoff between time and cost, such as comfort and convenience, and in the UK, for example, walking and waiting times are valued more highly than travelling times.

12.11 As a general guide, the following approach should be adopted:

(i) Measure time savings separately for working time and leisure time, as a minimum,
(ii) In the absence of better data, value working time at the average wage rate in the monetised economy, plus overheads,
(iii) Value non-working time in the range zero to 45 per cent of working time, unless there special reasons for attributing at higher value. It would normally be expected that values would be at the lower end of this range.

FREIGHT

12.12 The cost of delays in moving goods consists chiefly of costs due to interest on the capital which the goods represent, costs due to damage or spoilage of perishable goods, and ancillary costs which arise as a consequence of journey time, for example, where a piece of equipment is immobilised while waiting for a spare part. The cost of interest on capital is normally very small compared to the other elements of vehicle operating costs. Costs due to spoilage or damage may be significant, but care must be taken to ensure that a reduction in spoilage or damage of perishable goods is due primarily to reductions in journey time rather than the provision of a smoother road. If it is the latter, and this is more usually the case, then the cost savings should still be credited to the project but, strictly, not be allocated as a time saving.

12.13 Studies of modal choice for goods travelling by road and other modes have suggested that, even for nonperishable goods, consignors are usually willing to pay far more than interest cost on the goods to reduce travel time or to reduce uncertainty in time of delivery. This presumably reflects the size of the ancillary costs mentioned above.
13. REDUCTION IN ROAD ACCIDENTS

FORECASTING ACCIDENT REDUCTIONS

Factors leading to reductions

13.1 Although accidents are one of the inevitable costs of road transport, there are nevertheless a number of measures which can lead to their reduction with corresponding reductions in costs. Road accidents should therefore be included in an economic analysis of road improvements.

13.2 The factors contributing to road safety are usually referred to as the three ‘E’s: engineering, education and enforcement. Both education and enforcement fall outside the scope of this Note and will not be discussed further. However, it must be appreciated that these factors interact, and different combinations of factors are likely to have different impacts. Consequently, it is important that countries adopt a coordinated approach to road safety at national, regional and local levels.

13.3 The engineering factor can itself be broken down into five categories:

- geometric design
- road surfaces
- road markings and delineation
- road signs, streetlights and other road furniture
- traffic management.

13.4 The relationship between the various components of the engineering factor have been widely researched in industrialised countries and, although the findings are not totally clear cut, individual industrialised countries are able to make some predictions for accident reduction.

13.5 However, in developing countries, only a very few studies have been carried out and, at this stage, predictions cannot be made with any certainty. Also, many of the results indicate that the findings from developed countries cannot be directly transferred to the third world because of the different physical, cultural and traffic conditions found in typical developing countries.

13.6 In spite of this scarcity of data, specific comments on the effects of highway engineering improvements on accident rates in developing countries can be made. Examples of where appropriate engineering design can reduce accident rates are given in Fig 13.1. In considering these effects, a distinction can be drawn between:

- accident reduction resulting from low cost engineering counter measures introduced to improve the safety of specific sites.

Effect of highway design

13.7 The majority of highway design and safety studies in developing countries have investigated the correlation between personal injury accident rates and certain geometric design characteristics for rural roads. These have indicated that the number of junctions per kilometre appears to be the most significant factor related to accident rates, followed by improvements in horizontal and vertical curvature. In most of the countries studied, there was little variation in road width, so no conclusions could be drawn on the effect of this. However, in the one country where considerable variation did occur, road width was found to be a significant factor affecting accident rates. The data suggested that, on a range of roads carrying between 200 and 2000 vpd, an increase in width from 5 metres to 7 metres might reduce the accident rate by 40 per cent.

13.8 High accident rates were observed on gravel roads. Among the possible causes of this might be poor geometry, slipperiness of the surface in wet weather and poor visibility caused by dust and high vehicle speeds. Since, in two of the countries studied, accident rates reduced with reduced road roughness, it is likely that by paving gravel roads, accident rates will be reduced.

13.9 Further results obtained, suggest that the construction of a new dual carriageway road carrying up to 20 000 vpd between major towns can reduce all injury accidents by up to 50 per cent and fatal and serious accidents by about 25 per cent.

13.10 The effects of the different improvements in highway design are not additive and there is clearly a limit to the likely benefits that can be obtained from improved design. From the above results, it may be possible to expect up to a 40 per cent reduction in accident rates on an existing road with improvements in geometric design and planning.

Low cost remedial measures

13.11 There is increasing evidence from developed countries that the combination of relatively detailed local accident investigation with low cost engineering remedial measures, can be highly cost-effective. Because driver behaviour and knowledge are much poorer in developing countries than in industrialised countries, it may well be that engineering measures that are ‘self enforcing’, such as median barriers, guard rails, pedestrian segregation, etc, prove effective, whilst measures such as improved signs, road markings and speed limits may not. There is
<table>
<thead>
<tr>
<th>Route planning</th>
<th>Undesirable</th>
<th>Desirable</th>
<th>Principle applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>+ Land use controls</td>
<td></td>
<td></td>
<td>Major routes should by-pass towns and villages</td>
</tr>
<tr>
<td>Town planning</td>
<td></td>
<td></td>
<td>Maximum possible use of cul-de-sacs and loops in residential areas</td>
</tr>
<tr>
<td>Road layout</td>
<td>(i)</td>
<td>(ii)</td>
<td>Gently curving roads have lowest accident rates</td>
</tr>
<tr>
<td></td>
<td>(iii)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roadside access</td>
<td></td>
<td></td>
<td>Prohibit direct frontal access to major routes. Use Service Roads</td>
</tr>
<tr>
<td>Pedestrian and animal footpaths</td>
<td></td>
<td></td>
<td>Seal shoulder and provide rumble divider when pedestrian and animal traffic is significant</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Construct protected footpath for pedestrians and animals on bridges</td>
</tr>
<tr>
<td>Junction layout</td>
<td></td>
<td></td>
<td>Avoid crossroads</td>
</tr>
<tr>
<td></td>
<td>(a)</td>
<td>(b)</td>
<td>For driving-on-the-left, right-hand splayed T-junctions have best safety records</td>
</tr>
<tr>
<td></td>
<td>(a)</td>
<td>(b)</td>
<td>(a) Local widening at T-junctions can be highly cost-effective</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(b) Roundabouts have best safety record (in UK)</td>
</tr>
</tbody>
</table>

Fig.13.1 Examples of effect of engineering design on road safety
some evidence to suggest that these measures can be made effective if coupled with improved enforcement techniques.

**Effects of traffic**

13.12 If accident savings are to be included in highway project analysis, another factor that needs to be taken into account is that of the relationship between accident rates and traffic flow. Work on this subject tends to be inconclusive, even in the developed world. This uncertainty can be largely attributed to the multi-causal nature of accidents.

13.13 From an appraisal of work carried out in industrialised countries on lightly trafficked rural roads, it would appear that the number of single-vehicle accidents per unit of vehicle distance travelled, tends to decrease with increasing traffic, whilst the number of collisions between two or more vehicles tends to increase. With the scarcity of data available, the most sensible approach when estimating changes in accidents with traffic flow is to assume that they increase at the same rate.

**ROAD ACCIDENT COSTS**

**Material and subjective factors**

13.14 Whilst it is not easy to attribute monetary values to the losses arising from accidents, estimates of the magnitude of the material costs are an essential aid to decision-making in the road safety aspects of highway engineering projects. Accident costs are also needed for the appraisal and optimisation of road safety countermeasures. Resources for countermeasures are usually limited and, in the absence of accident costs, it would clearly be difficult to make an objective assessment of which proposed projects should be given priority.

13.15 Costs of road accidents arise from three areas:

- Damage to vehicles and other property
- Costs of police work, hospital treatment, administration, etc
- Loss of life and injury.

13.16 All losses which result directly or indirectly from the occurrence of road accidents should be incorporated into the cost analysis. Certain losses, such as damage, police and hospital costs, involve material resources and are normally readily defined, even though their values may be uncertain. They can be translated into economic terms without great difficulty. Costs relating to the loss of life and injury are subjective, involving the need to value human life and 'pain, grief and suffering'. It is conceptually awkward to assign monetary values to these.

13.17 Practical problems which are encountered when measuring material costs are frequently due to the ambiguity of the definitions used. In other cases, estimates have to be based on numerous assumptions because of limited empirical evidence. Therefore, it is not possible to give a 'correct' figure for accident costs, and estimates of costs, whatever their origin, must be interpreted and used with discretion. Accident cost studies should be used as an aid to decision making and not be regarded as definitive.

**Methods available for costing road accidents**

13.18 The selection of an accident cost methodology must be related to the objectives being pursued by the agency that will ultimately use the costs obtained. Three broad classes of objectives can be identified which encompass the primary goals of the majority of planners in developing countries:

- National output objectives such as maximisation of Gross National Product (GNP) or national income
- Social welfare objectives such as the minimisation of all types of accidents in the interests of the well-being of the community
- Mixed objectives whereby governments combine the above objectives in various forms; this inevitably leads to the trading-off of one objective against another.

13.19 All methods that have been used in the past for costing or valuing accidents have included the material or real resource costs of the accident in terms of damage, medical and police reports, etc. The contentious issue of valuing human life has been dealt with in a number of ways, as follows.

13.20 **Gross output** (or 'human capital') approach. The value of human life is taken as the discounted present value of the victim's future output.

13.21 **Net-output** approach. This differs from the 'gross output' approach only to the extent that the present value of the victim's future consumption is subtracted from the gross output figure.

13.22 **Life insurance** approach. The value of life is defined as the amount for which individuals are willing to insure themselves.

13.23 **Court award** approach. The sums awarded by the courts to the surviving dependants of those killed are treated as indicative of the cost that society associates with a fatality, or the value that it would have placed on its prevention. Real resource costs are then added to this figure to obtain the cost of an accident.
13.24 **Implicit public sector valuation** approach. This attempts to determine the costs and values that are implicitly placed on human life in safety legislation, or in public sector decisions, taken either in favour, or against, investment programmes that affect safety.

13.25 **Value of risk-change** approach. Each individual has their chance of being involved in a fatal accident reduced by a small margin if a road safety improvement is introduced. Thus, the value of preventing one fatality in one accident is defined as the amount, in aggregate, that all the affected individuals in society are willing to pay for these small risk reductions.

13.26 Whichever method is used, a significant sum may also be added to compensate for pain, grief and suffering. The value of this is also very contentious.

13.27 Not surprisingly these different approaches generate substantially different costs and values for accidents involving one fatality. Depending on which method is used, the cost of an accident involving a fatality can vary by several orders of magnitude.

### The relevance of alternative methods for developing countries

13.28 Typically, government objectives will involve the maximisation of either national output or social welfare. Two accident costing/valuation methods which are directly relevant to these are the 'gross output' and the 'value of risk-change' methods. There are practical problems in recommending that one or other of these objectives be followed without modification. Firstly, reliable data is essential and, secondly, practical and political problems may deter governments and their agencies from implementing certain objectives.

13.29 Since resource costs such as vehicle damage, police and medical costs, together with net output losses, form a common component of both gross output and value of risk-change, these should be regarded as an absolute minimum cost of an accident or value of accident prevention. If the maximisation of GNP is an important criteria for decision takers in developing countries, then a costing/valuation method based upon gross, rather than net, should be used. It should be borne in mind that this method does not take into account society's aversion to death. To resolve the latter, a component for pain, grief and suffering could be included. Most western countries use the gross output approach plus a component for pain, grief and suffering, although there is now some doubt as to whether even this methodology is satisfactory, and a value-of-risk approach is now being considered.

13.30 The feasibility of any of the preferred methods will, in the short term, be conditioned by the availability of data of the appropriate kind and quality. However, in the evaluation of accidents, the choice of objectives and methods should always be viewed as the starting point, with deficiencies of data being identified as a consequence, rather than vice versa.

13.31 The various accident costing methods should be viewed as a system which increases in comprehensiveness and sophistication. This moves from the hard and undeniable material costs of physical damage to vehicles and property, through to the valuation of human life, and onto highly subjective values based on willingness of individuals to pay for a reduction in their perceived risks of death or injury. Each country can operate at different stages of this system of increasing complexity depending on their choice of objectives and availability of data.

### Recommended method of costing

13.32 The 'gross output' or 'human capital' approach to accident costing or valuation is recommended where the maximisation of GNP is the most important criterion. In this case, the cost of a traffic accident involving one fatality is treated as the sum of the real resource costs of vehicle damage, medical and police costs, plus the discounted present value of the victim's future output. If accident costs and values are intended for use in conventional cost-benefit analysis, then it can be argued that only the 'value of risk change' approach is unambiguously relevant. In practice, however, this method has proved difficult to use even in the industrialised countries. Output-based methods, provided they include a 'pain, grief and suffering' component may be relevant providing they reflect individuals' attitudes to the prospect of their involvement in accidents.

13.33 Clearly, the valuing of human life is a difficult and often contentious process. No one method can be said to be ideal under all circumstances. However, the adoption of a single gross figure, based on national increase, for use as a broad indicator requires fewer dubious assumptions or unacceptable implications than the alternatives. Many of the objections to valuing life can be answered if it is clearly specified that the sum derived is a minimum that society would find worthwhile spending in order to avoid a fatal accident.

13.34 Failure to associate explicit costs to road accidents will lead to wide differences in the assessment of projects that affect road safety. The resulting inconsistent pattern of treatment could yield implicit costs that might range from zero to a significant proportion of the potential benefits of a project. Consequently, it would be unlikely that overall expenditure on road safety would be optimal in such cases. This would lead to an under investment in road safety at the national level.
14. Economic Development Benefits

The Impact of Different Forms of Road Investment

14.1 The immediate economic consequence of road investment is to lower transport costs. As a result, economic activity will be changed throughout the whole economy as the saved resources are redeployed, as producers adjust to their new cost and price structure, and as consumers adjust their pattern of expenditure. The extent to which the local economy adjacent to the road will benefit from the investment will be dependent on its economic potential, such as unused land and labour, and on the change in transport costs and prices. The effect on the economy is extremely complex and it is virtually impossible to model in detail.

14.2 For most road projects where vehicle access already exists, however rudimentary, the principal benefits from the project should be measured as road user cost savings as described in Sections 10, 12 and 13. In these cases, a 'consumer surplus' approach to assessing benefits should be used as described in para 14.7-11.

14.3 Generated traffic may arise as a result of transport cost savings when roads are upgraded (see para 3.22-26). This traffic is a measurable indicator that economic development benefits have arisen. Where the change in transport costs are relatively small, generated traffic benefits will, in most cases, represent a very small component of total benefits and can often be ignored. By contrast, when the change in transport costs are large, then generated traffic benefits are more likely to be important.

14.4 Generated traffic benefits are usually the most difficult component of benefits to estimate. As a result, the 'producer surplus' approach can sometimes be used as an alternative (see para 14.12-15). This approach predicts agricultural producer benefits resulting from the investment in the vicinity of the road. Other components of generated traffic, such as changes in passenger movements, still have to be estimated separately. The approach is of most use when a large change in transport costs is expected for crops which have low value to weight ratios, like sugar cane, or when new road access is planned to be accompanied by other agricultural development inputs that are transport intensive, such as the introduction of fertiliser. The producer surplus approach is difficult to use and should only be applied when there are good grounds for believing that it will give better results than predicting generated traffic benefits by more conventional means (see para 14.7-11).

14.5 When evaluating generated traffic benefits, it is useful to consider the current traffic composition and the nature of the proposed investment. Studies have shown that passenger traffic is more sensitive than freight traffic to changes in transport costs. Passenger fares are a direct component of consumers' final demand whereas freight costs represent only a small proportion of the final costs of both the product to the consumer and the revenue to the producer. Upgrading long lengths of inter-urban roads to a high standard may have little effect on freight traffic, but may well have an important effect on passenger traffic, particularly for private motor car traffic, which is often deterred from using poor quality road surfaces. However, upgrading short lengths of road will change transport costs very little and, as a result, will have little effect on traffic levels or on agricultural production. The only exception to this is when roads are cut for long periods during critical periods of the crop season, or if crops, like bananas for export, are damaged during transit. The majority of rural access road projects involve upgrading roads and tracks of up to about 20 km. For these projects, road user cost savings for forecast normal traffic is the most appropriate method of estimating benefits.

14.6 Providing completely new vehicle access can change transport costs dramatically. For example, the cost of headloading is typically twelve times the cost of motor truck transport. Where it is planned to build access roads to rural communities that previously had to rely on human or animal transport, then transport cost savings (including a valuation of passenger and walking time savings) for normal traffic will often be sufficient to justify the provision of motor vehicle access at MINIMUM standards (see Section 7). Initially, such access will probably require simple bridging and culverts, with the use of gravel surfacing material only in problem areas. Later on, if traffic levels warrant, the road can be upgraded.

Consumer Surplus

14.7 If reductions in transport cost result from a road project, there will be a direct benefit to road users which equals the product of the number of trips and the cost saving per trip. This cost saving, or consumer surplus, may be vehicle operating costs, time costs or road accident costs, of a combination of the three. Its evaluation has been discussed in Sections 10, 12 and 13. Technically, there is only a consumer surplus if cost savings are passed on to consumers through lower fares and freight charges; otherwise they accrue to vehicle operators as producers' surplus. It is therefore important to assess the prevailing market and make judgements as to how any transport costs reductions are likely to be distributed.

14.8 If the transport cost savings are sufficient, these may result in more trips being made and extra benefits will
accrue as a result of this generated traffic. Thus, generated traffic resulting from a road project is a measure of the extra consumer surplus, and can be used to determine the project's developmental benefits.

14.9 Consumer surplus benefits are best estimated using a demand curve as shown in Fig 14.1. If, before the project is undertaken, \( t_1 \) trips are made each day at a unit cost of \( c_1 \), then the transport cost is \( c_1t_1 \) per day. If, as a result of the project, unit transport costs are reduced to \( c_2 \), then the transport costs of the traffic \( t_1 \) are reduced to \( c_2t_1 \) per day giving a

\[
\text{Benefit to normal traffic} = (c_1 - c_2)t_1 \text{ per day.}
\]

This is the benefit discussed in Sections 10-13.

14.10 If additional traffic is generated as a result of the savings in unit transport cost, additional benefits will accrue. The prediction of generated traffic is discussed in para 3.22-26. The amount of traffic that is generated will depend on the size of the unit cost reduction and on the ability of the consumer to take advantage of this cost reduction. This ability is known as the elasticity of demand. A demand curve is shown in Fig 14.1. In this case, a cost reduction from \( c_1 \) to \( c_2 \) will result in an increased number of trips from \( t_1 \) to \( t_2 \); the greater the cost reduction, the more trips that will be generated. The demand curve can normally be approximated by a straight line whose gradient is related to the elasticity of demand. The area under the demand curve less the transport cost of the generated traffic, \( c_2(t_2 - t_1) \), gives the

\[
\text{Benefit to generated traffic} = 0.5 (c_1 - c_2)(t_2 - t_1) \text{ per day.}
\]

14.11 In areas where there already is considerable economic activity and traffic levels are relatively high, the consumer surplus approach should normally be used to provide an estimate of the total development benefits associated with a road project. For more complex situations, consumer surplus benefits can be estimated using the methods developed by the World Bank and described by Van der Tak and Ray (1971).

**PRODUCER SURPLUS**

14.12 In situations where no conventional road exists and a substantial improvement in vehicle accessibility is planned to help develop an area, the producer surplus approach may be the most appropriate way of estimating agricultural benefits arising from road investment. For this method to be used requires a great deal of knowledge of the agricultural production function such as might be the case in a rural development project.

14.13 The predicted benefits arising from the reduced transport cost of agricultural produce will normally be the same as that predicted by a consumer surplus approach. However, when the producer surplus method is used, passenger benefits and other non agricultural cost savings still need to be estimated separately.

14.14 The forecast increase in agricultural production and the size of producer benefits are predicted from.

(i) the rise in farmgate prices brought about by the decline in costs of transporting produce to market

(ii) the decline in transport costs of agricultural inputs.
14.15 Unfortunately, the practical application of the agricultural production approach in the field, has been poor. The empirical justification for estimating changes in agricultural production has been weak and a failure to consider all the relevant costs of production has often led to the benefits being grossly over valued. It is not recommended to use the approach unless there is a great deal of knowledge about agriculture and its likely supply response to changes in input and output prices. More details on using the producer surplus approach are given in World Bank Staff Working Paper No.241 (Garnemark et al 1976).

15. COST-BENEFIT ANALYSIS

PRINCIPLES

15.1 This section describes the standard techniques used by economists for cost-benefit analysis. It is included for completeness for the benefit of engineers, transport planners and administrators who may not be familiar with these techniques. More details on cost-benefit analysis will be found in the ODA guide to the economic appraisal of projects in developing countries (Overseas Development Administration 1988).

15.2 The purpose of carrying out cost-benefit analysis is primarily to ensure that an adequate return in terms of benefits results from making a capital investment. An additional purpose is to ensure that the investment option adopted gives the highest return of those considered in terms of such things as the choice of route, the design and structural standards, and the timing of the project.

15.3 For economic appraisal, the assessment is made in terms of the net contribution that the investment will make to the country as a whole. Thus, the analysis differs from that which would be undertaken by private companies in appraising commercial ventures in that it attempts to evaluate economic costs and benefits rather than financial ones. The essential characteristics is to use ‘opportunity costs’ as a measure of resource rather than market prices.

15.4 Each project is unique and has features that prevent analysis following an identical pattern, although the same overall approach can usually be followed. It is normal to determine the costs and benefits which will be incurred over the analysis period if no investment is made, and compare these with the costs and benefits arising as a result of making an investment. Costs should be determined as described in Sections 4 to 8 and benefits should be determined as described in Sections 9 to 14. These costs and benefits can then be compared as described in para 15.18-31 to determine whether the investment is worthwhile and to identify which is the best of the alternatives being considered.

15.5 The alternative in which no investment takes place is sometimes known as the 'baseline' or 'do nothing' case. However, it is unusual for future investment in such cases to be absolutely zero, as there is normally an existing road or track in existence which in the future will at least require some expenditure or maintenance. If traffic on the existing road is expected to grow rapidly in the future, perhaps because of some complementary investment, then relatively large capital investments may be needed just to prevent the road from becoming impassable. In cases such as this, the ‘do minimum’ alternative should be considered as the most realistic baseline case against
which alternative improvement projects should be evaluated. The choice of an appropriate ‘do minimum’ case is an extremely difficult decision and has a very large influence on the size of economic return obtained from a project. Considerable attention should therefore be given to its selection.

15.6 The project analysis and appraisal must always be carried out in terms of achieving the project's objectives as discussed in para 1.53-54.

**PRICES**

15.7 In order to carry out an economic analysis, it is necessary to make adjustments to costs and prices to ensure that they are all measured in the same units and that they represent real resource costs to the country as a whole.

**Inflation**

15.8 A first step in this is usually to remove the effect of inflation to enable values to be compared on the same basis over time. Costs and prices are normally expressed in constant monetary terms, usually for the first, or base year, of analysis. In most cases, it can be assumed that future inflation will affect both costs and benefits equally, and hence its effect can be ignored. However, there may be exceptions to this and, in these cases, different costs and prices will need to be assumed for different elements at different times in the project analysis period.

**Discounting**

15.9 It is also necessary to factor costs and benefits to take account of the different economic values of investments made at different times during the project's life. When money is invested commercially, compound interest is normally paid on the capital sum. The interest rate comprises inflation, risk and the real cost of postponing consumption. Thus, money used to invest in projects in the roads subsector could be invested elsewhere and earn a dividend. By using capital to invest in a project, the dividend is foregone and this should be taken into account in the analysis. To do this, all future costs and benefits are discounted to convert them to present values of cost using the formula:

\[
PVC = \frac{c_i}{(1 + (r / 100))^i}
\]

where
- \( c_i \) = costs or benefits incurred in year \( i \)
- \( r \) = discount rate expressed as a percentage
- \( i \) = year of analysis where, for the base year, \( i = 0 \).

Since the inflation element is dealt with separately (para 15.8) and risk also needs separate treatment, the discount rate used will differ from market interest rates.

15.10 The value of the discount rate used will clearly have a considerable influence on the balance between the effect of capital costs, which are typically spent early in the project life, and that of benefits obtained in the future. Discounted benefits may exceed costs at one discount rate, but not at another. The choice of discount rate is therefore crucial to the outcome of an appraisal in many cases.

15.11 The discount rate normally used is the government accounting rate of interest (ARI) which is the rate at which the value of uncommitted government income in constant price terms falls over time. The ARI is the opportunity cost of capital in the public sector, ie the rate of return on marginal public sector investments. The discount rate to be used in an appraisal will normally be provided by the planning authority responsible for the project. The method of determining its choice is described in the ODA guide to project appraisal, but is beyond the scope of this Note. In the absence of other information, figures of around 10 per cent are often used.

**Shadow prices**

15.12 If investment in the project is to improve the rate of economic growth through the reallocation of scarce resources, the taxation component of all prices should be deducted to give the economic price which should be used in the project analysis. This is because these charges do not reflect a demand on real resources, but represent a transfer of spending power from those benefiting from the project to the government. Other transfer charges include such items as vehicle licence fees which should also be excluded from the analysis.

15.13 Other distortion in the price system may arise through quotas, subsidies and through imperfect competition. Where market prices are fixed by institutional forces which cause them to be higher than would be expected in a completely deregulated market, resource costs would be exaggerated in the appraisal. The converse is also true. To overcome this problem, shadow pricing is used. Thus:

\[
\text{Economic price} = \text{market price} - \text{transfer charge} + \text{effect of other distortions}
\]

15.14 Many developing countries control the value of foreign exchange to keep it lower in relation to domestic currency than is justified by the goods and services priced in domestic currency. Because the official exchange rate overvalues domestic currency, imported items appear too cheap and domestic items too expensive with the result that it tends to encourage overinvestment in imported capital items. This can be overcome by valuing all resources at their border prices. Imports are valued at the international price inclusive of cost, insurance and freight,
but excluding import duty (c.i.f.), and the exports free of any export duty (f.o.b.). This approach will tend to reallocate resources towards a mix of output where a country will only import goods that cannot be produced more cheaply at home, paying for them by exports which can be produced comparatively cheaply.

15.15 Many developing countries have minimum wage laws or other regulations and inflexibilities which result in the wages being paid not correctly measuring the opportunity cost of labour. Where significant unemployment or under-employment exists, this results in the real cost of labour being much less than actual wage rates. A good estimate of the annual shadow wage for agricultural labour is the number of days in the year when most rural labour can expect to find employment, multiplied by the daily wage rate at such time. This may need to be modified further to account for overvalued domestic currency.

15.16 On the other hand, it would also appear that the real costs of skilled labour may be greater than the wages paid. The shadow price for this is difficult to estimate and advice should normally be sought from the relevant local ministry or commission. For both skilled and unskilled labour, shadow pricing should also be used when assessing benefits. If labour-saving equipment is introduced as part of a project, the real benefit is substantially less if the replaced labour remains unemployed for a significant period during the economic life of the equipment.

15.17 For further explanation of these issues see the ODA project appraisal guide.

**COMPARISON OF ALTERNATIVES**

15.18 In order to determine whether an adequate return in terms of benefits results from making a capital investment, cost-benefit analysis must be carried out. This can be done using either the 'net present value' or 'internal rate of return' decision rules. These rules may also be used for helping to determine which investment option gives the highest return of those considered. In addition, the 'first year rate of return' rule can be used to assess whether the project is timely.

**Net present value**

15.19 This is simply the difference between the discounted benefits and costs over the project analysis period.

\[
\text{NPV} = \sum_{i=0}^{n-1} \frac{b_i - c_i}{(1 + (r/100))^i}
\]

Where \( n \) = the project analysis period in years
\( i \) = current year, with \( i = 0 \) in the base year
\( b_i \) = the sum of all benefits in year \( i \)
\( c_i \) = the sum of all costs in year \( i \)
\( r \) = the planning discount rate expressed as a percentage.

15.20 A positive NPV indicates that the project is economically justified at the given discount rate and, the higher the NPV, the greater will be the benefits from the project. If there are budgetary constraints, then the choice between projects should be based on NPV.

15.21 The NPV can only be calculated from a predetermined discount rate which needs to be the same for each project being compared. The NPV should only be quoted in conjunction with the discount rate that has been used. The rate used should normally be the government's own estimate of the minimum acceptable rate of return on public investment (as in para 15.11).

15.22 One problem with the use of NPV is that, other things being equal, a large project will have a larger NPV than a smaller one, and on this criterion would always be chosen. This can cause difficulties when only two or three projects are being compared. However, if all projects that could be undertaken with available public investment were appraised and ranked according to the size of NPV, the best choice would be that collection that maximised overall NPV. In this event, several smaller projects which in aggregate had a higher NPV would be chosen over a single larger project.

15.23 A range of NPV's should always be quoted to reflect the range of scenarios being investigated by the feasibility study. It is also important to consider the results of the financial, social and environmental appraisals when deciding which is the best project.

**Internal rate of return**

15.24 This is the discount rate at which the present value of costs and benefits are equal; in other words, the NPV = 0. Calculation of IRR is not as straightforward as for NPV and is found by solving the following equation for \( r \).

\[
\sum_{i=0}^{n-1} \frac{b_i - c_i}{(1 + (r/100))^i} = 0
\]

Solutions are normally found graphically or by iteration. The IRR gives no indication of the size of the costs or benefits of a project, but acts as a guide to the profitability of the investment. The higher the IRR, the better the project. If it is larger than
the planning discount rate, then the project is economically justified.

**Project timing**

15.25 Cost-benefit analysis should also be used to assist in determining the best time that a project should start. Even if the analysis shows that the project is worthwhile, there may still be a case for delaying the start whilst traffic continues to grow to increase the rate of return to a more appropriate level. The best way of determining the timing of the start is to analyse the project with a range of investment timings to see which produces the highest NPV. However, for most road projects, where traffic continues to grow in the future, the first year rate of return criterion can be used.

15.26 The FYRR is simply the sum of the benefits in the first year of trafficking after project completion, divided by the present value of the capital cost, grossed up by the discount rate to the same year and expressed as a percentage. Thus the FYRR is given by:

\[
\text{FYRR} = \frac{100.b_j}{\sum_{i=0}^{j-1} c_i (1 + (r / 100))^{j-i}}
\]

where \( j \) = first year of benefits, with \( j = 0 \) in the base year and other notation as before.

15.27 If the FYRR is greater than the planning discount rate, then the project is timely and should go ahead. If it is less than the discount rate, but the NPV is positive, the start of the project should be deferred and further rates of return should be calculated to define the optimum starting date.

**Recommended approach**

15.28 In most cases, the NPV and IRR will give consistent results and will produce the same ranking of alternatives according to their attractiveness. However, in a few cases, the use of IRR will give a different ranking to that recommended by using NPV.

15.29 In general, where the government is using a target, or minimum cut-off rate of return on capital, maximising NPV should be the criterion. As already mentioned, the IRR method is particularly useful where discount rates are highly uncertain. Normally, both methods should be evaluated for a project and, in cases of conflict, other factors will usually indicate which of the methods is most appropriate in the particular circumstances.

15.30 Some sponsoring agencies dictate which method they require to be used and, clearly, recommendations should be based on that result. Nevertheless, results from
16. RURAL ACCESS ROADS

THE NEED FOR SPECIAL CONSIDERATIONS

16.1 The methods of determining benefits for rural access road projects were discussed in Section 14. Since the cost per kilometre of constructing rural access roads is relatively low, the expenditure of significant amounts of time and money to determine the detailed costs and benefits of those projects cannot normally be justified. Nevertheless, appraisals should still be carried out for all rural access road projects, but a different approach may be needed to that used for arterial and collector roads.

16.2 Investment in rural access roads has the following objectives:

- To maintain existing levels of access
- To provide new vehicle access to rural settlements
- To help promote rural/agricultural development
- To supply transport at minimum cost to new development projects
- To upgrade the quality of existing roads and tracks

16.3 Most rural access road programmes will be planned to meet a number of these objectives. When the project is being formulated at the outset, it is useful to specify its main objectives so that all concerned can design the project accordingly.

16.4 Upgrading existing vehicle access will have little impact on rural development and, in general, it is recommended that, where rural development is the prime goal, that other constraints to development should also be investigated. If necessary, a total package of road investment and other inputs should be prepared.

16.5 Evidence from the evaluation of past projects indicates that rural access roads have, in general, not been able to stimulate the agricultural benefits that had originally been anticipated. This is not very surprising if the relationships between transport costs for a given agricultural product and its selling price are investigated. Seldom are transport costs more than 10 per cent of the price at the market, so any savings made will give little incentive to the farmer to increase production. In general, rural development will be difficult without vehicle access, but vehicle access on its own will not necessarily promote rural development.

16.6 In most instances, the very low traffic levels encountered on rural access roads will only justify the minimum standards of construction. Expensive gravel or bitumen surfaces should not be provided without very good reasons.

16.7 Rural access roads are different to arterial and collector roads in ways that affect the choice of an appropriate institutional setting for their planning.

construction and maintenance. The preparation of a rural access road project frequently requires inputs from several agencies and from the communities to be served. In order to address these institutional issues, there is a need to consider the project in three separate ways:

- It is necessary to consider the place of rural access roads within the broader policy environment and the issues which may need to be addressed at this level.
- It is necessary to consider the issues that relate to the choice among organisational options for project execution.
- The role of local participation in the project must be considered.

An approach for taking these three considerations into account when appraising rural access roads is given in World Bank Staff Working Paper No 748 (Cook et al 1985).

16.8 Where roads are planned to form a minor part of the investment programme of an integrated development project, then it is sensible to plan the road investment to meet the forecast transport demand at minimum cost. In addition, it may also be necessary to check that the total project investment of roads plus other investments is viable.

16.9 Building completely new roads through previously inaccessible areas can produce dramatic effects on the local economy and the environment. Not all projects of this sort are successful: the land needs to be fertile, a mobile workforce must want to work there and the environmental effects may be substantial. In order to predict traffic, agricultural activity and the effect on the environment for this type of road investment, it is necessary to seek advice of experts in many fields and to look at similar recent experience elsewhere.

NON ECONOMIC CONSIDERATIONS

16.10 All investment decisions have political, social and environmental consequences, besides the economic effects that are the principal focus of attention in this guide. The relative importance attached to these different considerations will depend upon the nature of the road investment. In planning the investment of rural access roads, the consequences of providing new vehicle access will be very different from upgrading existing roads.

16.11 In planning main road investment, economic/engineering implications are usually paramount in the decisions to upgrade existing road surfaces. In principal, there is little difference with the decision to upgrade existing rural access roads and tracks. By contrast, when new access is provided, not only will the impact on the local economy be more important, but other considerations may also need to be considered. For
example, a new road will affect local drainage and may well interfere with crop irrigation. Likewise, there may be a substantial social/medical benefit if people can travel to hospital or clinic by vehicle rather than undertake an arduous walk.

16.12 For social, political and economic reasons, a number of governments have defined target minimum levels of accessibility for their rural populations. These targets are usually defined in terms of the minimum distance to roads of different standards for villages of different sizes. Another approach is to use more comprehensive ranking and screening criteria to take account of the non economic effects of rural access roads (Carnemark et al 1976, Beenhakker and Lago 1983). An alternative approach (Bovill 1978) is to value non economic benefits directly and then to incorporate them directly into the cost benefit framework.

16.13 If it is anticipated that the road investment will have major social or environmental consequences, then it is important to seek appropriate advice. Whatever method of appraisal is used, a statement should be prepared relating to those effects which have been omitted from the analysis so that they can be considered as part of the final decision.

SCREENING AND THE SIMPLIFICATION OF DATA COLLECTION

16.14 Typically, investments in rural access roads are planned by preparing an investment programme on an area wide basis. Because of the costs of collecting data direct from all road projects under consideration, it may be useful to simplify the data collection exercise by collecting together data common to the proposed road investment in each local area.

16.15 By using fairly simple relationships between known parameters (eg population and traffic), estimates of the key parameters used in an economic appraisal may be made without carrying out a full collection of data for each road. From these estimates, an appraisal of each road investment may be made and a ranking of each road project achieved. Net present values can also be determined, and this task is simplified when many road investments are being considered if access is available to a computer.

16.16 Where the key components of an economic analysis cannot be estimated easily and cheaply, then a first screening of likely road projects can be made from data which is easily available to enable projects that are not promising investments to be eliminated prior to any further field investigations.

Upgrading and maintaining existing access

16.17 If the final decisions on upgrading existing roads and tracks are to be on economic grounds, then any proposals to simplify the data collection exercise should be directed towards identifying and measuring the key parameters which figure in a cost-benefit analysis. These are:

- Current traffic levels
- Future traffic growth
- Current condition of existing roads
- The costs of upgrading the road surface.

16.18 It can be time-consuming and expensive to collect traffic data for each road section under consideration. However, provided some reliable traffic figures can be collected for a sample of roads, then estimates of traffic on the remainder may be made by relating traffic levels to factors such as adjacent rural population or agricultural output, if these are available.

16.19 If the areas to be investigated are fairly uniform, then there will be little need to provide separate estimates of traffic growth. However, if the areas are likely to have differences in their rates of growth of population or economic activity (eg because of new rural investment projects), then it may be useful to make different traffic projections for different areas.

16.20 The current condition of each road is usually extremely difficult to assess without making a field visit. If the roads are motorable, then in most cases a brief inspection of road condition can be carried out reasonably quickly. However, because of the serious consequences of a road or track becoming impassable, it is very important to look for those factors such as weak bridges, or broken or clogged culverts, which could cut vehicle access. Some likely clues to the condition of the road may be found from any existing road maintenance records and knowledge of weather, soils and terrain.

16.21 From an inventory of each road and knowledge of the terrain, soils and likely location of suitable roadmaking materials, estimates of the likely costs of upgrading the road surface can be made. Again, there is considerable scope for making simplifying assumptions and grouping together likely common factors to help estimate these costs.

New road access

16.22 When new road access is planned, the total costs of existing means of transport need to be matched against the costs of transport by inotor vehicle. As above, estimates must be made of traffic growth and of the costs of road construction. In addition, existing volumes of non
motorised traffic and the current costs of existing transport need to be found.

16.23 The following data estimates are required:

- The distance of the centres of population from the road network
- The volumes of goods moved by current means including headloading, animal transport and by agricultural tractor
- The costs of moving goods by the alternative means
- The volumes of movement by people, the opportunity costs of their time and the other costs involved (e.g., the costs of animal transport or of tractors used to transport people)
- The extent of diversion of existing traffic to motor vehicle once the new road access is provided.

16.24 There is again considerable scope for estimating the likely transport demand from a few limited surveys of typical areas and extrapolating the results to the rest of the area. Use can be made of detailed maps, census returns and agricultural production data.

16.25 Road access should first be planned to connect rural settlements to the road network. In most circumstances, this will provide a useful degree of direct road access to farming areas. In the early stages of development of commercial agriculture, there is little need to provide additional access to farming areas because agricultural demand is usually spread extremely thinly. In addition, farmers tend to store and process crops for sale in the vicinity of their home, and the typical small load sizes and short distances between farm and home (usually less than about 8 km) means that it is normally uneconomic to use conventional motor transport for this first movement of crops, even if a motorable road is available. Exceptions to these general rules can be made for crops with very low value to weight ratios like sugar cane, coconuts or melons, where farmers will be keen to transport the crops in large quantity straight from field to market.

17. ANALYSIS OF UNCERTAINTY

SCENARIO AND RISK ANALYSES

17.1 As noted in para 2.2-7, the data and parameters used in the analysis of a road project can be prone to substantial errors and it is important to recognise that these exist and to take steps to minimise them. Because of this, the results of a feasibility study are subject to uncertainty and there will be a risk associated with pursuing any course of action suggested by the appraisal.

17.2 It was recommended in para 2.5 that scenario analysis should be used for projects that are not well defined or at the early stages of the project cycle. In such cases, a range of scenarios should be examined covering future possibilities that might reasonably be expected to occur. For such scenarios, which will often be covering political, economic and social uncertainties, projects should be examined for their robustness in being able to deliver a satisfactory NPV over the range of scenarios considered.

17.3 Where projects are well defined, risk analysis is more appropriate and, in these cases, the effect on the NPV of combinations of uncertainties in the project's most sensitive parameters should be examined. Ideally, an approach based on probabilities should be used and the remainder of this section describes how this should be carried out.

EXPECTED VALUES

17.4 The basic calculation of net present value should incorporate the best estimates of the variables and parameters that determine the cost and benefit streams. The estimates should be the ‘expected values’ obtained, in principle by weighting each possible value by the probability of its occurrence. Using expected values ensures that the estimates are unbiased providing that the formation of the probability function of values is unbiased. In the absence of probability data, mid points of the range of expected values should be used. Biased estimates, such as conservative estimates of costs (on the high side) and of benefits (on the low side), should be avoided, since they distort the comparison of alternative projects.

17.5 In view of the uncertainties present, it will usually be preferable to show the results of a project analysis as a range of values reflecting major uncertainties, rather than as a single figure, as this aids the choice of the most robust project. It is therefore necessary to identify:

- those sensitive areas which have a critical importance on the success or failure of the project
17.6 Sensitivity analysis is appropriate for initial identification of sensitive inputs or parameters, but risk analysis is also relevant where correlated sets of inputs need to be identified, and to demonstrate clearly the range of possible outcomes for a project, even in the absence of correlated inputs. Sensitivity analysis is described in para 17.12-22 and risk analysis is described in para 17.23-26.

CONTINGENCY

17.7 It is usual to include in the estimates of capital costs a separate allowance to cover contingencies. These are of two types.

17.8 Expected costs. Allowances should be included to cover costs which have not been separately identified, but which experience indicates must inevitably occur during the construction period. A lump sum contingency allowance to take account of all the constituent parts should be used in such cases to cover a variety of items.

17.9 Tolerances. This form of contingency allowance is an estimate, usually based on past experience, of the probability of unforeseen costs arising and of their probable magnitude. Tolerances reflect the fact that costs may overrun due to physical contingencies, such as unexpected poor ground conditions or lack of finance which prolongs construction time. The best estimate of the allowance should be regarded for appraisal purposes as part of the cost of the project, even though it may not have to be spent.

17.10 Expected contingency allowances of up to about 25 per cent of the construction cost are normal for road projects in developing countries.

17.11 It is not necessary to make allowances in an economic appraisal to cover price increases due to inflation during the construction period providing that all prices are expressed in terms of constant base year values as described in para 15.8. However, any such price increase will affect the project's cash flow and will need to be estimated for budgetary purposes in the financial analysis. When preparing the project budget, it may also be necessary to consider separately the prices of imported items from those affecting the cost of local labour and materials.

SENSITIVITY ANALYSIS

17.12 Sensitivity analysis is carried out by varying the magnitude of the more important variables, normally one at a time, whilst keeping the values of the remaining variables fixed. By looking at higher and lower figures than those expected, it is possible to determine how sensitive the net present value is to such changes. The variables that are chosen for testing are a matter of judgement but, for most road schemes, the following should be considered as possible candidates, approximately in order of presentation here.

Traffic

17.13 The difficulty of obtaining reliable estimates for traffic and of forecasting future growth rates has been discussed in Section 3. In most projects, traffic levels will have a major affect on the level of benefits obtained. Thus sensitivity analysis should be carried out, both of baseline flows and of forecast growth. For baseline flows, ranges of values of up to plus or minus 50 per cent of the expected value should be examined for low traffic flows and up to plus or minus 25 per cent for high flows. Similarly, the effect of 'optimistic' and 'pessimistic' traffic growths of up to about 25 per cent for low growth rates and 50 per cent for high growth rates should be examined.

Project costs

17.14 Project costs are always difficult to estimate accurately in developing countries. Sensitivity to uncertainties in the project cost of plus or minus 25-100 per cent should normally be investigated. Note that the risk of price escalation should normally be taken into account in the financial analysis rather than through sensitivity testing in the economic analysis.

Delay

17.15 A major risk to be tested in the sensitivity analysis is delay in implementation. A test should therefore be carried out on a one year delay in implementation or with construction costs spread over one extra year. For very large projects, longer delays may be possible.

Generated traffic

17.16 As noted in Section 14, the forecasting of the level of economic development associated with a road project is extremely difficult. When dealing with arterial and collector roads, with relatively high traffic levels, the project outcome should be considered with and without benefits due to generated traffic. If the project is heavily dependent on generated traffic to provide a positive NPV, its acceptance should be viewed with some caution. For rural access roads with relatively low traffic flows, the project's sensitivity to variations in developmental benefits of up to about plus or minus 50 per cent should be considered.
Time and accident savings

17.17 For arterial and collector roads in rural areas, projects that are heavily dependent on time and accident savings to ensure a positive NPV should be viewed with caution in the same way as for generated traffic benefits. In such cases, the sensitivity of the project to variations in time values, accident rates and costs of up to about 25 per cent should be considered.

Shadow prices

17.18 In projects where the shadow prices used differ markedly from the market price minus transfer charges (see para 15.12-17), the sensitivity to uncertainties in the shadow price of up to about 25 per cent should be considered.

Maintenance

17.19 The importance of good management of a project, particularly during the operational phase has been emphasised in para 2.22-26 where the need to use the expected value of maintenance performance in project assessment was also stressed. It is difficult to examine the effect of uncertainty in this directly, but its consequences can be inferred by examining the sensitivity of the project to uncertainty in the rate of road deterioration and its effect on vehicle operating costs. For road improvement projects, vehicle operating cost savings should also be evaluated for a higher range of roughness levels, such as those in Table 10.2, for any particular road type. The vehicle operating cost figures obtained may then be used to determine the effect on project benefits.

Special factors

17.20 It may be that there is uncertainty about future events which could have an important bearing on the project. A dam, for instance, might be built which would flood the valley in which the road was built. If the dam project were to go ahead, then the road would have to be relocated in the future, although the cost of this would be included as part of the cost of the dam. A railway may be under consideration which, if constructed, would significantly affect the design requirements of the proposed road. Roads built in unstable hilly terrain are always at risk from landslide activity, even when planned using the principles described in Section 5, and these may need to be partially realigned and rebuilt in the future. Structures may be damaged in areas subject to flooding.

17.24 In such cases, or where there is doubt about the implementation of other major development projects which will affect the benefits of the road project, it is normally appropriate to carry out analyses based on the alternative assumptions that the event will or will not happen and risk analysis should normally be undertaken (see para 17.23-26).

Investment models

17.22 Providing that investment models, such as micro-RTIM2 or HDM-III, are being used to assist with the project appraisal, sensitivity analysis is easy and quick to do. Indeed, one of the principal advantages of such models is that they enable this to be done at low cost in terms of time. When investment models are not available, a limited amount of sensitivity testing should still be done. The effect of uncertainty in traffic should always be investigated even though the manual calculations needed may be time consuming. The effect of uncertainty in project cost is easy to evaluate by hand and should therefore normally be determined. In all cases, for arterial and collector roads, the NPV should be evaluated separately for:

- benefits to normal traffic
- benefits to generated traffic
- time and accident savings.

This will greatly assist the interpretation of results.

RISK ANALYSIS

17.23 Sensitivity analysis should indicate which of the parameters examined are likely to have the most significant effect on the feasibility of the project because of inherent uncertainty, but does not show the combined net effect of changes in all variables or the likelihood of changes occurring together. Where several parameters are identified whose estimated accuracy is critical to the successful outcome of the project, risk analysis may be appropriate.

17.24 Risk analysis, in its simplest form, requires specifying the probability of an individual input variable attaining a range of values. Using this, the probability distributions of the NPV and other output parameters can be determined. An approach for dealing with this is given in the ODA project appraisal guide (Overseas Development Administration 1988). Examples of the application of risk analysis to road projects are given by Pouliquen (1970).

17.25 Risk analysis provides a better basis for judging the relative merits of alternative projects, but it does nothing to diminish the risks. It is time consuming to carry out with projects that are as complex as roads, and such analysis must therefore be reserved for a very few variables in highly critical cases. Some risks identified by the sensitivity analysis can be reduced by carrying out further field investigations and redesign which may or may not be worthwhile depending on the cost of the
18. THE FEASIBILITY STUDY REPORT

PREPARATION

18.1 Decisions must be made at various stages throughout the project cycle. The early decisions on a project, however apparently innocuous have a disproportionate effect on the final shape of the scheme. At each stage, careful preparation and presentation are necessary to reveal and justify decisions taken or recommendations made. The feasibility study report marks the end of the appraisal process and should recommend whether the project should go ahead, and to what standards it should be built. The report may wish to recommend alternative designs or approaches to the project that would increase the rate of return in those areas where the original project is not viable.

18.2 In addition to these decisions about the nature of the project, the way in which the project is presented can be important for future projects of a similar kind, and for the future monitoring and evaluation of the project. It can, for instance, through scenario or sensitivity analysis, show the crucial factors which will make or break the project. These can give important signals to those concerned with checking the progress and reviewing the results of the project in the future.

18.3 Once the need for a project, and its objectives, have been identified, the extent of further investigation will depend on a number of considerations. The political, managerial, economic, technical and financial aspects need to be covered adequately in every case, but depending on who the report is being written for, some aspects have to be covered in greater depth than others.

18.4 Where reports are prepared for aid donors, each will have its own different requirements. An analysis carried out for a development bank will have to cover financial aspects very thoroughly. Projects prepared for aid agencies normally dwell heavily on socio-economic factors. The World Bank, for instance, has a highly formal, elaborate and thorough process of approving projects through its executive board, necessitating extremely careful and comprehensive preparation. The British Overseas Development Administration, likewise, imposes on itself a well-defined and rigorous procedure for approving large aid projects. Other development banks may have simpler procedures requiring briefer preparation, relying more on their judgement of the calibre of associated institutions, partners, or sponsors.

18.5 The team assigned to prepare the project should normally contain a range of professionals such as engineers, transport planners and economists. Sector specialists can be added where the size and complexity of
the project require, such as agronomists, engineering geologists, environmental specialists, etc. Where, as is often necessary, members of the project team are from an international consultant, the local government should participate as fully as possible in the investigations, and this normally requires the allocation of local professional staff to the project team. The finance and planning ministries should be made fully aware of progress and recommendations, although the promoting ministry should take responsibility for the detailed professional work.

PRESENTATION

18.6 The particular approval procedure to be used affects the way in which the project is presented. Some agencies insist on standardised presentations with bulky supporting documentation, while others prefer shorter and more sharply focused reports.

18.7 Whatever the nature of the approving body, there must be an assumption that the majority of the people who have to take the decision are non-specialists and busy. This argues for a clear and simple document with the accent on objectivity and brevity, and containing the more detailed discussion of technical and specialist aspects as annexes to the main document. It should contain a summary and conclusions. A map of the project location is usually essential, together with other visual aids like diagrams and bar charts. Where values are expressed in foreign currency, a conversion rate into local currency should be included.

18.8 In principle, the paper should be in a form that can be made available to other parties involved such as a foreign government providing the loan or aid, the local authority that will have to implement the work, etc. To this end, the document could be divided into two sections, one that can be distributed and the other containing information and views meant for the approval body only.

18.9 It is helpful if the submission clearly draws out the effects of the project on different parties who may be affected and on the wider economy of the country. Benefits and costs should be shown individually and the appraisal methodology used should be indicated. Likewise, the economic discussion should include scenario analysis, or sensitivity and risk analysis, in order to accentuate the most important factors governing the success or failure of the project. This analysis should be consistent with government policies of pricing, tariffs, procurement, incomes policies, etc, where they are likely to have influence on the outcome of the project.

18.10 One possible approach for presenting the feasibility study report is to follow the general order of topics as in this Note:

1. **Summary and conclusions**
2. **Brief description of project**
   - Objectives
   - Project type
   - Main features
3. **Preliminary considerations**
   - History and background to the project
   - Political factors
   - Method of project execution and technology to be used
   - Managerial, administrative and maintenance capability for implementation
4. **Assessment of demand**
   - Consideration of alternative routes, standards, modes
   - Current traffic levels and forecast growth
   - Diverted and generated traffic
5. **Determining costs**
   - Geotechnical considerations
   - Design and costs of:
     - pavement
     - alignment (earthworks)
     - drainage and structures
6. **Assessment of benefits**
   - Vehicle operating cost savings
   - Road maintenance benefits
   - Time savings
   - Reduction in road accidents
   - Economic development
7. **Economic analysis**
   - Cost-benefit analysis
   - Analysis of uncertainty
8. **Financial aspects**
   - Costs of construction
   - Inflation, contingencies and arrangements for cost overruns
   - Operation and revenues
   - Foreign exchange implications and exchange rate assumptions
   - Sources of funds: capital and recurrent
9. **Other aspects**
   - Environmental impact statement
   - Social consequences, etc
10. **Implementation**
    - Responsibility for implementation
    - Arrangements for construction
    - Maintenance
11. **Plans for monitoring and evaluation**
12. **Annexes** (these must be 'keyed in' to the main text, otherwise they may be ignored).

18.11 The conclusions in the project report should ensure that the following aspects of the project have been considered and are reflected in the final recommendations:

- the options investigated have been selected from the full range available
- the results for each option are presented as a range of values in terms of NPV, etc
- the main assumptions and sensitivity of the result to them are clearly identified
- the result may need to be interpreted, not in terms of profit, but as cost savings or benefits which are available for alternative use.

---

19. **CHECKLIST OF KEY POINTS**

19.1 This checklist is designed to assist those submitting or appraising project reports to check quickly whether all of the key issues have been included. References are given to the paragraphs where items can be followed up in the main text.

**OBJECTIVES**

19.2 What are the project's objectives (1.53-54)?

19.3 What is the nature of the project: new construction, upgrading (1.35-37), reconstruction rehabilitation (1.33-43), stage construction (1.44-45), road maintenance (1.46-51, 2.22-34), bridge construction (8.17-51)?

19.4 What stage of the project cycle has been reached (1.4-18)?

**BACKGROUND**

19.5 What alternatives to the project have been considered in terms of mode, route, standard, timing (1.26-34, 1.53-54, Sections 5-8, 15.25-27)?

19.6 Has the project been set against the background of a transport sector or road plan (1.53)?

19.7 What are the relevant features of terrain, relief, climate, vegetation, drainage, soils, rock, etc (5.4-19)?

19.8 What are the major economic activities (3.1-3, 3.14-26, Sections 9-14)?

19.9 How does the project complement the existing network (1.52)?

19.10 Have socio-economic considerations been taken into account (2.35-40)?

19.11 Have environmental considerations been taken into account (2.41-62)?

**INSTITUTIONAL AND MANAGERIAL ASPECTS**

19.12 Is the institutional framework conducive to the success of the project (2.16-17)?

19.13 Is there a project component for improving institutional development (2.18-21)?

19.14 What is the roads organisation's capability for carrying out maintenance (2.22-34)?

19.15 What form of contract will be used and will there be a supervising consultant (4.67-72)?
TRAFFIC

19.16 What is the volume of existing traffic, how is it classified and how were the estimates obtained (3.1-13)?

19.17 What is the projected traffic growth and how has this been derived (3.14-18)?

19.18 What is the estimate of diverted and generated traffic (3.19-26)?

DESIGN

19.19 What are the design features:
• Pavement (5.6-12, 6.1-47)
• Geometrics (5.13-16, 7.1-33)
• Structures (5.17-19, 8.1-42)?

19.20 What is the design life (1.56-57, 6.41-42)?

19.21 Have axle loads been measured and forecast (6.28-30)?

19.22 Is the method of construction appropriate (2.8-15)?

COSTS

19.23 What general methods of costing have been adopted (4.1-66)?

19.24 How have costs been determined for:
• Pavement (6.48)
• Earthworks (7.34-36)
• Structures (8.11-12, 8.16, 8.43-50)?

19.25 What are the estimates for recurrent costs (11.15-16)?

BENEFITS

19.26 What are expected direct benefits due to:
• Vehicle operating cost savings (Section 10)
• Economies in road maintenance (Section 11)
• Time savings (Section 2)
• Reduction in road accidents (Section 13)?

19.27 What are the indirect and induced benefits (Section 14)?

19.28 What are the results of the cost-benefit analysis (Section 15, 16)?

19.29 How dependent is the rate of return on generated traffic and time savings (17.16-17)?

19.30 How has uncertainty and risk been dealt with 2.2-7, 17.1-26)?

REFERENCES


APPENDIX A
ROAD UPGRAADING PROJECT

COMPONENTS OF THE STUDY

A.1 A feasibility study has been carried out for ODA by consultants to look at the upgrading of a 103 km road in Africa from a gravel to bitumen surface. The existing road was not all weather, although it was possible to drive the whole length in the dry season. An earlier design for an upgrading had been carried out by different consultants, but the high cost of construction to this design had proved not to be justified in terms of benefits generated. The project analysis therefore had four main components:

- to show savings in construction costs coupled with harmonisation of highway design throughout the project
- to design a road which conformed to the high standard of bitumen road construction which had been established in the country
- to ensure that the road when built would truly serve the population of this rich agricultural region of the country, bearing in mind its importance to the country as a whole
- to adopt design standards relevant to the speed and numbers of vehicles through and between the many centres of population along the route.

TRAFFIC SURVEYS

A.2 Classified counts and roadside interviews were carried out to determine the magnitude and variation in flow levels along the existing road. Information on vehicle loading was obtained from axle load measurements carried out both along the existing gravel road and on a nearby bituminous road that was thought to be more representative of the type of loadings that the road would carry after upgrading.

A.3 Moving observer counts were carried out along the existing road to determine what were the general flow patterns along its length and, as a result, four survey stations were set up for counting traffic. At the first station, a seven day classified count was carried out, for 24 hours on two of the days and for 16 hours on the remaining days. Roadside interviews were carried out on two of the days. At each of the other three sites, classified counts and roadside interviews were undertaken for two days. The results of these counts were considered in conjunction with the results of more extensive surveys carried out by other consultants for ODA some six months previously. Further counts were also carried out at other locations in order to give a more comprehensive picture of traffic movements.

A.4 The annual average daily traffic (ADT) was estimated from the results of the surveys carried out by the two consultants and is shown for different classes of vehicle in Table A1.

A.5 The objective of the roadside interviews was to sample vehicles to determine their type, start and end points of their journey, trip purpose, the number of passengers and any commodity carried. It proved to be very difficult to obtain a suitably representative sample.

<table>
<thead>
<tr>
<th>Counting station</th>
<th>Taxis</th>
<th>Private cars</th>
<th>Four wheel drive pickups/LGVs</th>
<th>Minibuses</th>
<th>Lorries 2-axle</th>
<th>Lorries 3-axle</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey 2</td>
<td>663</td>
<td>1253</td>
<td>470</td>
<td>227</td>
<td>150</td>
<td>181</td>
<td>56</td>
</tr>
<tr>
<td>Survey 1</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>133</td>
<td>—</td>
</tr>
<tr>
<td>Average</td>
<td>702</td>
<td>485</td>
<td>550</td>
<td>266</td>
<td>166</td>
<td>95</td>
<td>2264</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey 2</td>
<td>119</td>
<td>165</td>
<td>244</td>
<td>137</td>
<td>70</td>
<td>42</td>
<td>—</td>
</tr>
<tr>
<td>Survey 1</td>
<td>—</td>
<td>223</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>108</td>
<td>—</td>
</tr>
<tr>
<td>Average</td>
<td>106</td>
<td>148</td>
<td>250</td>
<td>140</td>
<td>89</td>
<td>83</td>
<td>816</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey 2</td>
<td>103</td>
<td>183</td>
<td>234</td>
<td>143</td>
<td>64</td>
<td>39</td>
<td>—</td>
</tr>
<tr>
<td>Survey 1</td>
<td>—</td>
<td>319</td>
<td>—</td>
<td>418</td>
<td>196</td>
<td>221</td>
<td>—</td>
</tr>
<tr>
<td>Average</td>
<td>109</td>
<td>194</td>
<td>247</td>
<td>150</td>
<td>130</td>
<td>960</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Survey 2</td>
<td>211</td>
<td>172</td>
<td>166</td>
<td>107</td>
<td>46</td>
<td>27</td>
<td>—</td>
</tr>
<tr>
<td>Survey 1</td>
<td>—</td>
<td>316</td>
<td>—</td>
<td>304</td>
<td>89</td>
<td>76</td>
<td>—</td>
</tr>
<tr>
<td>Average</td>
<td>193</td>
<td>157</td>
<td>173</td>
<td>113</td>
<td>68</td>
<td>52</td>
<td>759</td>
</tr>
</tbody>
</table>
and the results did not give a clear picture of the variation in traffic flows or loads carried, either between stations or between weekdays and weekends. Since a very large amount of data was collected, it was theoretically possible to derive trip matrices for each survey station by type of vehicle and trip purpose for each hour of the day. However, the disaggregation of the data was such as to make such an exercise virtually worthless, so results were not analysed fully. However, the interview data was used to help derive equivalence factors for vehicles and to establish both occupancy rates for each vehicle type and trip purpose for estimating average values of time for use in the economic analysis.

A.6 Measurements of vehicle wheel load were carried out using a portable weighbridge in connection with the roadside interviews. Due to delays in clearing the weighbridge through customs, the time available for obtaining information was limited. The traffic counts indicated that a large number of lorries were travelling very early in the morning and at night, so special surveys were undertaken to weigh these vehicles. The mean equivalence factors derived from the axle load surveys and the roadside interviews are shown in Table A2. From the limited number of measurements made, there is clear evidence of overloading.

### TABLE A2
**ESTIMATES OF MEAN EQUIVALENCE FACTORS**

<table>
<thead>
<tr>
<th>Road section</th>
<th>2 axle</th>
<th>3 axle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Outward</td>
<td>Inward</td>
</tr>
<tr>
<td>Section 1 (Start-</td>
<td>3.0</td>
<td>2.1</td>
</tr>
<tr>
<td>Station 1)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 2 (Station 1-</td>
<td>2.7</td>
<td>3.7</td>
</tr>
<tr>
<td>Station 3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Section 3 (Station 3-end)</td>
<td>4.0</td>
<td>7.1</td>
</tr>
</tbody>
</table>

A.7 There was considered to be limited opportunity for traffic diversion and, since the numbers involved were expected to be small, they were ignored for the analysis.

**TRAFFIC GROWTH**

A.8 Traffic growth in terms of both trip numbers and trip lengths were determined based on several factors, the most significant of which were:

- Population size
- Vehicle fleet and levels of motorisation
- Disposable income
- Economic activity and growth
- Costs and patterns of current vehicle operations.

Data in these areas proved to be neither comprehensive nor reliable.

A.9 These socio-economic parameters suggested traffic growth rates for individual vehicle types for normal traffic varying from 2.0 to 8.0 per cent per annum and 2.5 to 10.7 per cent per annum for the growth of both normal and generated traffic (see Table A3). These could be set against a background of economic growth for the whole country in terms of GDP quoted variously between 7.5 and 8.5 per cent per annum.

A.10 Historical evidence in the country suggested that, when a new road opened, there was likely to be an immediate generation of traffic of the order of 10 per cent and this figure was assumed for this study. The actual generated traffic figures were obtained by determining the total traffic from Tables A1 and A3, and subtracting the normal traffic figures from the totals for each year. The growth rates for generated traffic were reduced to zero towards the end of the project analysis period because there was some uncertainty as to whether the earlier increases in generated traffic flows could be maintained. The resulting forecast traffic for the final year of analysis (2003) is shown in Table A4.

A.11 A further check was carried out on the plausibility of growth rates for generated traffic by considering vehicle operating cost savings and demand elasticities. The

### TABLE A3
**ESTIMATES OF TRAFFIC GROWTH RATES**

<table>
<thead>
<tr>
<th>Socio-economic parameters</th>
<th>Base case</th>
<th>With generation from upgrading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (A)</td>
<td>1.6</td>
<td>2.0</td>
</tr>
<tr>
<td>Vehicle (B)</td>
<td>5.0</td>
<td>8.5</td>
</tr>
<tr>
<td>Income (C)</td>
<td>-</td>
<td>0.5</td>
</tr>
<tr>
<td>Agricultural growth (D)</td>
<td>6.0</td>
<td>8.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Traffic</th>
<th>Base case</th>
<th>With generation from upgrading</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Car/taxi (B)</td>
<td>5.0</td>
<td>8.5</td>
</tr>
<tr>
<td>2. Pickups/LGV’s (AXCD)</td>
<td>8.0</td>
<td>10.7</td>
</tr>
<tr>
<td>3. Minibuses (AxC)</td>
<td>2.0</td>
<td>2.5</td>
</tr>
<tr>
<td>4. 2 and 3-axle trucks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>based on growth in:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- consumer goods</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- consumption (A x C)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- (D)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- construction materials</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(mainly AX C but also</td>
<td></td>
<td></td>
</tr>
<tr>
<td>affected by economic</td>
<td></td>
<td></td>
</tr>
<tr>
<td>growth)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Weighted average: 5.0 8.0
TABLE A4

FORECAST 2003 ADT VALUES

<table>
<thead>
<tr>
<th>Section</th>
<th>Private cars</th>
<th>Taxis</th>
<th>LGV’s</th>
<th>Minibuses</th>
<th>Lorries 2-axle</th>
<th>Lorries 3-axle</th>
<th>Buses</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1109</td>
<td>2027</td>
<td>370</td>
<td>320</td>
<td>182</td>
<td>1604</td>
<td>0</td>
<td>5612</td>
</tr>
<tr>
<td></td>
<td>418</td>
<td>923</td>
<td>0</td>
<td>108</td>
<td>58</td>
<td>605</td>
<td>42</td>
<td>2154</td>
</tr>
<tr>
<td>Total</td>
<td>1527</td>
<td>2950</td>
<td>370</td>
<td>428</td>
<td>240</td>
<td>2209</td>
<td>42</td>
<td>7766</td>
</tr>
<tr>
<td>2</td>
<td>416</td>
<td>925</td>
<td>224</td>
<td>234</td>
<td>234</td>
<td>277</td>
<td>0</td>
<td>2310</td>
</tr>
<tr>
<td></td>
<td>157</td>
<td>422</td>
<td>0</td>
<td>74</td>
<td>74</td>
<td>105</td>
<td>25</td>
<td>857</td>
</tr>
<tr>
<td>Total</td>
<td>573</td>
<td>1347</td>
<td>224</td>
<td>308</td>
<td>308</td>
<td>382</td>
<td>25</td>
<td>3167</td>
</tr>
<tr>
<td>3</td>
<td>446</td>
<td>646</td>
<td>158</td>
<td>139</td>
<td>95</td>
<td>356</td>
<td>0</td>
<td>1840</td>
</tr>
<tr>
<td></td>
<td>168</td>
<td>294</td>
<td>0</td>
<td>44</td>
<td>30</td>
<td>134</td>
<td>18</td>
<td>688</td>
</tr>
<tr>
<td>Total</td>
<td>614</td>
<td>940</td>
<td>158</td>
<td>183</td>
<td>125</td>
<td>490</td>
<td>18</td>
<td>2528</td>
</tr>
</tbody>
</table>

TABLE A5

TRAFFIC GROWTH BASED ON ELASTICITIES

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Cost saving (%)</th>
<th>Elasticity</th>
<th>Growth (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Passenger traffic = 1.0</td>
<td>Goods traffic = 0.1 to 0.2</td>
</tr>
<tr>
<td>Private cars</td>
<td>43.95</td>
<td>1.0</td>
<td>43.95</td>
</tr>
<tr>
<td>Pickups</td>
<td>56.94</td>
<td>0.575*</td>
<td>32.74</td>
</tr>
<tr>
<td>Minibuses</td>
<td>55.47</td>
<td>1.0</td>
<td>55.47</td>
</tr>
<tr>
<td>2 axle trucks</td>
<td>45.50</td>
<td>0.15</td>
<td>6.825</td>
</tr>
<tr>
<td>3 axle trucks</td>
<td>44.22</td>
<td>0.15</td>
<td>6.633</td>
</tr>
<tr>
<td>Taxis</td>
<td>57.94</td>
<td>1.0</td>
<td>57.94</td>
</tr>
</tbody>
</table>

*Average value for passenger and freight

These growth figures compare with a flat figure of 10 per cent used in the study in the first year of operation of the new road.

vehicle operating costs per kilometre for each vehicle type were derived for the existing and the new road. The cost savings from using the new road were expressed as a percentage of the costs on the existing road and multiplied by the elasticity to give the likely growth following upgrading as shown in Table A5. Elasticities were assumed to be constant across the range of cost savings.

ENGINEERING DESIGN

A.12 The traffic used as the basis of the pavement design for the 15 year analysis period is shown in Table A6. On the basis of these figures, the same payment structure was designed for the entire road length consisting of a double surface dressing on 200 mm of crushed rock road base with a 225 mm laterite sub-base. It was planned that, after one year, the pavement would be overlaid with 50 mm of asphaltic concrete.

A.13 When carrying out the geometric design, the following factors were taken into account:
• the existing alignment should be followed wherever possible
• as few houses as possible should be destroyed
• the alignment should stay as close as possible to the existing ground level.

A.14 The geometric standard used in the redesign can be summarised as follows:

• Generally, standards for a 60 km/h design speed were recommended for crest and sag curves, but earthworks savings were made by reducing the radius of selected crest curves nearer to the minimum standard
• In some of the more rugged sections, the minimum radius for a 60 km/h design speed could not be achieved so, in isolated instances, design speed was reduced to 40 km/h
• Earthworks savings were obtained by the use of steeper gradients, with a maximum of 10 per cent in the most rugged sections of the route; where a long climb in open country could be avoided by a shorter climb of up to 10 per cent gradient, these were included
• Climbing lanes were used except where long straights enabled safe overtaking without a climbing lane
• Special urban cross-sections were used where the road passed through villages.

A.15 The minimum standards used are shown in Table A7.

## TABLE A7
MINIMUM GEOMETRIC STANDARDS ADOPTED

<table>
<thead>
<tr>
<th>Design speed (km/h)</th>
<th>80</th>
<th>60</th>
<th>40</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute minimum horizontal radius (m) (maximum super-elevation 7%)</td>
<td>240</td>
<td>120</td>
<td>40</td>
</tr>
<tr>
<td>Normal minimum horizontal radius (m) (maximum super-elevation 5%)</td>
<td>450</td>
<td>250</td>
<td>110</td>
</tr>
<tr>
<td>Maximum grade</td>
<td>10%</td>
<td>10%</td>
<td>10%</td>
</tr>
<tr>
<td>Minimum crest vertical curve (m)</td>
<td>4500</td>
<td>1600</td>
<td>500</td>
</tr>
<tr>
<td>Minimum sag vertical curve (m)</td>
<td>2200</td>
<td>1500</td>
<td>700</td>
</tr>
</tbody>
</table>

A.16 In areas where detailed mapping did not exist, topographic surveys were carried out to provide data for input to a computer model used to derive cross-section information and to estimate earthworks quantities.

A.17 Considerable geotechnical investigation had been carried out by the previous consultant and further work was undertaken to augment this and, to a limited extent, verify the earlier work. Further geotechnical studies were also carried out wherever realignments were proposed. In particular, the aim of these studies was to investigate:

• the stability of cutting and side slopes
• the California bearing ratios used for the pavement design
• the nature of soft ground crossings.

A.18 Site work consisted of inspecting existing earthworks, digging of trial pits and the use of a mackintosh probe to investigate subsoil conditions. Laboratory tests were carried out to analyse samples that were collected. An investigation was carried out of materials available from cuttings and borrow areas needed to allow construction of the proposed road.

A.19 Rainfall data were collected from records and were used with field observations to determine hydrological and drainage requirements. Runoff was estimated using a variety of methods to arrive at appropriate values. Culverts were designed for a 10 year return period and larger culverts were checked for the possible consequences of a 25 year return flood period. Where it was considered that this larger flood might seriously damage the road or structure, then culvert capacity was increased. Bridges were designed for a 50 year return period of flood.

## CONSTRUCTION COSTS

A.20 The estimate of construction cost that was based on the engineering design and used for the economic analysis is shown in Table A8. A separate financial cost analysis was also carried out.

## TABLE A8
ESTIMATE OF CONSTRUCTION COST FOR THE ECONOMIC ANALYSIS (1986 prices)

<table>
<thead>
<tr>
<th>Length</th>
<th>Section 1</th>
<th>Section 2</th>
<th>Section 3</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.2km</td>
<td>106</td>
<td>1691</td>
<td>476</td>
<td>2273</td>
</tr>
<tr>
<td>71.3km</td>
<td>24</td>
<td>281</td>
<td>70</td>
<td>375</td>
</tr>
<tr>
<td>17.5km</td>
<td>169</td>
<td>1994</td>
<td>492</td>
<td>2655</td>
</tr>
<tr>
<td>95km</td>
<td>88</td>
<td>1013</td>
<td>256</td>
<td>1357</td>
</tr>
<tr>
<td>Earthworks</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel sub-base</td>
<td>112</td>
<td>1304</td>
<td>332</td>
<td>1748</td>
</tr>
<tr>
<td>Crushed rock base</td>
<td>165</td>
<td>1800</td>
<td>705</td>
<td>2670</td>
</tr>
<tr>
<td>Double seal</td>
<td>100</td>
<td>1212</td>
<td>350</td>
<td>1662</td>
</tr>
<tr>
<td>surface dressing</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Asphaltic concrete</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>surfacing</td>
<td>764</td>
<td>9295</td>
<td>2681</td>
<td>12740</td>
</tr>
<tr>
<td>Drainage</td>
<td>210</td>
<td>2557</td>
<td>737</td>
<td>3504</td>
</tr>
<tr>
<td>Miscellaneous (15%)</td>
<td>86</td>
<td>12782</td>
<td>3683</td>
<td>17518</td>
</tr>
<tr>
<td>Prelim &amp; general (10%)</td>
<td>76</td>
<td>930</td>
<td>268</td>
<td>1274</td>
</tr>
<tr>
<td>Contingencies &amp; dayworks (25%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1050</td>
<td>12782</td>
<td>3683</td>
<td>17518</td>
</tr>
</tbody>
</table>
A.21 It was anticipated that the construction would be divided into two lots and would start in 1987, lasting for four years. Expenditure through this period used for the economic analysis is shown in Table A9.

<table>
<thead>
<tr>
<th>Year</th>
<th>Lot 1</th>
<th>Lot 2</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1987 (30%)</td>
<td>2752</td>
<td>2503</td>
<td>5255</td>
</tr>
<tr>
<td>1988 (45%)</td>
<td>4128</td>
<td>3755</td>
<td>7883</td>
</tr>
<tr>
<td>1989 (15%)</td>
<td>1376</td>
<td>1252</td>
<td>2628</td>
</tr>
<tr>
<td>1990 (10%)</td>
<td>917</td>
<td>835</td>
<td>1752</td>
</tr>
<tr>
<td>Totals</td>
<td>9173</td>
<td>8345</td>
<td>17518</td>
</tr>
</tbody>
</table>

A.22 In order to determine the residual value of the project at the end of the 15 year economic analysis period, the following assumptions were made:

- All earthworks were assumed to be satisfactory and their cost treated as part of the residual value
- Large drainage structures would have many years of useful life ahead of them, but the small steel pipe culverts might be starting to fall into disrepair; it was assumed that 50 per cent of the capital cost of drainage works would form part of the residual value
- None of the pavement construction would have any value after 15 years although, if maintenance were to be carried out satisfactorily, much of it might still be useful.

As a result of the above, a figure of 25 per cent of the capital cost of construction was taken as the residual value of the road.

A.23 Experience has shown that, for a road as heavily trafficked as this, costs of maintenance of both a baseline and a study case would be extremely low when compared with the vehicle operating costs. The results of an economic analysis are thus insensitive to large variations in maintenance costs. This was borne out by the results of this study.

A.24 At the time of the fieldwork for the project, the study team were impressed by the success of maintenance being carried out, both on the existing gravel road and on other roads. The road was regraded at least twice a year and minor pavement reconstruction and recompaction was normally carried out on one of these occasions. For the baseline case of the economic analysis, it was assumed that this policy would continue.

A.25 Costs of maintenance were obtained from the road maintenance organisation in the country.

A.26 Data on vehicle operating costs and operating patterns were gathering for typical vehicle classes:

- Private car: Toyota Cressida Break
- Pick-up: Toyota Hilux LN6S Double Cab Standard (Four wheel drive)
- Minibus: Toyota Hiace 15 Seater
- Two axle truck: Toyota DA 110 Benne
- Three axle truck: Volvo N1033 6x4
- Taxi: Nissan Sunny

A.27 Vehicle and tyre costs were obtained from distributors. Overheads costs and operating patterns were established from interviews with local businessmen, operators and officials, and from published sources, such as insurance and licencing price lists.

A.28 Values of passenger time were obtained by factoring vehicle occupancy (based on observations and counts) by standard wage rates for typical passengers, obtained from national wage rate charts, and making allowances for the proportion of passengers travelling for business and personal reasons found from traffic surveys.

A.29 Some adjustments were made to the pattern of vehicle operation and costs in the case of the road being upgraded. It was not thought likely that there would be a decline in the number of four wheel drive vehicles, as access would still be required to outlying parts but their proportion of the total car/pickup fleet might drop.

A.30 The sizes of buses and trucks would almost certainly increase. Interviews with vehicle operators indicated that the paving and realignment of the road would lead to:

- a rapid replacement of 15-18 seat minibuses with 20-25 seat midibuses: this was taken into account in the traffic forecasts by assuming a progressive transfer over the analysis period from one type of bus to the other.
- a progressive change from 2-axle to 3-axle trucks for general utility purposes, as old vehicles were retired: this did not appear to make a great difference in terms of road deterioration and was ignored in the traffic forecasts.
- fitting of trailers to 3-axle trucks for heavy haulage: again, this did not appear to affect the road deterioration and was ignored in the traffic growth calculations.

A.31 In terms of maintenance practice, it was thought likely that urban taxis would start to use remould tyres;
originally they operated part of their journeys over the unpaved road and therefore invested in new tyres. The cost differences were reflected in the unit tyre prices assumed.

A.32 Another outcome of road improvements would be a growth in the number of two-wheeled vehicles. These would mainly be in addition to, rather than instead of, the number of motor vehicles discussed above, and inconsequential in terms of road deterioration. Costs and benefits in terms of operating costs and user time savings were not taken into account for these vehicles.

COST-BENEFIT ANALYSIS

A.33 The project was analysed using the TRRL RTIM2 computer program. The basic analysis used the most likely forecasts of the various parameters to compare the situation over the years 1989 to 2003 for the case where the existing situation was to be maintained with its present characteristics, and with the situation which would follow the upgrading of the road.

A.34 Analysis was carried out separately for the three sections of road and for three separate benefit streams:

- Operating cost benefit to base traffic (existing traffic that would be on the road plus the projected growth in traffic even if the road were not improved)
- Operating cost benefits to base traffic plus the additional traffic generated by improvements to the road
- Operating cost benefits to these two sets of traffic plus the value of time savings by passengers in the vehicles on the road.

Results are shown in terms of NPV and IRR in Table A.10.

A.35 It can be seen that each section of the project and the project overall (at an IRR of 20.6 per cent) all appear to be economically viable even on the basis of only operating cost savings to base traffic. Once the generated traffic and time savings are included, the IRR rises to 23.9 per cent for the whole road. It should be noted that, in every case, the addition of the benefits to generated traffic and from passenger time savings made relatively little difference to the rates of return obtained from considering only the base traffic; the savings in vehicle operating costs to base traffic alone yield a firm basis for assessing the viability of the project.

### TABLE A10
**ECONOMIC ANALYSIS RESULTS OF THE MOST LIKELY CASE**

<table>
<thead>
<tr>
<th>Road section</th>
<th>Base traffic only</th>
<th>Base plus generated traffic</th>
<th>Traffic benefits plus time savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NPV (at 10% discount rate)</td>
<td>IRR (%)</td>
<td>NPV (at 10% discount rate)</td>
</tr>
<tr>
<td>1 (6.2km)</td>
<td>3000</td>
<td>46.8</td>
<td>3554</td>
</tr>
<tr>
<td>2 (71.3km)</td>
<td>8143</td>
<td>20.0</td>
<td>10658</td>
</tr>
<tr>
<td>3 (17.5km)</td>
<td>882</td>
<td>14.0</td>
<td>1406</td>
</tr>
<tr>
<td>Total project</td>
<td>12025</td>
<td>20.6</td>
<td>15618</td>
</tr>
</tbody>
</table>

### TABLE A11
**DEPENDENCE OF NPV ON DISCOUNT RATE**

<table>
<thead>
<tr>
<th>Section</th>
<th>Base traffic only</th>
<th>Base plus generated traffic</th>
<th>Traffic benefits plus time savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>7.5%</td>
<td>12.5%</td>
<td>7.5%</td>
</tr>
<tr>
<td>1</td>
<td>3898</td>
<td>2327</td>
<td>4612</td>
</tr>
<tr>
<td>2</td>
<td>12231</td>
<td>5148</td>
<td>15466</td>
</tr>
<tr>
<td>3</td>
<td>1723</td>
<td>275</td>
<td>2397</td>
</tr>
<tr>
<td>Total project</td>
<td>17852</td>
<td>7750</td>
<td>22475</td>
</tr>
</tbody>
</table>
A.36 Clearly, the most heavily trafficked section of the road (Section 1) shows the highest internal rate of return, but the least trafficked (Section 3) shows an IRR of 14.0 per cent for operating cost savings to basic traffic, and 17.1 per cent when benefits to all traffic and the value of time savings are also included. The highest NPV is, not surprisingly, generated by the longest section of road (Section 2) in all cases.

A.37 Overall, the project is clearly viable with the assumptions considered to be the most likely for each of the input parameters, and even the least trafficked section is viable on the basis of benefits to existing base traffic only. The robustness of the project's viability is further demonstrated by the sensitivity tests which were subsequently carried out.

**SENSITIVITY TESTS**

A.38 Because of the uncertainties surrounding many of the base year data and, therefore, the scope for uncertainty in many of the forecasts, extensive sensitivity testing was carried out. The parameters considered were as follows:

- Discount rate
- ADT
- Traffic growth rates
- Construction cost
- Road maintenance

**Discount rate**

The project was analysed for discount rates 25 per cent above and below the test discount rate of 10 per cent. The effect on NPV is shown in Table A12. It will be seen that, at all discount rates, all individual sections of road, as well as the total project, always produced a positive NPV.

**Variations in ADT**

A.40 Sensitivity tests were carried out for ADT levels 25 per cent above and below the estimated values used in the most likely cases, which were derived from traffic counts. The sensitivity of NPV is shown in Table A12 and that of IRR is shown in Table A13. The use of a discount rate of 10 per cent led to the NPV for Section 3, including benefits to base traffic only, becoming negative; the IRR was below 10 per cent. All other cases had a positive NPV. The economic return for the project as a whole was satisfactory when considering benefits to normal traffic only and its viability seemed robust.

**TABLE A12**

<table>
<thead>
<tr>
<th>Road section</th>
<th>Base traffic only</th>
<th>Base plus generated traffic</th>
<th>Traffic benefits plus time savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>1</td>
<td>2701</td>
<td>3912</td>
<td>2490</td>
</tr>
<tr>
<td>2</td>
<td>3816</td>
<td>12451</td>
<td>5726</td>
</tr>
<tr>
<td>3</td>
<td>-21</td>
<td>1769</td>
<td>374</td>
</tr>
<tr>
<td>Total project</td>
<td>5866</td>
<td>18132</td>
<td>8590</td>
</tr>
</tbody>
</table>

**TABLE A13**

<table>
<thead>
<tr>
<th>Road section</th>
<th>Base traffic only</th>
<th>Base plus generated traffic</th>
<th>Traffic benefits plus time savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>1</td>
<td>36.7</td>
<td>56.4</td>
<td>39.7</td>
</tr>
<tr>
<td>2</td>
<td>14.9</td>
<td>24.8</td>
<td>17.0</td>
</tr>
<tr>
<td>3</td>
<td>9.9</td>
<td>17.7</td>
<td>11.7</td>
</tr>
<tr>
<td>Total project</td>
<td>15.4</td>
<td>25.6</td>
<td>17.5</td>
</tr>
</tbody>
</table>
Traffic growth rates

A.41 Three variations in traffic growth rates were considered in the sensitivity tests:

- Zero traffic scenario: no growth at all in either base traffic or generated traffic
- Low traffic scenario: 3 per cent growth in base traffic and 5 per cent growth in generated traffic
- High traffic scenario: 7 per cent growth in base traffic and 11 per cent growth in generated traffic.

In each case, the percentages given for traffic growth were weighted averages across the different vehicle types which comprised the total traffic flow. The results of these analyses are shown in Tables A14 and A15.

A.42 It was demonstrated that the viability of the project was robust under varying traffic assumptions, which was plausible given the high rates of return demonstrated for the most likely case and the satisfactory results for lower than estimated ADT. Even in the case of zero traffic growth, the project remained extremely viable overall, at 16.1 per cent IRR on benefits to base traffic only (18.0 per cent if all the benefits are included). The small variation in economic return between the low and high traffic growth scenarios again illustrated that a significant element of the net benefit accrued from the cost savings to existing base traffic.

TABLE A14
DEPENDENCE OF NPV ON TRAFFIC GROWTH RATES

<table>
<thead>
<tr>
<th>Road section</th>
<th>Base traffic only</th>
<th>Base plus generated traffic</th>
<th>Traffic benefits plus time savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zero</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>1</td>
<td>2053</td>
<td>2571</td>
<td>3512</td>
</tr>
<tr>
<td>2</td>
<td>3658</td>
<td>6081</td>
<td>10563</td>
</tr>
<tr>
<td>3</td>
<td>-26</td>
<td>471</td>
<td>1374</td>
</tr>
<tr>
<td>Total project</td>
<td>5685</td>
<td>9123</td>
<td>15449</td>
</tr>
</tbody>
</table>

TABLE A15
DEPENDENCE OF IRR ON TRAFFIC GROWTH RATES

<table>
<thead>
<tr>
<th>Road section</th>
<th>Base traffic only</th>
<th>Base plus generated traffic</th>
<th>Traffic benefits plus time savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Zero</td>
<td>Low</td>
<td>High</td>
</tr>
<tr>
<td>1</td>
<td>42.0</td>
<td>44.9</td>
<td>48.7</td>
</tr>
<tr>
<td>2</td>
<td>15.4</td>
<td>18.1</td>
<td>22.0</td>
</tr>
<tr>
<td>3</td>
<td>9.9</td>
<td>12.3</td>
<td>15.8</td>
</tr>
<tr>
<td>Total project</td>
<td>16.1</td>
<td>18.8</td>
<td>22.6</td>
</tr>
</tbody>
</table>

Construction cost

A.43 The sensitivity of the project's viability to variations in the construction cost was tested by assuming costs 25 per cent higher and 25 per cent lower than the most likely case. Even in the high cost case, all road sections remain viable, as shown in Tables A16 and A17.

A.44 The effect of assuming changes in construction cost had more effect on the economic return of the project than had been exhibited in the sensitivity tests on traffic levels and growth. However, where the low cost assumptions produced a marked increase in the rates of return, the high cost assumptions did not generally depress the IRR's to the same levels as the sensitivity tests on traffic.

Maintenance capability

A.45 The economic analysis was carried out on the assumption that maintenance would continue at existing levels observed in the country. Sensitivity testing was carried out to try and predict the consequences of future levels of maintenance falling from these levels. It was not possible to investigate this directly with the investment model so, instead, it was assumed that poor maintenance would result in a pavement that was effectively weaker than it otherwise would be. The best estimate of
TABLE A16

DEPENDENCE OF NPV ON CONSTRUCTION COST

| Road section | Base traffic only | | Base plus generated traffic | | Traffic benefits plus time savings | |
|--------------|------------------|------------------|------------------|------------------|------------------|
|              | Low | High | Low | High | Low | High | Low | High | |
| 1            | 3204 | 2796 | 3758 | 3350 | 3980 | 3572 | |
| 2            | 10624 | 5661 | 13140 | 8177 | 13880 | 8917 | |
| 3            | 1600 | 164 | 2124 | 688 | 2405 | 969 | |
| Total project | 15428 | 8621 | 19022 | 12215 | 20265 | 13458 | |

TABLE A17

DEPENDENCE OF IRR ON CONSTRUCTION COST

| Road section | Base traffic only | | Base plus generated traffic | | Traffic benefits plus time savings | |
|--------------|------------------|------------------|------------------|------------------|------------------|
|              | Low | High | Low | High | Low | High | Low | High | |
| 1            | 59.6 | 38.6 | 63.4 | 41.7 | 66.2 | 43.5 | |
| 2            | 26.5 | 15.8 | 29.0 | 17.9 | 30.0 | 18.6 | |
| 3            | 19.0 | 10.6 | 21.3 | 12.5 | 22.6 | 13.4 | |
| Total project | 27.3 | 16.3 | 29.8 | 18.5 | 31.0 | 19.3 | |

TABLE A18

EFFECT ON NPV AND IRR OF A REDUCED MAINTENANCE CAPABILITY

| Road section | Base traffic only | | Base plus generated traffic | | Traffic benefits plus time savings | |
|--------------|------------------|------------------|------------------|------------------|------------------|
|              | NPV | IRR | NPV | IRR | NPV | IRR | |
| 1            | 2782 | 46.1 | 3301 | 49.5 | 3522 | 51.8 | |
| 2            | 6190 | 18.3 | 8458 | 20.6 | 9187 | 21.5 | |
| 3            | 631 | 13.0 | 1126 | 15.0 | 1406 | 16.2 | |
| Total project | 9603 | 19.1 | 12885 | 21.5 | 14115 | 22.5 | |

Pavement strength was that it would have a ‘modified structural number’ of 4.0, so the effect of reducing this to 3.2 was examined in order to study the implications of a reduction in maintenance capability. The result are shown in Table A18.

A.46 In each case, the economic return was very slightly lower than in the most likely case because of the increased vehicle operating costs, but were still more than acceptable in all cases.

OTHER BENEFITS

A.47 In addition to the quantified factors included in the analysis, a number of benefits were omitted, either because RTIM2 does not allow for their inclusion, or because the base data were not available to permit their ready quantification. However, although the project appeared robust without their inclusion, they are described below.

Time savings for freight

A.48 The benefits from saving time in the transport of freight were seen as the prevention of deterioration of produce and other perishable commodities. It was thought that greater damage to produce was caused by it having to be hauled over a rough road, rather than it perishing due to long journey time. However there would be an accumulation of small benefits from saving time in
freight haulage, in terms of getting produce to markets more quickly, which were not included in the economic analysis.

**Diverted traffic**

A.49 Turning movement counts and interviews from freight hauliers suggested that there would be some limited diversion from other roads. As it was difficult to quantify the extent of the current use of these roads and to predict the degree of diversion after the paving of the road, diverted traffic was omitted from the analysis.

A.50 It is clear, however, that there would be two sets of benefits from such diversion:

- Traffic diverting on to the new road would experience vehicle operating cost saving since that which did not, would not divert
- There would be maintenance cost savings on the existing unpaved roads if the level of use of them by trucks decreased.

There would be disbenefits in terms of road deterioration and speed/flow effects if the level of diverted traffic were very high but, as a proportion of the total traffic on the new road, it was likely to be small.

**Socio-economic integration**

A.51 The study suggested that a major, but largely unquantifiable benefit, from the proposed scheme would be the enhanced socio-economic integration of the province in which the road was sited into the rest of the country. Many of these effects would be manifested as generated traffic, but it was likely that there would be other beneficial effects from a governmental and public perception of the province becoming more accessible. For example, it should prove easier to attract doctors and teachers to work in the remoter areas, and banks which were currently inhibited from establishing new branches along the road would feel more secure in transporting money along its length.

**Improved consumer choice**

A.52 The possibility of using larger trucks on an improved road would lead to more economic distribution of consumer items, and thus to a greater choice and availability of local and imported manufactured goods in the markets along the road.

**Increased export earnings**

A.53 There appeared to be considerable potential for diversification into high altitude, temperate climate agricultural produce, much of it high value/low weight. There were good markets in the country's capital for this but, more importantly, good possibilities for air freight export as black hauls, as is currently practised from other African countries. Produce of this type could not be transported without considerable and uneconomic damage and loss.

**Road safety**

A.54 It proved impossible to determine the number of accidents along the road, or to establish the total number of road accidents even at the provincial level, due to incomplete recording of damage-only accidents and the absence of a reliable data-base on injury accidents. Neither were data readily available to enable road accidents to be costed in a scientific manner. It did appear, however, that the prevailing level of road accidents is, rightly, of major concern to the government. It was clear that accidents throughout this country were contributed to by poor road alignment and inadequate sightlines but, in the absence of any thorough investigation of the cause of accidents, it was difficult to express a view on the matter, and any costs or benefits in this respect were omitted from the analysis.
APPENDIX B
ROAD SHORTENING PROJECT

BACKGROUND TO THE STUDY

B.1 The TRRL road investment model was used as part of an appraisal of a road project by ODA. The existing gravel road traversed an area of dense population and high agricultural potential. The topography in the area was rugged and included 10 mountain rivers and 30 streams. The new alignment replaced the old road and shortened the direct route length by 30 km, from 84.40 to 54.38 km. The principal benefits considered were the economic value of road user savings resulting from shortening the route and improving the road surface to bitumen standard. These were principally vehicle operating cost savings for the expected 'normal' traffic over the life of the project, but the value of time savings for this traffic was also considered. A further source of benefits was a reduction in road maintenance costs as a result of the project. The effect of generated traffic was also considered.

B.2 The existing road followed the contours of the ground, having a tortuous horizontal alignment, but relatively flat gradients. The new road was to have gentle horizontal curves and steeper gradients and involved the construction of substantial earthworks. On completion of the project, the existing road was to have been abandoned. Predicted traffic levels suggested that the ADT for normal traffic in 1985 would be just under 200 vpd rising to more than 600 vpd, with generated traffic rising from 300 to over 1200 vpd after 20 years.

ROAD USER COST SAVINGS

B.3 The vehicle operating costs of traffic on the road would be affected by the severity of the road geometry and the condition of the road surface (roughness). On the existing road, it was predicted that roughness would vary from 5.0 m/km on average in the first year up to about 11.0 m/km with the same level of maintenance in the final year. On the new project, roughness would rise steadily from 2.5 m/km in the first year of trafficking to 3.5 m/km in the last. Vehicle operating costs were also affected by the age of vehicle. It was estimated that vehicles would achieve higher utilisation on the new project which implied that, on average, vehicles would be older in terms of the total number of kilometres travelled since new. The differences in road user costs for the 'with' and 'without' project situations are illustrated in Table B 1 which shows costs for the first year of traffic and the final year of analysis.

B.4 There would be a reduction in vehicle operating costs per kilometre for all vehicle types following the construction of the project in both the first year of trafficking and the final year of analysis. The reduction ranged from 10 to 43 per cent for different vehicle types and in different project years. These changes in cost were caused by the reduction in road roughness and the increase in speed and vehicle utilisation. All these savings would be increased further because of the shortening of the road length.

B.5 The assessment of time savings per kilometre was particularly interesting. The new road had lower roughness levels than the original, but had steeper gradients, and vehicle speed, and consequently time savings, would depend on the relative magnitude of

<table>
<thead>
<tr>
<th>TABLE B1</th>
<th>ROAD USER COST SAVINGS PER VEHICLE KM</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vehicle operating costs</td>
</tr>
<tr>
<td></td>
<td>Existing road</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>First year of trafficking</td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>1.03</td>
</tr>
<tr>
<td>Lt. Goods</td>
<td>2.29</td>
</tr>
<tr>
<td>Truck</td>
<td>4.87</td>
</tr>
<tr>
<td>Bus</td>
<td>3.32</td>
</tr>
<tr>
<td>Final year of analysis</td>
<td></td>
</tr>
<tr>
<td>Car</td>
<td>1.28</td>
</tr>
<tr>
<td>Lt. Goods</td>
<td>2.72</td>
</tr>
<tr>
<td>Truck</td>
<td>5.59</td>
</tr>
<tr>
<td>Bus</td>
<td>3.84</td>
</tr>
</tbody>
</table>
## Table B2

### Annual costs for new project

<table>
<thead>
<tr>
<th>YEAR</th>
<th>CONSTRUCTION</th>
<th>MAINTENANCE</th>
<th>VEHICLE OPERATING COSTS</th>
<th>TIME COSTS</th>
<th>OTHER BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>NORMAL TRAFFIC</td>
<td>GENERATED TRAFFIC</td>
<td>NORMAL TRAFFIC</td>
</tr>
<tr>
<td>1978</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1979</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1980</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1981</td>
<td>87393600.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1982</td>
<td>65545200.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1983</td>
<td>65545200.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1984</td>
<td>12138000.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>1985</td>
<td>79856.70</td>
<td>79856.70</td>
<td>6631835.20</td>
<td>11253822.20</td>
<td>590469.50</td>
</tr>
<tr>
<td>1986</td>
<td>79856.70</td>
<td>79856.70</td>
<td>7001392.62</td>
<td>14040812.88</td>
<td>626017.73</td>
</tr>
<tr>
<td>1987</td>
<td>79856.70</td>
<td>79856.70</td>
<td>759671.30</td>
<td>1532503.58</td>
<td>685009.95</td>
</tr>
<tr>
<td>1988</td>
<td>79856.70</td>
<td>79856.70</td>
<td>8037285.37</td>
<td>1628777.12</td>
<td>749646.07</td>
</tr>
<tr>
<td>1989</td>
<td>79856.70</td>
<td>79856.70</td>
<td>8728050.01</td>
<td>17625197.22</td>
<td>812376.34</td>
</tr>
<tr>
<td>1990</td>
<td>79856.70</td>
<td>79856.70</td>
<td>9566383.56</td>
<td>19302598.22</td>
<td>881766.05</td>
</tr>
<tr>
<td>1991</td>
<td>79856.70</td>
<td>79856.70</td>
<td>10650234.97</td>
<td>21345136.74</td>
<td>956503.05</td>
</tr>
<tr>
<td>1992</td>
<td>79856.70</td>
<td>2486633.93</td>
<td>11950363.16</td>
<td>23410760.66</td>
<td>1028143.54</td>
</tr>
<tr>
<td>1993</td>
<td>79856.70</td>
<td>79856.70</td>
<td>12593510.01</td>
<td>25615616.24</td>
<td>1105221.85</td>
</tr>
<tr>
<td>1994</td>
<td>79856.70</td>
<td>79856.70</td>
<td>13722530.75</td>
<td>28002463.99</td>
<td>1188157.47</td>
</tr>
<tr>
<td>1995</td>
<td>79856.70</td>
<td>79856.70</td>
<td>14779723.39</td>
<td>30261275.55</td>
<td>1265604.59</td>
</tr>
<tr>
<td>1996</td>
<td>79856.70</td>
<td>79856.70</td>
<td>15922225.45</td>
<td>32705683.22</td>
<td>1343298.77</td>
</tr>
<tr>
<td>1997</td>
<td>79856.70</td>
<td>79856.70</td>
<td>17101022.93</td>
<td>35424935.16</td>
<td>1436621.17</td>
</tr>
<tr>
<td>1998</td>
<td>79856.70</td>
<td>1841611.94</td>
<td>18278357.42</td>
<td>37811409.12</td>
<td>1516589.91</td>
</tr>
<tr>
<td>1999</td>
<td>79856.70</td>
<td>279496.76</td>
<td>19421284.77</td>
<td>40288112.93</td>
<td>1601274.62</td>
</tr>
<tr>
<td>2000</td>
<td>79856.70</td>
<td>2700102.50</td>
<td>20746857.13</td>
<td>43153848.91</td>
<td>1690984.21</td>
</tr>
<tr>
<td>2001</td>
<td>79856.70</td>
<td>21978208.80</td>
<td>21978208.80</td>
<td>45841929.35</td>
<td>1768891.80</td>
</tr>
<tr>
<td>2002</td>
<td>79856.70</td>
<td>2332689.80</td>
<td>2332689.80</td>
<td>48790567.56</td>
<td>1850487.67</td>
</tr>
<tr>
<td>2003</td>
<td>79856.70</td>
<td>24787522.76</td>
<td>24787522.76</td>
<td>51976730.30</td>
<td>1936181.42</td>
</tr>
<tr>
<td>2004</td>
<td>79856.70</td>
<td>26339404.70</td>
<td>26339404.70</td>
<td>55393223.94</td>
<td>2026212.43</td>
</tr>
<tr>
<td>2005</td>
<td>79856.70</td>
<td>298871664.13</td>
<td>298871664.13</td>
<td>51976730.30</td>
<td>2026212.43</td>
</tr>
<tr>
<td>2006</td>
<td>79856.70</td>
<td>298871664.13</td>
<td>298871664.13</td>
<td>51976730.30</td>
<td>2026212.43</td>
</tr>
</tbody>
</table>

| 242760000.00 | 7010152.24 |
| 298871664.13 | 613677177.87 | 25055058.15 | 70061690.22 | 20000000.00 |
these components. In the case of cars and light goods vehicles, the effect of reduction in roughness outweighed the increased gradients in the first year of traffic and considerable time savings were predicted. This saving was increased further in the last year of traffic. However, in the case of trucks and buses, the balance of these effects caused speed to fall rapidly in the first year of trafficking which resulted in an increased time cost. This increase was so large that, even allowing for the shorter road length, it would be quicker for trucks and buses to use the old route. By the time of the final year of analysis, it was predicted that roughness levels on the old road would have outweighed the effect of steeper gradients, and positive time savings per kilometre would occur on the new project.

B.6 Tables B2 and B3 show the undiscounted cost streams for all cost components for both the new project and the existing road over the analysis period. The vehicle operating cost and time cost columns show clearly the gradual increase in these costs over time for both normal and generated traffic. This increase is due both to the growth in traffic over time and to the effect on vehicle operating costs of the deterioration of the road surface condition with time.

ENGINEERING COSTS

B.7 Table B2 shows how the construction cost was spread over the five years 1981-1985, with different percentages being spent in each of these years. For the existing road, in Table B3, a regravelling operation was programmed for 1984 in the ‘do-nothing’ or ‘do minimum’ case.

B.8 The inputs of periodic maintenance can be clearly seen in the ‘Maintenance’ columns of Tables B2 and B3. Table B2 shows the cost peaks where surface dressing would be carried out in 1992 and 2000. The cost of £9856.70 represents the cost of drainage and shoulder maintenance plus the cost of maintenance overheads. The slight escalation of maintenance cost in 1998 and 1999 represented the cost of patching cracks and pot-holes. Notice that the need for this was eliminated following a surface dressing. Table B3 shows that regravelling was planned to be carried out in 1984, 1988, 1992, 1996, 2000 and 2004. This was based on the estimate of regravelling needs because of the rate at which gravel would be worn away by traffic and rainfall. The remaining costs represented drainage and overhead costs plus the cost of grading the road which was expected to be carried out at the same frequency throughout the life of the project.

B.9 A benefit of 200 million currency units was included in the final year of the project to cover the residual value of the earthworks and drainage structures at the end of the analysis period.

B.10 The costs in Tables B2 and B3 are not discounted and it is interesting to note that the maintenance cost of the new project was less than 3 per cent of the construction cost and less than 2 per cent of the total cost (construction plus maintenance plus vehicle operating cost). For the existing road, maintenance still represented less than 4 per cent of the total life cycle cost.

BENEFITS

B.11 The undiscounted annual net benefits for the project are shown in Table B4. The benefits due to construction, maintenance, and vehicle operation and time for normal traffic were found by the investment model by subtracting the costs in Table B2 from those in Table B3. The vehicle operating cost and time benefits due to generated traffic were evaluated using the consumer surplus method as described in para 14.7-11. The investment model has determined these automatically. Road accident savings were not included in the analysis in this case.

B.12 The discount rate used for this study was 12 per cent and, at the bottom of Table B4, the various cost stream totals have been discounted at this rate and at rates three per cent on either side of this. It was predicted that the project would produce direct savings in vehicle operating costs of 52 million currency units, savings in maintenance costs of 2.6 million, but at a discounted capital cost of 150 million. These values were used to determine the NPV’s shown in Table B5. Both NPV, IRR and FYRR values have been presented separately for:

(i) construction, maintenance and vehicle operating cost benefits to normal traffic only
(ii) as (i), but with the addition of vehicle operating cost benefits to generated traffic (consumer surplus)
(iii) as (ii) but, with the addition of time saving benefits.

B.13 It is clear from these figures that, at a 12 per cent discount rate, the project was not justifiable. At a 9 per cent rate, it was worth going ahead providing generated traffic and time benefits were included, but the timing of the start of the project should be reassessed.

SENSITIVITY TESTING

B.14 The road investment model was used to carry out sensitivity analysis of the key variables. The sensitivity to discount rate, developmental benefits (generated traffic) and time savings were carried out during the initial analysis using expected values of data. The sensitivity of the result to other variables was determined by carrying out additional analysis with the model.
TABLE B3

Annual costs for existing road

<table>
<thead>
<tr>
<th>YEAR</th>
<th>CONSTRUCTION</th>
<th>MAINTENANCE</th>
<th>VEHICLE OPERATING COSTS</th>
<th>TIME COSTS</th>
<th>OTHER BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>NORMAL TRAFFIC</td>
<td>GENERATED TRAFFIC</td>
<td>NORMAL TRAFFIC</td>
</tr>
<tr>
<td>1978</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1979</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1980</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1981</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1982</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1983</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1984</td>
<td>3793442.40</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1985</td>
<td>.00</td>
<td>174075.22</td>
<td>14306334.52</td>
<td>.00</td>
<td>1367303.31</td>
</tr>
<tr>
<td>1986</td>
<td>.00</td>
<td>174075.22</td>
<td>15280781.41</td>
<td>.00</td>
<td>1498336.71</td>
</tr>
<tr>
<td>1987</td>
<td>.00</td>
<td>174075.22</td>
<td>16399344.17</td>
<td>.00</td>
<td>1643183.19</td>
</tr>
<tr>
<td>1988</td>
<td>.00</td>
<td>3967517.62</td>
<td>16964017.73</td>
<td>.00</td>
<td>1803916.94</td>
</tr>
<tr>
<td>1989</td>
<td>.00</td>
<td>174075.22</td>
<td>18407326.96</td>
<td>.00</td>
<td>1963492.75</td>
</tr>
<tr>
<td>1990</td>
<td>.00</td>
<td>174075.22</td>
<td>20234386.37</td>
<td>.00</td>
<td>2140528.02</td>
</tr>
<tr>
<td>1991</td>
<td>.00</td>
<td>174075.22</td>
<td>22471582.96</td>
<td>.00</td>
<td>2338445.27</td>
</tr>
<tr>
<td>1992</td>
<td>.00</td>
<td>3967517.62</td>
<td>24744510.40</td>
<td>.00</td>
<td>2534139.67</td>
</tr>
<tr>
<td>1993</td>
<td>.00</td>
<td>174075.22</td>
<td>27177196.31</td>
<td>.00</td>
<td>2754291.13</td>
</tr>
<tr>
<td>1994</td>
<td>.00</td>
<td>174075.22</td>
<td>29908064.10</td>
<td>.00</td>
<td>3005208.19</td>
</tr>
<tr>
<td>1995</td>
<td>.00</td>
<td>174075.22</td>
<td>32544203.20</td>
<td>.00</td>
<td>3254297.67</td>
</tr>
<tr>
<td>1996</td>
<td>.00</td>
<td>3967517.62</td>
<td>35408628.48</td>
<td>.00</td>
<td>3541879.36</td>
</tr>
<tr>
<td>1997</td>
<td>.00</td>
<td>174075.22</td>
<td>38375185.98</td>
<td>.00</td>
<td>3880417.29</td>
</tr>
<tr>
<td>1998</td>
<td>.00</td>
<td>174075.22</td>
<td>41406335.40</td>
<td>.00</td>
<td>4219907.15</td>
</tr>
<tr>
<td>1999</td>
<td>.00</td>
<td>174075.22</td>
<td>44459533.70</td>
<td>.00</td>
<td>4626672.36</td>
</tr>
<tr>
<td>2000</td>
<td>.00</td>
<td>3967517.62</td>
<td>47783888.72</td>
<td>.00</td>
<td>5127491.91</td>
</tr>
<tr>
<td>2001</td>
<td>.00</td>
<td>174075.22</td>
<td>50769246.78</td>
<td>.00</td>
<td>5636032.58</td>
</tr>
<tr>
<td>2002</td>
<td>.00</td>
<td>174075.22</td>
<td>54106810.79</td>
<td>.00</td>
<td>6276251.81</td>
</tr>
<tr>
<td>2003</td>
<td>.00</td>
<td>174075.22</td>
<td>57623613.70</td>
<td>.00</td>
<td>7116586.02</td>
</tr>
<tr>
<td>2004</td>
<td>.00</td>
<td>3967517.62</td>
<td>61388509.52</td>
<td>.00</td>
<td>8289899.95</td>
</tr>
</tbody>
</table>

**ANNUAL COST MATRIX**

**VEHICLE OPERATING COSTS**

**TIME COSTS**

**OTHER BENEFITS**

**SUMMARY OF COSTS**

| 3793442.40 | 2244816.40 | 669759471.20 | 0.00 | 73018272.27 | 0.00 | 0.00 |

---
### TABLE B4

**Annual benefits for project**

<table>
<thead>
<tr>
<th>YEAR</th>
<th>CONSTRUCTION</th>
<th>MAINTENANCE</th>
<th>VEHICLE OPERATING COSTS</th>
<th>TIME COSTS</th>
<th>OTHER BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>NORMAL TRAFFIC</td>
<td>GENERATED TRAFFIC</td>
<td>NORMAL TRAFFIC</td>
</tr>
<tr>
<td>1978</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1979</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1980</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1981</td>
<td>-87393600.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1982</td>
<td>-65545200.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1983</td>
<td>-65545200.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1984</td>
<td>-8344557.60</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
<td>.00</td>
</tr>
<tr>
<td>1985</td>
<td>-12138000.00</td>
<td>94218.52</td>
<td>94218.52</td>
<td>7674499.32</td>
<td>6438052.21</td>
</tr>
<tr>
<td>1986</td>
<td>.00</td>
<td>94218.52</td>
<td>8279388.78</td>
<td>8110421.67</td>
<td>872318.98</td>
</tr>
<tr>
<td>1987</td>
<td>.00</td>
<td>94218.52</td>
<td>8803622.87</td>
<td>8634780.64</td>
<td>958173.24</td>
</tr>
<tr>
<td>1988</td>
<td>.00</td>
<td>3687660.92</td>
<td>6926732.36</td>
<td>6766836.06</td>
<td>1054270.67</td>
</tr>
<tr>
<td>1989</td>
<td>.00</td>
<td>94218.52</td>
<td>9679276.95</td>
<td>9517983.46</td>
<td>1150516.40</td>
</tr>
<tr>
<td>1990</td>
<td>.00</td>
<td>94218.52</td>
<td>10668002.81</td>
<td>10503951.95</td>
<td>1258761.97</td>
</tr>
<tr>
<td>1991</td>
<td>.00</td>
<td>94218.52</td>
<td>11913287.98</td>
<td>11745688.41</td>
<td>1381942.22</td>
</tr>
<tr>
<td>1992</td>
<td>.00</td>
<td>1480883.69</td>
<td>13194147.24</td>
<td>13025948.68</td>
<td>1505996.12</td>
</tr>
<tr>
<td>1993</td>
<td>.00</td>
<td>94218.52</td>
<td>1456386.30</td>
<td>14417379.40</td>
<td>1649069.28</td>
</tr>
<tr>
<td>1994</td>
<td>.00</td>
<td>94218.52</td>
<td>16185623.25</td>
<td>16022962.18</td>
<td>1817050.72</td>
</tr>
<tr>
<td>1995</td>
<td>.00</td>
<td>94218.52</td>
<td>17765479.81</td>
<td>17611720.20</td>
<td>1988593.08</td>
</tr>
<tr>
<td>1996</td>
<td>.00</td>
<td>3887660.92</td>
<td>19486403.03</td>
<td>19345121.18</td>
<td>2193580.59</td>
</tr>
<tr>
<td>1997</td>
<td>.00</td>
<td>94218.52</td>
<td>21274143.05</td>
<td>21150124.89</td>
<td>2443796.12</td>
</tr>
<tr>
<td>1998</td>
<td>.00</td>
<td>10086.72</td>
<td>2312797.98</td>
<td>23026695.44</td>
<td>2703317.24</td>
</tr>
<tr>
<td>1999</td>
<td>.00</td>
<td>-105421.54</td>
<td>25038248.93</td>
<td>24963337.67</td>
<td>3025397.74</td>
</tr>
<tr>
<td>2000</td>
<td>.00</td>
<td>1267415.12</td>
<td>27037031.58</td>
<td>26998400.26</td>
<td>3436507.20</td>
</tr>
<tr>
<td>2001</td>
<td>.00</td>
<td>94218.52</td>
<td>28751037.98</td>
<td>28793493.82</td>
<td>3867140.79</td>
</tr>
<tr>
<td>2002</td>
<td>.00</td>
<td>94218.52</td>
<td>30774120.99</td>
<td>30823857.70</td>
<td>4425764.13</td>
</tr>
<tr>
<td>2003</td>
<td>.00</td>
<td>94218.52</td>
<td>32836090.93</td>
<td>32939876.72</td>
<td>5180404.60</td>
</tr>
<tr>
<td>2004</td>
<td>.00</td>
<td>94218.52</td>
<td>35049104.82</td>
<td>35214824.69</td>
<td>6263607.82</td>
</tr>
</tbody>
</table>

**DISCOUNT RATE**

PER CENT

| 9.0  | 16813337.75  | 3854332.27  | 7968917.88  | 78381301.66  | 9712917.43  | 9573617.12  | 21278501.94 |
| 12.0 | 150770531.91 | 2617560.13  | 51584816.03 | 50569410.61  | 6183132.60  | 6074943.19  | 10504161.88 |
| 15.0 | -135096646.31| 1804059.02  | 34588968.92  | 33767274.49  | 4082035.02  | 3997026.58  | 5283067.34  |
Discount rate, developmental benefits and time

B.15 The sensitivity of the result to these variables is shown in Table B5. The discount rate was varied to examine the NPV at discount rates of 9 and 15 per cent. Table B5 enabled the NPV to be compared with and without generated traffic, and with and without time savings.

B.16 Considering the benefits to normal traffic alone, the NPV was negative at all discount rates tested. This was because the relatively large construction cost involved was not offset by the vehicle operating cost savings obtainable. The internal rate of return was less than half the test discount rate. A large amount of generated traffic was expected on the project and it was only when the benefits from this were considered in conjunction with a discount rate of 9 per cent that the project produced a positive NPV. In this case, the inclusion of time savings doubled the NPV. However, time savings were insufficient to produce a positive NPV at any other discount rate. Even including both benefits to generated traffic and time savings, an internal rate of return of less than 11 per cent was expected.

B.17 Consideration of the FYRR, with values ranging from 3.5 to less than 8 per cent, compared with a discount rate of 12 per cent, confirmed that the project was premature.

Traffic

B.18 The sensitivity to both baseline traffic levels and traffic growth was examined for values of plus or minus 50 per cent of that expected. The results are shown in Table B6.

B.19 Clearly, with a negative NPV, reducing either baseline flows or growth rates would reduce the value of the NPV further. However, even increasing the ADT or growth rate by 50 per cent could not produce a positive NPV unless generated traffic was taken into account, in which case benefits of 30-40 million currency units were anticipated. The inclusion of time savings more than doubled this value.

Construction cost

B.20 As expected, increasing the construction cost by 25 per cent reduced the NPV of the project even further. Reducing costs by this amount produces a marginally positive NPV when generated traffic benefits were
### TABLE B6

**SENSITIVITY ANALYSIS**

<table>
<thead>
<tr>
<th></th>
<th>Normal traffic only</th>
<th>Plus generated traffic</th>
<th>Plus time savings</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>NPV (millions)</td>
<td>Per cent change</td>
<td>NPV (millions)</td>
</tr>
<tr>
<td>Expected values</td>
<td>-86</td>
<td>-</td>
<td>-35</td>
</tr>
<tr>
<td>Discount rate -25%</td>
<td>-63</td>
<td>+27%</td>
<td>+15</td>
</tr>
<tr>
<td>Discount rate +25%</td>
<td>-94</td>
<td>-9%</td>
<td>-60</td>
</tr>
<tr>
<td>ADT –50%</td>
<td>-115</td>
<td>-34%</td>
<td>-93</td>
</tr>
<tr>
<td>ADT +50%</td>
<td>-48</td>
<td>+44%</td>
<td>+41</td>
</tr>
<tr>
<td>Traffic growth –50%</td>
<td>-103</td>
<td>-16%</td>
<td>-70</td>
</tr>
<tr>
<td>Traffic growth +50%</td>
<td>-54</td>
<td>+37%</td>
<td>+29</td>
</tr>
<tr>
<td>Construction –25%</td>
<td>-48</td>
<td>+44%</td>
<td>+3</td>
</tr>
<tr>
<td>Construction +25%</td>
<td>-124</td>
<td>-44%</td>
<td>-74</td>
</tr>
</tbody>
</table>

Included. Considering time savings as well gave an NPV of 15 million currency units with this level of reduction in construction cost.

### Relative sensitivities

B.21 Table B6 shows the changes in NPV for various percentage changes in discount rate, traffic, construction cost, and for the inclusion of developmental benefits (generated traffic) and time savings. The results from Table B6 show that the effect on NPV of reducing the discount rate was much more significant than increasing the discount rate. Changing either the ADT or traffic growth rate by plus or minus 50 per cent caused a smaller change in the NPV, and a slightly larger change was caused by increases, rather than decreases, in traffic. The NPV was increased dramatically when the effect of generated traffic was included. A 25 per cent change in construction cost caused a much larger change in NPV and this change was the same for both increases and decreases in values.

B.22 The parameter whose sensitivity had most effect on the NPV for normal traffic benefits was that of construction cost, but when generated traffic benefits were included, the baseline flow and traffic growth rate parameters were those whose sensitivity was most likely to give rise to a positive NPV. Reductions in NPV were most likely to be caused by an increase in construction cost.
NOTES
A guide to road project appraisal