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A guide to road project appraisal

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Overseas Road Notes

Overseas Road Notes are prepared principally for road and transport organisations in developing countries. A limited number of copies are available to other organisations and to individuals with an interest in road management, and may be obtained from:

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Table of Contents

List of Acronyms

AADT	Annual Average Daily Traffic
AC	Asphaltic Concrete
AHP	Analytical Hierarchy Process
ARI	Accounting Rate of Interest
CBA	Cost Benefit Analysis
DBM	Dense Bitumen Macadam
DFID	Department for International Development
DGD	Detailed Geotechnical Design
EF	Equivalent Factor
EIA	Environmental Impact Assessment
EIS	Environmental Impact Statement
EMP	Environmental Management Plan
ESA	Equivalent Standard Axle
FED	Final Engineering Design
FYRR	First Year Rate of Return
GA	Geotechnical Assessment
GDP	Gross Domestic Product
GDR	Geotechnical Difficulty Rating
GI	Ground Investigation
GNP	Gross National Product
GR	Geotechnical Review
HC	Human Capital
HDM	Highway Development and Management System
HRA	Hot Rolled Asphalt
IRR	Internal Rate of Return
MCA	Multi-Criteria Analysis
NGO	Non-Government Organisation
NPV	Net Present Value
ORN	Overseas Road Note
PCE	Passenger Car Equivalent
PCSE	Passenger Car Space Equivalent
PCU	Passenger Car Unit
PED	Preliminary Engineering Design
PGR	Preliminary Geotechnical Review
PVC	Present Values of Cost
RED	Road Economics Decision Model
RP	Revealed Preference
SEA	Strategic Environmental Assessment
SIA	Social Impact Assessment
SP	Stated Preference
gTKP	global Transport Knowledge Partnership
TOR	Terms of Reference
VEC	Valued Ecosystem Components
VOC	Vehicle Operating Cost
WTP	Willingness to Pay

Glossary

Access roads These cater for within-district travel by linking access zones to roads of a higher functional class.

Accessibility The ease of reaching desired destinations.

Activity Any work or intervention that is carried out on the road network, including works to undertake road maintenance, new construction, improvements, and the like.

Administration The operation and maintaining existing systems and procedures, originating elsewhere, as effectively and efficiently as possible.

Agency agreement A ‘framework’ agreement that sets down the general principles of the relationship between a client and a supplier of services, but leave the supplier with considerable discretion about the detailed operational requirements; known as a ‘contract plan’ in Francophone countries.

Alignment The vertical and the horizontal alignments are the terms used to describe the geometric features of the road in the vertical plane (i.e. as seen from the side) and the horizontal plane (as seen from above).

Appraisal Process of justifying and reaching a decision to invest resources in the road being appraised

Arterial roads Main roads connecting national and international centres.

Asset The physical infrastructure being managed.

Asset management A term applied to the management of assets using life cycle cost techniques, and often involving the assignment of a monetary value to the asset and all activities and operations undertaken in relation to the asset.

Audit A physical check, usually on a sample basis, that work has been carried out, where specified, to pre-defined standards or procedures, and that costs and other resources have been accounted for properly.

Availability (of travel and transport) Capable of being used, or within the reach of travellers; requires both the existence of transport infrastructure and services that are in a condition or state that enables them to be used.

Axle load survey Roadside survey undertaken to estimate the numbers of ‘equivalent standard axles’ currently using a road.

Budget head A category under which a budget is broken down for the purposes of its allocation.

Business plan A document describing the contribution to achieving corporate objectives of each of the divisions within an organization and setting out the annual objectives, tasks and programmes.

Camber The centre of the road is made higher than the edges to promote lateral run-off of water

Capital budget The government budget normally used to fund major projects.

Carriageway That part of the road used by traffic.

Chainage Distance measured along the road from a defined datum.

Client The body commissioning works or services.

Collector roads These roads link traffic to and from rural areas, either direct to adjacent urban centres, or to the arterial road network.

Committed works Works for which a budget has been approved.

Condition index A parameter that combines individual defect measurements to reflect a generic indication of defectiveness.

Condition-responsive treatment Works that are carried out in response to defects exceeding a defined threshold.

Construction ‘Development works’.

Contract An agreement between two willing parties to perform some action, where there has been an ‘offer’, an ‘acceptance’ and a ‘consideration’ (usually money).

Contractor The supplier of works or services under a contract.

Contractual claim A request made by a contractor for additional payment or an extension of time necessary to undertake works that are unforeseen or not specified in the contract.

Core road network That part of the road network, normally of a strategic nature, that will always be maintained even when available resources are extremely limited.

Corporate plan A document describing the business of an organization and setting out its mission and medium term objectives, and strategy for meeting these.

Cost estimation Procedure used for estimating the costs of a road scheme. The three basic techniques are the global rate, unit rate and operational methods.

Cost-effective The ratio of 'effectiveness' to 'cost', where effectiveness is a measure of the future value or worth resulting from a decision that is taken, and cost is the present-day cost of implementing that decision.

Cost-benefit analysis A formal comparison of costs and benefits to determine whether or not an investment is worthwhile.

Cost-plus contract Works contract where the contractor is paid for monies actually spent plus a mark-up for overheads and profit.

Customer The beneficiary of a service being provided. The main customers for a road administration are the road users, who include: owners and operators of commercial vehicles and buses; representatives of industry, commerce and agriculture, who have a vested interest in an efficient road network to support their business operations; and the travelling public using the road network.

Cuts and Cuttings Sections where material has been removed to lower the elevation of the road.

Cyclic works Routine maintenance works carried out each year whose frequency depends on environment and not traffic.

Data Facts (quantities, values, names, etc) from which other information may be inferred.

Defect Deteriorated from new condition.

Designated road A road that is a legal entity under a Roads Act or similar legislation (the terms 'adopted', 'declared', 'gazetted', 'proclaimed' are used in some countries).

Development works Works which extend the capacity of the network by widening, realignment or constructing a new section.

Direct labour 'In-house works implementation'.

Emergency works Works carried out on the network to reopen a cut or blocked road.

Environmental impact assessment (EIA) The process of assessing the environmental factors that will influence road planning and design. Often a legal requirement, with formal reporting, full disclosure and open to public scrutiny.

Equipment-based works Works that are undertaken mainly with the assistance of mechanical equipment.

Equivalence factor (EF) The pavement damaging effect of an axle in relation to the damage created by a standard axle.

Equivalent standard axle (load) All axle loads (measured in an axle load survey) are converted to an equivalent number of standard axles (ESA) and pavement design is usually based upon the total cumulative ESAs that the pavement will have to carry over its design life.

Evaluation Strictly the assessment of whether a completed project met the appraisal expectations. But often used synonymously with appraisal.

Gazetteer A list of designated links or sections that defines the road network

Global cost The 'broadest brush' category of cost-estimating technique which relies on libraries of achieved costs of similar works related to the overall size or capacity of the asset being considered.

Feasibility The final and most detailed stage of road appraisal before commitment to final design and procurement.

Feature A fundamental component of the road, such as the carriageway, shoulder, footway, etc.

Fills Material that has been moved from one place to another to build up the elevation of the road

Final engineering design (FED) The final stage of design when the drawings and bills of quantities are produced for use in the procurement and implementation process.

Force account 'In-house works implementation'.

Framework document A document describing ministerial policy requirements for an organization and in terms of its overall aims.

Functional specification A specification that is defined in terms of the end-result to be achieved.

Geotechnical investigations The surveys, analysis and reporting of the geological features that will critically affect road planning and design (e.g. nature of the terrain, soil properties, location and suitability of building materials, hydrology, etc.)

Goal-orientated project planning (GOPP) A project development process that works backwards from a problem statement by identifying the causes of problems, then breaks these down into smaller and smaller components, and then identifies solutions to each of the small components, building these back up again in such a way to find a solution to the problem; sometimes called 'problem tree analysis' or 'ZOPP'.

Heavy vehicle A vehicle with an unladen mass in excess of 3,500kg.

In-house works implementation Works undertaken by a unit of the client's own organization.

Information Data that has been transformed to be meaningful through processing and dissemination.

Information quality level (IQL) Criteria developed by the World Bank for grouping data in terms of their level of detail and other attributes to assist in specifying data collection that is cost-effective when used in conjunction with road management systems.

Institutional appraisal An investigation of an organization that identifies its strengths and weaknesses, success in meeting defined aims, and the constraints under which it operates.

Intermediate means of transport (IMT) Motorized vehicles with less than four wheels; unconventional motorized vehicles; and non-motorized vehicles, including bicycles, wheel barrows, hand and animal-drawn carts, and the like.

Intervention level The threshold above or below which action must be taken to ensure that standards are met, often expressed in terms of defined thresholds of road condition, response time, or performance.

Inventory The physical attributes of the road or other asset being managed.

Labour-based works Works that are undertaken mainly by manual labour with the assistance only of tools and small items of mechanical equipment.

Lengthworker An individual responsible for carrying out maintenance works on a defined length of road.

Level of service A subjective measure of user requirements

Life cycle (costs) All of the costs associated with an investment from the present time to the future.

Link A length of road where traffic volumes are reasonably uniform.

Lump sum contract Works contract where the contractor is paid a pre-agreed fixed sum for all works carried out.

Maintenance The group of works that enables a road to continue to provide an acceptable level of service. Maintenance reduces road deterioration, lowers road user costs, and keeps the road open on a continuous basis.

Management The planned and organized use of resources to achieve particular goals or objectives

Management cycle A series of well-defined steps which take the management process through the decision making tasks. Typical steps would be i) define aims; ii) assess needs; iii) determine options; iv) choose actions; v) implement activities; vi) monitor and audit. The process typically completes the cycle once in each periodic cycle of the particular management function.

Management functions Areas where road management decisions are made, normally sub-divided into (strategic) planning, programming, preparation, and operations management.

Management system A set of procedures to assist with management.

Marker post A fixed item at the roadside to indicate location.

Mission (statement) This outlines, in broad terms, the nature of the operation being managed by the organization responsible for the road network.

Mobility The ability of individuals to move about.

Monitoring Reviewing past activities to learn from experience to enable better objectives to be set in the future.

Moving observer count Method of determining traffic flow whilst driving along a length of road.

Multi-criteria analysis (MCA) A method for comparing the worth of alternative options on the basis of their 'performance' against a set of pre-determined criteria.

Multi-year programme A schedule of road works planned to take place in discrete years into the future.

Network A particular grouping of roads for management purposes; examples are the national road network; trunk road network; paved road network, etc.

Network management The process of managing a road network, including the activities of 'strategic planning', 'programming', 'preparation' and 'operations management.

Network referencing The process of breaking the road network down into successively smaller links, segments and sections, each of which can be defined uniquely for road management purposes.

Network screening Preliminary determination of which road sections are likely to need treatment.

Node The start and end point of a road section.

Objective A specific and measurable goal or target to be achieved by a body within the short to medium term (tactical) or long term (strategic) time scale.

Operation(s) The on-going activities of an organization, decisions on the management of which are made on a near-term basis, typically daily or weekly, including the scheduling of work to be carried out, monitoring in terms of labour, equipment and materials, the recording of work completed, and the use of this information for monitoring and control.

Operational cost A fundamental cost-estimating technique that compiles the total cost of the work from consideration of the constituent operations or activities revealed by the method statement and programme, and from the accumulated demand for resources.

Overlay works The addition of material on top of a pavement for the purpose of increasing its structural strength.

Path Narrow cleared way for pedestrian traffic and, in some cases, bicycles and motorcycles.

Performance bond An unconditional bank guarantee, in favour of the client, that a contractor will meet all contractual requirements.

Performance indicator A sub-set of objectives, performance against which is published for public scrutiny.

Performance standard This specifies the resource requirements for each activity to be carried out, and builds up a consistent description of the activity based on a preferred and specified method of working, and resources of equipment, labour and materials to perform the activity in accordance with the preferred method.

Periodic works Works carried out on the network planned at discrete intervals in time of several years.

Plan A systematic and formalized process for directing and controlling future operations in such a manner that policy objectives are achieved.

Planning (strategic) This involves an analysis of the road system as a whole, typically requiring the preparation of long term, or strategic, estimates of expenditure for road development and conservation under various budgetary and economic scenarios; predictions may be made of expenditure under selected budget heads, and forecasts of road conditions, in terms of key indicators, under a variety of funding levels.

Policy The statement or series of statements which define the basic rules and requirements which can guide all decisions and actions that need to be taken.

Policy document A document containing a written statement of policy; a 'statement of intent'.

Policy instrument The means of putting policy in place.

Policy framework A hierarchical set of statements that define policy relevant to different bodies or levels of administration; typically consisting of mission statement, objectives and standards that define in detail the aims of an organization and how it proposes to achieve these.

Preliminary engineering design (PED) Engineering drawings done to a limited level of detail, which may be prepared as an output from a feasibility study.

Preparation The near-term planning stage where road schemes and projects are packaged for implementation. At this stage, designs are refined and prepared in more detail; bills of quantities and detailed costings are made; together with work instructions and contracts; detailed specifications and costings are likely to be drawn up.

Pre-feasibilty An intermediate stage in road planning, when a number of transport solutions are appraised in relation to a specified problem. It will be clear at the end of this stage whether a road solution is likely to be worthwhile, and hence further investigated with a feasibility study.

Preventive works Periodic works on the network designed to prevent the rapid escalation of deterioration.

Prioritization The process of allocating scarce resources between the competing 'claims' of different road projects.

Priority index A parameter whose numerical value indicates where in a list of priorities particular actions lie.

Procedure A documented series of steps for carrying out a particular activity or task.

Procedural specification A specification that is defined in terms of the method to be followed.

Programming The preparation, under budget constraints, of multi-year works and expenditure programmes in which those sections of the network likely to require treatment, and new construction possibilities, are identified and selected; a tactical planning exercise.

Project A set of activities with a defined start and finish, and which consume resources in moving from start to finish.

Project cycle A defined sequence of steps to be followed in executing a project.

Quality control Checking completed works to ensure that specifications have been met.

Quality management An approach to management that encompasses all activities of the overall management function, and that determines the overall direction and intentions of an organization are designed in such a way that ensures that expressed customer requirements are met first time, every time.

Quality management system The organizational structure, procedures, processes and resources needed to implement a policy of quality management.

Rating A score assigned to indicate condition or priority.

Reactive works Routine maintenance activities that are carried out each year whose extent depends on a combination of traffic and environmental effects.

Reconstruction Works requiring the replacement of some of the existing infrastructure asset; eg pavement reconstruction requiring removal and replacement of road surfacing material.

Recurrent budget The budget head often used to fund on-going activities and maintenance works.

Rehabilitation Works that are needed to restore a road to a maintainable condition.

Renewal Works to restore a road to a similar condition to when it was new.

Resurfacing works The addition of material on top of a pavement for the purpose of reducing roughness or surface distress.

Road administration The body responsible for managing the road network.

Road agency A body carrying out work under an agency agreement. A road administration (terminology used in World Bank documents) [note that these definitions are in conflict]

Road authority A road administration that is authorized through legislation to be the manager of the road network
A parastatal body that manages the road network (terminology used in World Bank documents)
[note that these definitions are in conflict]

Road class/hierarchy A grouping of road sections according to pre-defined rules, often based on issues of ownership, function, funding source, etc.

Road management The process of maintaining and improving the existing road network to enable its continued use by traffic efficiently and safely, normally in a manner that is effective, and environmentally sensitive; a process that is attempting to optimize the overall performance of the road network over time.

Roads board A committee set up to administer or to advise on the administration and management of a road network.

Roads register A ‘gazetteer’.

Roughness Longitudinal unevenness of the road surface that impacts on the suspension of vehicles.

Routine works Works carried out on the network that are needed each year.

Rural roads Access roads, arterial and collector roads in rural areas.

Rural transport infrastructure Tracks, trails, paths and roads in rural areas.

Safety audit A formal, systematic procedure for assessing the safety of a road scheme, and for recommending remedial measures to address identified hazards.

Schedule A short to medium term plan for carrying out activities.

Scheduled treatment Works that are carried out at pre-defined intervals of time.

Scheme Term which is loosely used synonymously with a road option or a road project.

Screening The general process of sifting alternative solutions in order to derive a preferred option to meet a specific transport problem. Similar to appraisal, but conveys a wider scope of solutions, and a coarser approach to selection of a few options that may then be appraised.

Sector A sub-division of government administration; e.g. transport sector; road sub-sector.

Section A length of road that is reasonably uniform in terms of its physical characteristics.

Segment A length of road that is reasonably uniform in terms of geometry.

Sensitivity analysis The assessment of a decision to changes in assumptions about key variables (demand levels, project costs, etc.)

Serviceability ‘Level of service’.

Social benefits Benefits resulting from an investment that improve that quality of life of the population, or parts of the population, but which may not be quantifiable in economic or monetary terms.

Social impact assessment (SIA) The process of assessing the social implications of a road development, and hence for suggesting remedial measures that may be required to address specific social issues of concern.

Special works Works whose frequency cannot be determined with any certainty in advance, such as emergency works.

Specification A detailed description of the attributes of the output from an activity, or of the steps by which that activity is carried out.

Specificity The feature of an organization that enables it to identify and focus on specific objectives, without being side-tracked to unproductive tasks.

Spoil Unwanted material that needs to be disposed of safely

Stakeholder Someone with a vested interest in the performance of the road administration, including the road users, industry, agriculture and commerce, who are its ‘customers’, plus the road administration itself and the road engineering industry.

Standard A detailed operational target to be achieved by an individual unit in an organization to enable policy to be implemented; a requirement, sometimes legally enforceable, that a road administration is obliged to meet as part of its road management activity.

Standard axle load A standard axle load is 8.16 metric tonnes

Strategic Pertaining to actions designed to achieve, in the longer term, a wide-ranging mission.

Strategy A plan for implementing policy.

Structural Number A measure of the overall strength of the road. It is essentially a weighted thickness

Subgrade The soil on which the road is built

Sustainability The pursuit of development that meets the needs of the present without compromizing the ability of future generations to meet their needs.

System Entities forming a complex whole that are grouped together in a structured way to enable for a particular purpose; examples are:
A ‘computer system’, which is a collection of software and hardware designed to carry out a particular function
A ‘management system’ which is a set of procedures designed to assist the management process (which may also include a computer system)

Tactical Pertaining to actions designed to achieve defined objectives in the short to medium term.

Target price contract Works contract where the contractor is paid a fixed price plus an incentive payment for meeting pre-defined targets.

Task A sub-division of an activity.

Tender A formal written offer to carry out works, or to supply goods, material or services.

Terms of reference (TOR) The ‘brief’ prepared by a client which instructs appointed consultants/contractors in their expected activities and outputs. The TOR for a feasibility study should be drafted as part of the associated pre-feasibility work.

Tracks Single lane, cleared and improved seasonal roads that connect to higher class roads; used mainly by non-motorized traffic and pedestrian travellers, but traversable at certain times by light four-wheel drive vehicles, pick-up trucks, animal-drawn carts and pack animals; sometimes known as community roads.

Trails Narrow tracks suitable only for two-wheel vehicles, pedestrians and pack animals.

Training levels A formalized way of classifying skills and needs of individuals that assists in identifying training needs.

Transport The movement of passengers and freight from one place to another.

Travel Making journeys; moving around.

Treatment Works to correct defects.

Treatment length Contiguous lengths of road requiring common treatments.

Treatment option One of a number of treatments that can be applied to correct the same defects.

Undesignated road A road that has not been designated as a legal entity under a Roads Act or similar legislation.

Unit rate A cost-estimating technique based on the traditional bill of quantity approach to pricing engineering work, typically relating to aggregate quantities of work to be carried out, measured in accordance with an appropriate method of measurement.

Upgrading Works to increase the standard of a road; eg pavement strengthening, road widening.

Utility Public service infrastructure; eg telecommunications, electricity, water.

Vision (statement) A broad indication of the general direction in which policy should develop over time.

Visual inspection An inspection based on the use of simple measurements, or on subjective judgement.

Work package A collection of works that are carried out under one contract or work instruction.

Works All construction and maintenance activities that are carried out on the road network, normally sub-divided into routine maintenance, periodic maintenance, special works, rehabilitation, and development.

Work order/instruction Written authorization to carry out certain works.

PART 1

Overview of Appraisal and Policy Framework

1. Purpose and Structure of this Note

This Note gives guidance on carrying out feasibility studies for 'capital' road projects (rehabilitation and development) in developing and transition countries. In scope it deals with all types of road (trunk, urban and rural) that can accommodate motorized vehicles. It is intended for use by administrators, economists, transport planners and engineers in road and transport ministries, their organizations and local government who are responsible for preparing or appraising project submissions.

The approach includes consideration of many aspects that support greater sustainability, for example, setting the appraisal within the context of an overall transport strategy and greater emphasis on social, environmental and policy issues.

The Note is structured in four parts:

Part 1. An introduction to road appraisal and the feasibility process that indicates the scope of work involved, how individual tasks relate to one another and the outputs that should be expected from a study. This provides a basic outline that will be of value to the administrators, policy-advisors and decision-takers who may not be concerned with the detailed workings of a feasibility study, but need to be alerted to its key components.

Part 2. This part of the guide covers the main fieldwork and surveys undertaken as part of the feasibility process. These surveys provide the key information used by both the design and the appraisal teams. They inform on the basic issues like demand (for the road improvement), the nature of the terrain, possible alignments, quality and availability of materials, and the environmental and social issues that will need to be addressed.

Part 3. This part presents the main tasks undertaken by the engineering design team in the feasibility process. These tasks may be undertaken largely as desk-based exercises, though clearly the design team will need to be familiar with the terrain and alignment opportunities.

Part 4. This part addresses the process by which a preferred engineering option is selected and recommended, based on a comparison of the costs and benefits of alternatives.

In Parts 2 - 4 the individual analytical components of a feasibility study are presented in sufficient detail to give the technical reader knowledge of what information needs to be collected, how it is analyzed and used, and how it complements the overall feasibility process. It is not intended that the chapters contain sufficient technical knowledge for the inexperienced reader to carry out an appraisal on their own and to carry out the engineering designs to the accuracy that is appropriate. The focus is on process, with the reader being referred to other texts for more detailed technical explanations.

Figure 1.1 illustrates the structure of Overseas Road Note 5 (ORN5) and also how it relates to external documents of a more technical nature. The list of key technical documents is not exhaustive, but represents a range of documents that are relatively easily available through TRL, the World Bank and/or the global Transport Knowledge Partnership (gTKP). A bibliography listing more detailed sources of information is also provided at the end of each chapter.

The glossary gives a summary description for many of the terms used in this document. For clarity, a few key terms used throughout the document are repeated here. A road *appraisal* is the process of justifying and reaching a decision to invest resources in the road being appraised; it is project-oriented. It involves a sifting process for choosing between options (for solving a transport problem) and screening out less-deserving options. Through this process of screening, a preferred choice is eventually recommended (or all options may be rejected as inadequate). Appraisal also helps to *prioritize* the allocation of limited funds between different projects, an important requirement for the programming of road investment. Appraisal usually involves several distinct stages, of which the *feasibility* stage is the last and most detailed prior to final road design. As such, it should be expected to incur high expenditure. *Evaluation* of a road project occurs after the road has been built, and addresses the question whether the investment was beneficial.

ORN5		National supporting technical references	Examples of generic supporting technical references (for a comprehensive bibliography see each chapter)
Part 1: Overview of appraisal and policy framework	Chapters 1-3 Feasibility process, context for appraisal & glossary	Development and vision statements; Poverty reduction strategy papers (PRSPs); Transport policy statement	■ Appraisal of investments in improved rural access ■ Road engineering for development ■ MG11 - HIV/AIDS considerations ■ The rural transport policy toolkit ■ Cities on the move ■ Highway development and management model (HDM-4) ■ Design and appraisal of rural transport infrastructure
Part 2: Fieldwork and surveys	Chapters 4-8 Traffic demand, geotechnical investigations, environmental, social & safety considerations	Environmental policy and regulations	■ MG 1 - Low volume traffic counts ■ MG 2 - Effect of passability on traffic demand ■ MG 8 - Forecasting future traffic demand ■ MG 12 - Environmental considerations ■ ORN 11 - Urban road traffic surveys ■ ORN 40 - A guide to axle load surveys and traffic counts for determining traffic loads on pavements ■ Towards safer roads in developing countries
Part 3: Engineering design	Chapters 9-12 Pavement & geometric design, drainage & structures	Design standards	■ ORN 6 - A guide to geometric design ■ ORN 9 - A guide to small bridge design for highway engineers ■ ORN 14 - Hydrological design manual for slope stability in the tropics ■ ORN16 - Principles of low-cost road engineering in mountainous regions ■ ORN 31 - Guide to structural design of bitumen surfaced roads in tropical and sub-tropical countries
Part 4: Option selection	Chapters 13-15 Costings, benefits, analysis & reporting	Government investment guidlines	■ ORN10 - Costing road accidents in developing countries ■ ORN 22 - A guide to pro-poor transport appraisal ■ MG 3 - Operating costs of non-motorised vehicles ■ MG 4 - Value of time ■ MG 5 - Valuation of multi-task trips ■ MG 6- Cost of walking and headloading ■ MG 7 - Transport services appraisal ■ MG 9 - Thresholds of economic viability ■ MG10 - Distribution analysis and impact on poverty ■ Toolkit for the economic evaluation of World Bank transport projects HDM 4 - Knowledge and software

Figure 1.1: Outline structure of ORN5

2. Overview of Appraisal

2.1 THE PROJECT CYCLE

2.1.1 Components of the project cycle

Projects are planned and carried out following a sequence of activities, often 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:

- *Problem identification*
- *Pre-feasibility*
- *Feasibility*
- Design
- Procurement and negotiation
- Implementation
- Operation
- Monitoring and evaluation.

The first three steps (1-3) make up the planning phases of the project cycle, though evaluation (step 8) may also be considered integral to the planning process by providing feedback on the wisdom and processes of past decisions. Figure 2.1 provides an outline of the stages of the project cycle.

The planning phases of the cycle involve a gradual process of screening and refining alternative options (for resolving an earlier identified problem). In this process there are clear decision points (at the end of each stage) when potential projects are either rejected or taken forward for further and more detailed analysis. Dubious projects should be rejected at an early planning stage (and before feasibility) as they gain a 'momentum of their own', and hence become increasingly difficult to stop at the later stages in the cycle when minor changes of detail are often all that are possible.

Within each of the planning phases (project identification, pre-feasibility and feasibility), the same basic process of analysis is adopted. Differences occur largely in the level of detail applied. Sometimes phases are merged, with pre-feasibility becoming an extension of the project identification, or a first step in the feasibility stage. Table 2.1 sets out a framework for the appraisal process as applied to different types of road.

2.1.2 Problem identification

The first stage of the cycle is to find potential projects. General planning identifies key transport constraints and sketches solutions at a global or macro level, and should prioritize these as to the need and urgency for resolution. The planning process takes into account government policies and programmes (in all relevant sectors) which impact on transport development. The need for general road development is therefore examined in a very wide socio-economic and policy-orientated context.

The framework for general planning could be cross-sectoral in nature or it could also be focused specifically on transport issues. In all cases, however, the scope is 'macro' in nature, taking in a complete region or city. Examples of such spatial (or structure) plans and transportation studies include:

- A national or regional development study (e.g. regional spatial plans)
- An urban development study (or master plan)
- A national or regional transport study (sometimes known as a multi-modal or inter-modal transport study)
- An urban land-use/transportation study
- An integrated rural accessibility plan
- A road safety strategic plan

2.1.3 Pre-feasibility

At the start of the pre-feasibility stage there is a clearly defined transport problem (identified in general planning), but no strong evidence that this problem could be solved by road improvement, or any other transport solution (e.g. improvements to transport services) in an environmentally or economically acceptable manner. By the end of the pre-feasibility stage, there will be clear evidence whether or not a road improvement project is worthwhile. If it is, the pre-feasibility will normally identify what type of project would be suitable, checks that the project is not premature and provides the information needed to commission a feasibility study. Typically, this phase might identify 'corridors' that require a new road.

An affirmative pre-feasibility study will also trigger the inclusion of a 'line-item' in the long-term road preparation budget (of the ministry or its highway agency). It gives advance warning that monies will need to be budgeted for the future implementation of this particular project.

The pre-feasibility study may indicate that the proposed road improvement project would not be effective in solving the problem, or should be reconsidered later, perhaps when there is more traffic). In that case the process should be terminated or shelved without incurring the high cost of a feasibility study.

2.1.4 Feasibility

The feasibility study finds the most suitable road improvement project for solving or helping to solve an identified transport problem. At the start of the study there is a clearly defined problem with an expectation that the problem can

Project Cycle	Inputs	Processes	Outputs
1. Problem identification (general planning)	Policy and regulatory framework Spatial framework; economic development; existing transport system and network performance; demand forecasts	Coarse traffic assessment; broad environmental, economic assessment and engineering assessment	Definition and prioritisation of transport problems within regional or urban framework; sketch solutions;TOR for Pre-feasibility Study
2. Pre-feasibility Study (Initial identifcation of solutions)	Problem location (e.g. corridors identified); development; existing transport system and network performance; demand forecasts; environmental factors	Preliminary traffic and economic assessment; broad environmental and engineering assessment; preliminary costing	Identification of transport solutions that are likely to be feasible; TOR for Feasibility Study and Preliminary Engineering Design (PED)
3. Feasibility Study/ Preliminary Engineering Design (Screening of solutions to preferred option)	Some solution options; development; existing transport system and network performance; demand forecasts; environmental factors	Detailed traffic,environmental, economic and engineering assessment; detailed costing	Preferred solution and recommendation for Final Engineering Design (FED); PED (drawings and costings); TOR for FED; cost information for budget process
4. Final Engineering Design (Specifying the preferred option for bidding)	PED/route alignment	Detailed engineering assessment; preparation of working drawings and bills of quantities	FED (drawings, bills of quantities and other tender/contract documents)
5. Procurement & negotiation (pre-construction)	Specified right-of-way & FED	Implement land acquisition and resettlement programme. Undertake tendering and contract process	Alignment ready for construction; appointment of contractors/supervising engineers; project management plans
6. Implementation (construction)	Specified construction inputs and management	Build to design specification	Completed project hand-over
7. Operation	Completed project; Maintenance standards; Traffic law and regulations	Maintenance programmes; Enforrcement of traffic law and regulations; operation of asset by road manager	Maintenance of road performance and availability to users
8. Monitoring and Evaluation	Operational road	Traffic and road condition surveys; social and environmental impact surveys	Post-evaluation reports; maintenance requirements

Figure 2.1: Outline of stages in project cycle

be solved by some form of road improvement, in a manner that is environmentally, socially and economically acceptable. This expectation is backed up by the evidence needed to justify the considerable cost of carrying out a feasibility study (identified in a pre-feasibility study).

By the end of the study there should be a clear recommendation for a specific road improvement project. The study will provide evidence that this particular project should be carried out and that this project provides the most suitable solution to the problem, taking into account its operational benefits and its environmental and economic implications. It will also provide a detailed description and a preliminary engineering design (PED) and associated drawings of the proposed project to enable costs to be determined at a level of detail to enable funding decisions to be made.

The feasibility study will also provide an input to the road preparation budget process, giving greater detail (than earlier phases) of costs that will be incurred and project timings.

Project appraisal phase		Major roads			Minor roads		
		National	Provincial	Urban		Local	Community
Problem identification The stage at which a project is identified from within a broad survey of potential transport developments that are needed to service economic development. The project represents the possible solution to a particular transport problem.	Study	National or regional development study		Urban master plan or urban transport study		Rural development plan	
	Demand	National/ regional development studies to indicate growth potential. Related traffic and axle-load estimates based on existing data, supplemented by limited surveys. Modal split issues (if appropriate) based on simple cost-based choice models.		Urban development plan that identifies growth. Estimates of travel (desire lines, etc) based on the development plan and existing traffic flow data, supplemented by traffic counts on major roads. Possible use of traffic model (likely to be at strategic level and focussed on principle routes) to indicate traffic loadings, taking account of modal choice issues and policies.		Rural plan that identifies growth, based on development studies. Some limited participatory work that identifies travel habits and needs (like access to employment, educational, medical and other social opportunities)	
	Environmental	Identification of likely environmental issues and implications for engineering solutions, costs and impacts. Will include issues like resettlement, re-instatement, severance, noise, etc... Based on mapping and site surveys in collaboration with design team. All necessary environmental safeguards are addressed.				Very limited assessment based on few site surveys	
	Social	Identification of social issues like gender specific impacts. Based on mapping and site surveys in collaboration with design and environmental teams.				Identification of social issues through limited participatory work (in collaboration with demand studies)	
	Safety	Broad appraisal of accident rates associated with different road types, used to influence design work and to inform the evaluation.			Limited assessment.	Very limited assessment based on few site surveys	
	Engineering	Broad-brush approach based on inventory of existing infrastructure, demand forecasts and broad categorization of engineering conditions (e.g. mountainous, hilly, flat) to indicate design requirements and costs. Takes account of need for any major structures required.		As for other major roads. There will be greater emphasis on junction design (possible need for substantial structures) and the application of traffic management measures.	Very limited work, based on existing inventories, mapping, aerial photos and few site surveys.	Very broad-brush approach based on inventory of existing infrastructure and demand forecasts. Takes account of numbers of small structures (e.g. river crossings) that may be required.	Very limited work, based on existing inventories, mapping and few site surveys.
	Cost estimation	Level of detail related to engineering detail. Based on historic costs (inflated as appropriate) which may be categorized to reflect nature of terrain, amount of labour-based input, number of structures, etc. (Global costs)					
	Analysis	Largely based on a broad-brush cost-benefit analysis (CBA), with vehicle operating costs as major saving. Environmental costs will be factored into the engineering designs as remedial measures. Social implications listed but may not be considered a significant component of analysis.		Largely based on a broad-brush CBA, with time savings as major benefit. Environmental costs will be factored into the engineering designs as remedial measures. Social implications listed but may not be considered a significant component of analysis. The analysis will treat minor roads in very peremptory fashion.		CBA probably inappropriate. Recourse to qualitative analysis of social benefits.	

Table 2.1: Framework for the appraisal process

Project appraisal phase		Major roads			Minor roads	
		National	Provincial	Urban	Local	Community
	Outputs	Identification of key road projects and priorities. Terms of Reference for Pre-Feasibility Studies		Identification of key transport projects and priorities. Terms of Reference for Pre-Feasibility Studies	Identification of infrastructure network needs. Terms of Reference for next phase.	
Pre-feasibility The stage at which a project is refined to give clearer definition as to its specification and economic worth. Various options will have been compared in order to develop a preferred solution that has a probable alignment, outline geometric and engineering specification and likely impacts are approximately known.	Study	For high-value road projects, it is sensible to have a pre-feasibility phase to check the the project is worth pursuing. Data collected at this stage can be further deployed at the Feasibility Stage.		The urban transport study (see above) may be sufficiently detailed that the pre-feasibility phase is not required	It is unlikely that separate pre-feasibility and feasibility studies will be carried out for this class of roads.	
	Demand	Traffic is forecast using existing counts (supplemented as needed with fresh surveys), demographic and economic activity forecasts. At its simplest, trends are used. Traffic composition is established and estimates of axle-loadings made from these and historic knowledge of axle-loadings for different vehicle types.		Travel patterns need to be established, often based on historic origin/ destination matrices. These, together with travel costs, trip times, etc. are used to feed transport models that predict future loadings on the project for given scenarios (policies, prices, etc)	Travel and social issues are likely to be examined as part of community participatory work. This involves focus groups, in-depth interviews, etc .. The enquiry will be particularly looking to how transport can improve livelihoods of communities and individuals.	
	Environmental	Field surveys and mapping to estimate impacts of road alignments on communities. Estimates made of land-take, resettlement (and compensation) levels. Effects on land drainage, land use and other impacts assessed. In urban areas, severance and noise may need to be assessed, based on mapping. Remedial measures are factored into the design team's work. All necessary environmental safeguards are addressed.			The environmental impacts are unlikely to be significant for this class of roads; even so, an audit should be undertaken, and all necessary environmental safeguards addressed.	
	Social	Identification of social issues like gender specific impacts, Based on mapping and site surveys in collaboration with design and environmental teams.			Undertaken as part of the travel enquiries (see above)	
	Safety	For each option that is evaluated, a safety audit is undertaken in association with the design work. Estimates are made of the likely accident rates with and without the project.			Where the project is specifically focused on safety (e.g. calming traffic on minor urban roads), a detailed safety audit will be undertaken as part of the design process. There should also be audits on other types of road to inform the design team on issues like the design of drainage features, bridge abutments, etc.	
	Engineering	Each option is broadly specified in terms of alignment, geometric and pavement design and structures. Limited geotechnical surveys may be undertaken, together with use of historic surveys, to give some assurance on designs, and availability of materials. Urban roads will need closer attention to junction design and traffic management.			This is likely to be a one-off exercise with little need to examine alternative options; each solution will evolve through dialogue between the design team and the community.	
	Cost estimation	Level of detail related to engineering detail. Based on historic costs (inflated as appropriate) which may be categorized to reflect nature of terrain, amount of labour-based input, number of structures, etc. Some indications of materials sources used to estimate their costs.				

Table 2.1: Framework for the appraisal process

Project appraisal phase		Major roads			Minor roads	
		National	Provincial	Urban	Local	Community
	Analysis	Largely based on a CBA, with vehicle operating costs as major saving. Environmental costs will be factored into the engineering designs as remedial measures. Social implications listed but may not be considered a significant component of evaluation. HDM-4 (or similar) may be used to aid the evaluation process.		Largely based on CBA, with time savings as major benefit. Environmental costs will be factored into the engineering designs as remedial measures. Social implications listed but may not be considered a significant component of evaluation.	CBA used if appropriate; otherwise recourse to qualitative analysis of social benefits and some form of multi-criteria analysis.	
	Outputs	Pre-Feasibility Report with preferred option to address a particular problem Terms of Reference for Feasibility Studies			Set of designs that can be implemented.	
Feasibility/Preliminary Engineering Design The stage at which a project is further refined and fixed. The alignment and engineering features are resolved, and the economic worth of the project is assured. All social, environmental and safety issues have been resolved to meet prevailing standards. Finally, the preliminary engineering designs are developed	Study	Full Feasibility Study			Pre-feasibility and Feasibility stages likely to be combined (see above)	
	Demand	Traffic is forecast using new counts (supplemented with historic data), demographic and economic activity forecasts. At its simplest, trends are used. Traffic composition is established and surveys of axle-loadings are undertaken. Network modelling may be used if the project is an urban by-pass.		Travel patterns established, based on cordon surveys and/or household surveys. These, together with travel costs, trip times, etc. are used to feed transport models that predict future loadings on the project for given scenarios (policies, prices, etc).		
	Environmental	Field surveys and mapping to estimate impacts of road alignments on communities. Fine estimates made of land-take, resettlement (and compensation) levels. Effects on land drainage, land use and other impacts assessed in detail. In urban areas, severance and noise are assessed, based on mapping.And measurement. Remedial measures are factored into the design team's work. All necessary environmental safeguards are addressed, and a mitigation plan prepared.				
	Social	Identification of social issues like gender specific impacts, Based on mapping and site surveys in collaboration with design and environmental teams.				
	Safety	A safety audit is undertaken in association with the design work. Estimates are made of the likely accident rates with and without the project.				
	Engineering	The preferred option is specified in terms of alignment, geometric and pavement design and structures. Large-scale geotechnical surveys may be undertaken (particular in uncertain terrain) to give some assurance on designs, and availability of materials. Urban roads will need closer attention to junction design and traffic management, using appropriate models.				

Table 2.1: Framework for the appraisal process

Project appraisal phase		Major roads			Minor roads	
		National	Provincial	Urban	Local	Community
	Cost estimation	Level of detail related to engineering detail. Based on historic costs (inflated as appropriate) but highly geared to reflect nature of terrain, materials requirement (and sources) amount of labour-based input, number of structures, etc. (Unit rates used).				
	Analysis	Largely based on a CBA, with vehicle operating costs as major saving. Environmental costs will be factored into the engineering designs as remedial measures. Social implications listed but may not be considered a significant component of evaluation. HDM4 (or similar) likely to be used to aid the evaluation process. Risk analysis developed and recorded.		Largely based on CBA, with time savings as major benefit. Environmental costs will be factored into the engineering designs as remedial measures. Social implications listed but may not be considered a significant component of evaluation. Risk analysis developed and recorded.		
	Outputs	Feasibility Report with Preliminary Engineering Designs Terms of Reference for Final Design and supervision.				

Table 2.1: Framework for the appraisal process

2.2 THE PROCESS OF APPRAISAL

This Note is concerned primarily with the feasibility stage of the project cycle, but guidance in the Note will also be of use at other stages in the appraisal process. When carrying out a feasibility study, it is recommended that the steps shown in Table 2.2 are undertaken.

These steps are broadly sequential, though many of the tasks are carried out in parallel, and there is scope for many feedback loops between tasks. Figure 2.2 provides a simplified illustration of the technical process of appraisal (Parts 2, 3 and 4 of this document), showing how individual tasks relate to each other and contribute to the general appraisal process. It also shows that steps are not necessarily sequential. Feedback loops are not shown in the diagram, but it should be assumed that iteration between steps is common; attention to environmental and safety issues, for example, is likely to be recurrent throughout the analysis (and indeed, throughout the project cycle).

A key concept in the appraisal process is the comparison of the project against the situation that would have prevailed without the project. These are the basic 'with' and 'without' cases that are used in the economic analysis of the project; the appraisal process should always have this comparison in view.

Stage	Task	Location of further information
Context and objectives	Define objectives and the macro-economic context	Chapters 2 and 3
	Locate the project within its geographic, economic and social context, and determine alternative ways of meeting objectives	
	Preliminary considerations, including assessment of institutional capabilities and governance.	
Fieldwork and surveys	Assess traffic demand (both vehicular and person movements)	Chapter 4
	Geotechnical investigations for route location, materials, hydrology, etc.	Chapter 5
	Environmental surveys	Chapter 6
	Social surveys	Chapter 7
	Safety considerations	Chapter 8
Engineering design	Pavement design	Chapter 9
	Geometric design	Chapter 10
	Design of structures and drainage	Chapters 11 and 12
Selecting the preferred option	Establishing project costs	Chapter 13
	Establishing project benefits	Chapter 14
	Comparative analysis (economic or cost-effectiveness, and financial if appropriate)	Chapter 15
	Sensitivity and risk analysis	
	Reporting the feasibility study	Chapter 16

Table 2.2: Main tasks in a feasibility study

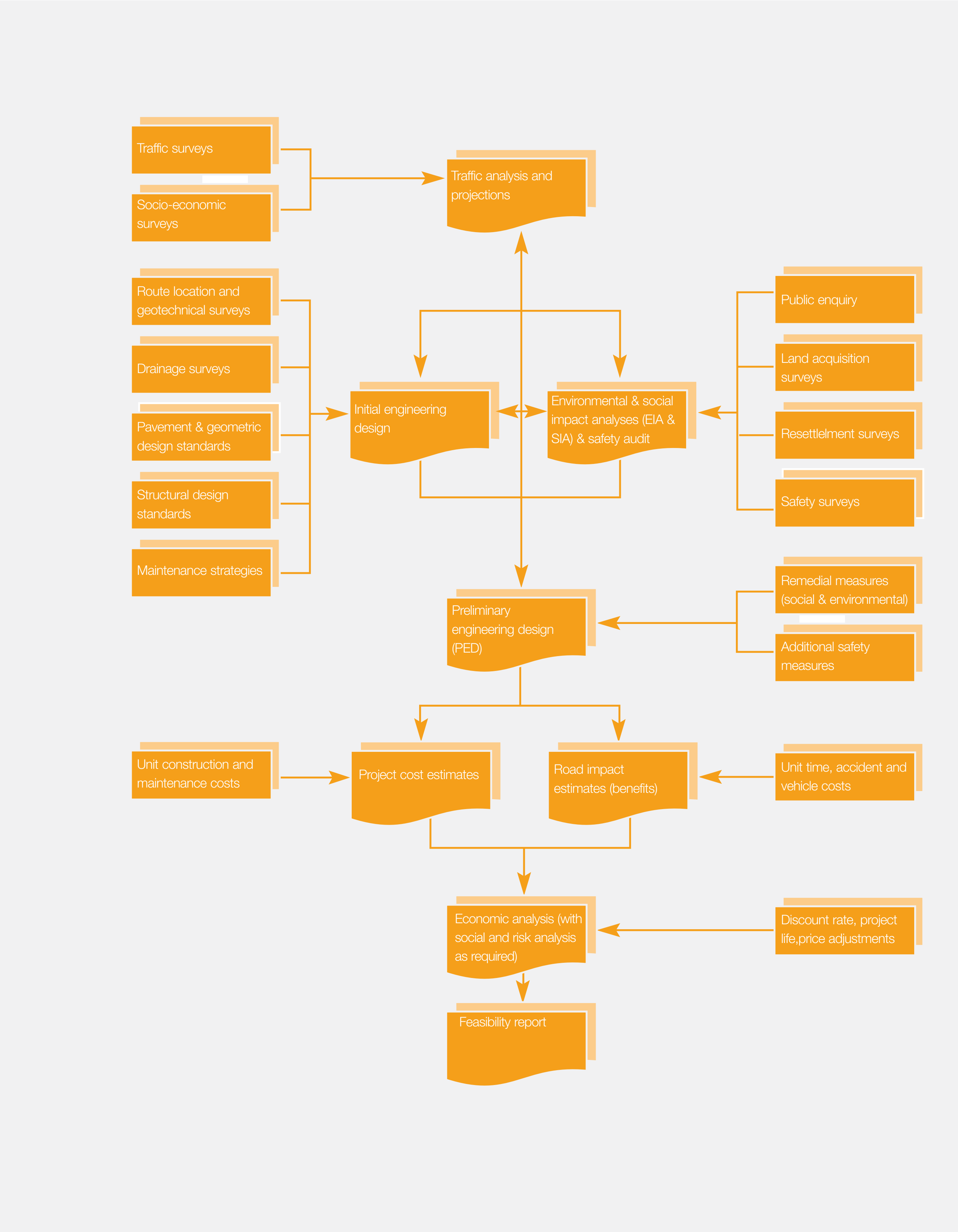

Figure 2.2: The feasibility study process

2.3 PROJECT TYPES AND OTHER CONSIDERATIONS

2.3.1 The need for improvement

The project objectives need to be clearly defined from the outset. The need may arise for a variety of reasons, including:

- To support some other developmental activity
- To provide fundamental links in the national or a district road network
- To meet a strategic need
- To increase the structural capacity or trafficability of an existing road to cope with higher traffic flows
- To provide an alternative to an existing transport link or service
- To address a major safety hazard, environmental or social problem
- To rectify damage or failure that has caused sudden deterioration of the existing road

2.3.2 Road types and functions

In this Note a road improvement is any engineered alignment for the specific use of motor vehicles. There are four broad categories of road type. These are:

- Urban roads that lie within the confines of the city (or major town)
- Inter-urban roads that link a city (or main town) with other cities (or large towns)
- Rural access roads which link towns to villages and hamlets.
- Rural transport infrastructure, including tracks, and trails and paths.

Within each broad category there is likely to be a hierarchy that corresponds to the different functions of roads. The type and functional category of a road will largely determine the standards that are used in the planning and design process for the particular project under consideration. Table 2.3 presents examples of the ways in which roads are classified.

The nature of the appraisal process will be significantly influenced by the type of road under consideration. In forecasting travel demand, for example, urban roads and by-passes are likely to require complex traffic analysis modelling, because of the scope for traffic diversion between alternative routes and modes. On the other hand, rural access roads will require simple traffic analysis, though will require informed estimates of the developmental impacts that may emerge from their construction. Similarly, the major benefits of urban road projects are likely to be time savings resulting from reduced congestion, whereas the major benefits of an inter-urban road are likely to be savings in vehicle operating costs. The benefits of rural access roads are developmental or social, and hence difficult to quantify in money terms.

The format of the following chapters is to present, where possible, a generic appraisal process followed by qualifications that relate to the specific nature of the road type and function.

Nature of classification	Classes					
Network priority	Primary	Secondary			Tertiary	
Functional	Arterial or trunk	Collector or distributor			Access	
Type	Major (road has a mainly economic function)				Minor (road has a mainly social function)	
	Major rural or non-urban		Urban		Rural transport infrastructure	
Designation	National	Provincial/regional	Municipal/urban		Local (rural government)	Community (undesignated)
Typical characteristics						
Physical characteristics	Two and more lanes paved	Two lanes paved or gravel			Single lane gravel or earth	Tracks, trails and paths
Traffic (vehicles per day)	>2000	50-2000			<50	<10
Journey function	Mobility					Access
Trip length	Long					Short
Percent of total network length	~20		~10	~30		~40

Table 2.3: Examples of different forms of road classification

Source: Overseas Road Note 1. Road maintenance management for District Engineers

2.3.3 Types of road improvement

The definitions of work activities, in respect of improving road pavements and shoulders, conform to those adopted in *Overseas Road Note 1.* The three broad areas of activity are:

- Maintenance
- Renewal (pavement reconstruction)
- Development (construction, widening, new carriageway works)

Table 2.4 sets out the main characteristics of each of these activities. While maintenance is not the subject of this guide, it is included for completeness, and to contrast with the other two activities which are covered.

2.3.4 Stage construction

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 is a form of development project in that any later improvements in capacity are planned from the outset.

When considered purely in terms of optimal economic benefits, 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 improvement at the correct time in the project life. Experience has shown that budget constraints often prevent the later improvement phase of stage construction projects from being funded, with the result that anticipated benefits from the project do not materialize.

Stage construction is a risk in any situation, and is particularly unlikely to be an option for rural or urban roads, because of the specific uncertainties of traffic demand in these environments.

Activity	Category	Type	Examples
Maintenance	Routine planned		Cleaning side drains
	Routine unplanned	Reactive	Patching
		Seasonal	Snow removal
		Emergency	Landslip removal
	Periodic (planned)	Preventive	Slurry seal
		Resurfacing	Thin overlay
		Road marking	Renew markings
Renewal (also referred to as reconstruction)		Overlay	Structural asphalt Bonded concrete
		Pavement reconstruction	Mill and replace Inlay
		Spot improvements	Provision of permanent water crossings
Development (also referred to as upgrading or new construction)		Widening	Lane addition Shoulder provision
		Realignment	Local geometric improvement Junction improvement
		New section	Dualling By-pass construction

Table 2.4: Road work activities

Source: Adapted from Overseas Road Note 1. Road maintenance management for District Engineers

2.3.5 Network considerations

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. Analyses of this kind can be carried out using appropriate computer-based tools such as HDM-4 (Chapters 14 and 15)

2.3.6 Analysis period and design life

The analysis period may be partly dictated by the nature of the investigation. For example, long periods are useful when comparing mutually exclusive projects, whereas short 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.

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 analyzed 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 realistic traffic forecast for a reasonable period into the future (perhaps 10 years).

2.3.7 Uncertainty and risk

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

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.

Risk is also associated with the ability to implement the recommended solution. Governance of the road sector and the institutional capacity of the executing agency will impact on whether the planned design can be implemented as conceived. The feasibility appraisal team must work largely within the constraints of existing organization structures and procedures relating to road procurement and maintenance practice but it would be sensible for the team to comment on these where they may have an impact on the outcome of the road appraisal.

Projects should not only be appraised with a recognition of uncertainty, but they should be designed to minimize the associated 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.

Scenario analysis requires the examination of a range of future possibilities that might reasonably be expected to occur. Normally three to five 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.

2.5 CHECKLIST OF THE EXPECTED OUTPUTS

Table 2.5 contains a checklist of the key outputs that should be expected in a feasibility study report. A fuller description of each output is contained in the final chapter on reporting the feasibility study.

Topic	Main outputs
Existing road	Physical characteristics Traffic characteristics Maintenance regime Road user costs
Proposed works	Nature of works Environmental issues Social factors Traffic projections Maintenance regime Road user costs
Analysis	Do-nothing/do-minimum analysis Analysis of individual options Economic analysis Sensitivity analysis Multi-criteria analysis (where appropriate) Recommendation

Table 2.5: Outline of expected contents of a feasibility study report

3. The Context for Road Appraisal

3.1 OVERVIEW

There is strong emphasis in this Note that a road project should not be conducted in isolation. It should have its origins within a broad transport policy framework, and be part of a programmed approach to investment in road infrastructure operation, maintenance, renewal and development. Justification and prioritization of a road project should be based upon its relative contribution to achieving overall transport goals. The Note does not attempt to present the detailed process that should be adopted to comply with such a policy and programmed approach to road investment. However, in recognition of the critical importance of this concept, this chapter includes a brief discussion of transport policy, road planning and the evolving institutional framework within which roads are being developed.

3.2 POLICY AND REGULATORY FRAMEWORK

Ideally, transport planning is undertaken within the framework of a transport policy and the surrounding regulatory environment. Transport policy indicates the direction of development of the transport sector expected by government. It is based on a number of factors including:

- Expectations of national and regional development (the economy, society and the environment) and the role that transport must play in achieving these
- Strategic needs and expectations of the transport sector (in respect, say, of national security strategy)
- The roles of both the public and private sectors
- The existing characteristics of the transport sector, and where comparative advantage may lie
- Constraints and opportunities for developing the transport sector.

Over-riding all of this is likely to be the increasing emphasis on the goals for achieving national poverty reduction and economic growth, and the role that transport can play in meeting these goals.

Thus a clearly defined policy provides the guiding principles for development of the transport sector, indicating the broad expectations and directions of growth. This is the starting point for the investment prioritization process, providing the sign-posts for focusing effort. The policy will indicate, for example, the relative expectations of sub-sectors (like rail and road), the focus of attention within a sub-sector (e.g. the relative importance of rural and inter-urban roads) and the relative importance of motor vehicles versus non motorized transport modes. The policy should also have a lot to say about efficiency measures (making the most of existing resources), about the expected level of public and private involvement, and about social, environmental and traffic safety issues.

Depending on the nature of government intervention, the policy may be prescriptive in the way it allocates resources, or it may rely on the creation of the right investment and operating environment through appropriate sector financial and regulatory incentives and controls. In either event, the regulatory framework for the transport sector should be seen as an intimate part of transport policy since it will strongly influence the basis for decision making at all levels of planning.

3.3 A ROAD POLICY DOCUMENT

Policies determine the course of action as to how future decisions are to be made and are clearly distinct from plans. A road policy framework provides a framework of advice for policy makers, planners, engineers and technicians working at different levels within government and the road administration. It is suggested that the policy framework should be set out in a policy document and should comprise:

i) *A mission statement.* This sets out the broad goals of how the road network is to be managed. It is necessarily brief and should broadly cover the overall planning function and objectives of the organization. It is usually of most concern to senior policy makers and senior management within a road administration.

ii) *Objectives.* In order to translate the broad goals into meaningful instructions it is necessary to set specific objectives for each area of the mission statement. The objectives need to be measurable, relevant, specific and achievable. Specific objectives are deemed to be of most relevance to the programming function of road management. Their application is of most concern to professional engineers and middle level management.

iii) *Standards and intervention levels.* These specify detailed targets or the precise instructions as to when an intervention is to be made. The application of standards and interventions is of most concern to junior professional and technicians in the preparation and operations function of road management.

The existence of a written policy framework does not, of course, guarantee that the objectives are consistent or logically follow from the mission statement; neither does it guarantee that the standards and interventions that are applied logically follow from the specified objectives.

3.4 GOVERNANCE OF ROAD PROGRAMMES AND PROJECTS

3.4.1 Institutional framework

A key aspect of policy development is the institutional framework that develops, 'owns' and 'drives' policy forward, and delivers the expected outcomes. In very broad terms this framework should cover a wide range of interests from top-to-bottom of the transport sector, including: ministerial interests; government agencies and departments; transport parastatals; private transport operators; representatives of industry, commerce and agriculture; construction companies; transport users and the public at large. In developing the policy, attention should be given to how effectively these institutions work, and how they can be re-shaped and strengthened in order to achieve the policy goals.

An organizational model that many counties are trying to emulate involves the functional separation of higher level planning and administration from maintenance operations, with the latter being fulfilled through competitive bidding by contractors. Thus roles can be split into the following categories:

- The owner which is typically a ministry, department or local authority with overall responsibility for the network
- The administrator which is typically a roads authority or agency responsible for implementing policy
- The manager who is responsible for specifying activities, letting contracts, and supervising and monitoring work. In most instances this is done by the roads authority but in some countries this activity may be contracted out to consultants
- The contractor who is responsible for directly undertaking the physical work on the network.

Although there are examples to the contrary, the balance of evidence points to substantial savings if road maintenance is undertaken via competitive contract rather than being carried out 'in-house' by force account.

3.4.2 Decentralization

There is currently a trend towards delegation of central decision making (relating to the rural road network) either to local authorities or through deconcentration of central authority to the regional or local office of the road ministry or department. The justification for these changes has been to provide greater transparency, accountability, responsiveness, probity, efficiency, equity and opportunities for mass participation. Decentralization is seen as a way to simplify complex bureaucratic procedures, increase sensitivity to local conditions and needs, help national government ministries reach a wide range of groups in decision making and help increase political stability through allowing citizens to have more control over public programmes at the local level. However, although rural roads may be technically less complex than main roads, their management and procurement problems are just as complex and planning problems are very far from being simple.

3.4.3 Road Fund Boards

The increasing trend towards transparency and value for money in the prioritization of public and donor funds is strongly influencing the way in which the transport sector is being organized. In the roads sector in particular, some governments have created a road fund which is independent of the general government revenue system (and hence exclusively used for roads expenditure), and is administered by Road Fund Boards. A board may have the task of prioritizing road expenditure, based on guiding principles set out in their regulations of establishment. Transparency is further enhanced by the separation of ministerial responsibilities for policy and legislation, with executive powers (for road works programming, design and implementation) being devolved to semi-autonomous road administrations. These bodies are established as legal entities with a commercial approach to management, and may operate under an agency agreement, independently of government and civil service structures.

3.4.4 Private initiatives

Some countries rely to some extent on private sector finance for road investment. The usual model is where government grants a concession to a private sector entity to provide and operate a designated piece of road infrastructure for a specified period of time. The private entity becomes the temporary 'owner' of the road and it is reimbursed either through tolls, shadow tolls (in which a toll is paid by the government or other road owner to the road operator based on traffic counts on the road and an agreed rate per vehicle/type), or a combination of both. Private sector ownership complicates the appraisal process since the private entity seeks a return on investment at market prices, reflected by the levels of traffic using the road, while the government seeks to ensure that the project remains viable in terms of normal cost benefit analysis measures i.e. to ensure that normal investment criteria for a public good are upheld (this essentially distinguishes a financial from an economic analysis).

3.4.5 Scope for corruption

Road investment and maintenance is a very big business in any country, not least in developing and transition countries. There is a clear need for governments and their road agents to properly account for the huge sums of public finance (from whatever source, be it tax revenues or donor grants and loans) being processed, and to address the possibilities for fraud and corruption. Many of the institutional measures discussed above are helping to create the right framework for addressing corruption.

The opportunities for corruption occur at all stages in the project cycle, but will evidently be more 'rewarding' at the implementation stages when large contracts are being put in place. Independent auditing and competitive bidding procedures, which are requirements of donor-funded procurement, are an attempt to limit the scope for corruption.

At the feasibility stage of project development, the scope for corruption may be fairly limited; even so, the risk analysis of a feasibility study should include within its scope a commentary on the risks associated with any deviation from implementation of the project as specified. Deviation from the design (due say to corrupt procurement practices) could well have a significant impact on the road performance.

3.5 PRIORITIZING ROAD EXPENDITURES

3.5.1 Value-for-money

The process of prioritizing investment in transport projects is all about seeking value-for-money, i.e. how should limited resources best be deployed to meet the goals of the transport sector (and ultimately poverty reduction goals). At a general level of planning, the issue may concern whether to invest, say, in rail or road; at the more detailed level of planning (e.g. feasibility) the emphasis may be on choosing the best route or design option for the selected project.

Cost-benefit analysis (CBA) is the method of choice for establishing both value-for-money and priorities at all levels of planning enquiry. CBA establishes both the absolute and relative worth of an individual project which must then be compared with all the other projects that might potentially be included in the road administration's annual programme of works. This raises the issue of how many projects the road administration can afford to implement, given the availability of funds from the government budget (or Road Fund), donor funds and other grants and loans. In this context, value-for-money means choosing the right projects and implementing them at the right time.

CBA has its limitations, however, as there may be many unquantifiable (in money terms) impacts (benefits and costs) of transport investment which cannot be directly included in the analysis. Many rural road infrastructure projects, for example, are difficult to justify using a standard CBA approach because of the difficulty of measuring all the benefits (e.g. the value a community places on access to basic public services). Thus, for example, the utility of CBA is limited in isolated areas where agricultural productivity, population density and traffic volume (preconditions for use of CBA) are low. Furthermore, the distribution of costs and benefits is finding increasing importance in decision-making with the current emphasis on poverty reduction.

Value-for-money must therefore be seen in the wider context of social and environmental impacts, as well as budget constraints and economic efficiency and gain.

3.5.2 Maintenance and capital expenditure

Maintenance and renewal of the existing infrastructure are vital activities for any highway administration, and should take priority over all new capital works other than in exceptional circumstances. New investment not only competes with maintenance for scarce revenues, but also increases the burden on future maintenance requirements. The trade-off between maintenance and investment should ideally be explored through a long-term cash-flow programme which shows, on an annual basis, what resources are available, how much is required for maintenance and the balance left over for new investment. While this Note strongly endorses this approach, it does not contain guidance on the procedures for maintenance programming and prioritization, these are described in *Overseas Road Note 1.*

Maintenance is the group of works that enables a road to continue to provide an acceptable level of service. 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 safe, 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 development works designed to increase the strength or improve the alignment of the road, i.e. capital expenditure.

However, maintenance does have a place in the appraisal of a capital roads project: the costs of maintaining the new road over its lifetime must be factored into the CBA. Furthermore, these must be weighed against the maintenance costs that would have been incurred without the construction of the new road.

3.5.3 Allocating funds between competing choices

Budget allocations for rehabilitation and maintenance need to be disbursed amongst different levels of the road network, between rural and urban roads and also among different districts. Although a rational funds allocation procedure is essential, the process is often very opaque and prone to 'political' interference. The procedures may be based on bidding and negotiation between national and local authorities and road organizations or they may be based on formulae which account for characteristics such as road length, area, population and income per head.

Maintenance management systems now exist that can prioritize maintenance expenditure based on road condition surveys and the application of economic CBA to the problem. They include optimization of multiple options and full life-cycle analysis of both road administration and user costs. The approaches can maximize the net present value (a measure of economic worth used in CBA - see Chapter 15) of a maintenance programme subject to a budget constraint. This provides a rational economic basis for the allocation of maintenance funds and is perhaps most useful in helping to decide when the larger scale interventions, such as resealing or overlays, should take place. However, these models cannot satisfactorily allocate maintenance resources for the lowest volume roads (which the models do not address) when vehicle accessibility becomes a major problem or when funding is extremely limited and routine maintenance is threatened.

Computer programming techniques have been developed to determine an optimal investment and maintenance programme. The objective of the computer program might be to, say, maximize the long run net present value of the road investment programme subject to a set of budget constraints.

DETAILED SOURCES OF INFORMATION

Gwilliam, K and Ajay Kumar (2002). *Road Funds Revisited.* TWU-47. World Bank, Washington, DC.

Malmberg Calvo, C (1998). *Options for managing and financing rural transport infrastructure.* Technical paper 411. World Bank, Washington, DC.

Heggie, I G and P Vickers (1998). *Commercial management and financing of roads.* (Chapters 3, 7, and 8 plus Annexes). Technical Paper 409. World Bank, Washington, DC.

Heggie, I G (2003). *Commercializing management and financing of roads in developing and transition countries.* Transport Reviews, Vol. 23, No. 2, 139-160.

PART 2

Fieldwork and Surveys

4. Assessing Traffic Demand

4.1 PURPOSE AND PROCESS

Traffic assessment is the process of estimating future traffic loadings on the road or network under review. Traffic forecasts are needed for two key reasons:

- As an input to the geometric, pavement and bridge design process
- As an input to the environmental, economic and social impact analyses.

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. For the structural design of paved roads, only the number and axle loading of the heavier vehicles need be considered as lighter vehicles contribute so little to pavement damage.

For the purpose of the economic analysis, it is also necessary to separate traffic into the following three categories:

- Normal traffic which is what would pass along the existing road being considered by the project if no investment took place
- Diverted or reassigned traffic which is traffic that changes from another route (or mode) to the project road, but still travels between the same origin and destination
- Generated or developmental traffic which is the additional traffic which occurs in response to the provision or improvement of a road.

The basic traffic assessment process will generally include some or all of the following phases:

- Data review
- Development of a forecasting approach
- Data surveys
- Application of the forecasting approach

4.2 DATA REVIEW AND SURVEYS

4.2.1 Data needs and surveys

Table 4.1 outlines the main data requirements and survey types. Fundamental to all enquiries is a baseline traffic count. Most road design, particularly where heavy goods vehicles are an important component of traffic demand, will also require an estimate of axle loadings.

Survey type	Purpose	Main application
Highway and traffic surveys Surveys that yield data relating to the highway network and its use		
■ Manual and automatic classified counts	To derive traffic volumes (link flows; junction movements; passenger flows; traffic variability; peak-hour factors; AADT)	All road types
■ Screen-line and cordon surveys	To establish characteristics of road use which, in the case of interviews, may be related to driver characteristics (traffic origins and destinations; traffic variation)	Mainly for urban roads and by-passes
■ Vehicle registration number surveys	To establish characteristics of road use (origins and destinations, travel times)	Mainly for urban roads
■ On-vehicle surveys	'Floating car method' to establish network performance (network speeds and delays; link speeds; congestion points).	Mainly for urban roads
■ Axle-load surveys	To establish the 'wear' on roads (truck load profiles, and degree of overloading.	Mainly for inter-urban roads
■ Vehicle speed surveys	To provide baseline speeds to determine vehicle operating costs and passenger time savings	All road types
Surveys to elicit information about vehicle utilization Mainly needed for estimating vehicle operating costs. Particularly useful for 'informal' sector and non-motorized transport.		
■ On-vehicle surveys	To estimate daily km, loadings, etc.	All road types
■ Driver and owner surveys	To establish vehicle running costs and to cross-check utilization data from 'on-vehicle' surveys	All road types
Surveys of travellers and travel demand characteristics Information about travellers and their demand for travel may be used to develop and calibrate traffic forecasting models.		
■ Household surveys	For deriving information on individuals and households concerning their trip characteristics (e.g. journey purpose; frequency; origin and destination; mode used)	Mainly for urban roads
■ Revealed (RP) and stated preference (SP) surveys	Used to measure and explain respondents actual (as in RP) or intended (as in SP) travel reactions (like changes in use) to highway investment	Mainly for urban roads
■ Vehicle occupancy surveys	To identify average vehicle occupancy levels.	All road types
■ Participatory surveys	To target communities or specific groups within a community who will be affected by the highway investment, as a way of understanding their concerns and involving them in the decision process	All road types, but particularly for community access roads
Other surveys There are a number of other surveys that may be appropriate in specific circumstances.		
■ Junction delay surveys	To measure specific junction performance (e.g. turning movements; delays)	Mainly for urban roads
■ Parking inventories and parking use surveys.	Location and availability of space; frequency of use; duration of use	Urban roads

Table 4.1: Main traffic and transport surveys

4.2.2 Traffic counts

The basis for forecasting traffic demand and axle loadings are current traffic counts and classifications for the existing road. Many highways administrations collect this information routinely (in support of maintenance planning, for example) for their main trunk network. Appropriate information is less likely to be available for urban and rural roads.

The estimate used should be the annual average daily traffic (AADT) currently using the route. 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 AADT is estimated. The traffic count is either classified into vehicle categories, or agglomerated into 'equivalent units' of traffic (see Box 4.1).

The classification of traffic is partly dependent on the nature of the enquiry and partly on survey resources which may limit the number of different vehicle types that can be competently recorded. Rural roads, for example, are likely to require a much greater emphasis on capturing non-vehicular traffic movements, whereas axle-load surveys are mainly concerned with the numbers and types of the heavier categories of vehicle. Examples of traffic classification are contained in Table 4.2. In practice many of these categories will be amalgamated to suit the nature of the survey.

Box 4.1: Traffic equivalence units used to agglomerate traffic statistics

Passenger car unit (equivalent)
The Passenger Car Unit or Equivalent (PCU or PCE) is an index of the impedance effect of a vehicle on other vehicles, using the car as the basic unit (taking the value 1.0). This index is particularly useful in urban areas where the impedance effects of larger, less 'nimble' vehicles may critically affect the performance of a geometric design. PCU values are usually measured under maximum flow conditions (saturated flow) and, as such, are largely independent of other factors like traffic flow and road width.

Passenger car space equivalent
In non-saturated traffic (i.e. free flowing), the PCU value of a vehicle is likely to vary with speed. To account for this, the Passenger Car Space Equivalent (PCSE) provides an index which is similar in nature to the PCU, but is measured at a constant speed. Values for different vehicle types are used as an input in HDM-4. *(Volume 7 of the HDM-4 series).*

Equivalent traffic weighting
The Equivalent Traffic Weighting is a variant of the PCU, used in rural areas where the pedestrian is taken as the base. *(DFID Economists Guide).*

Equivalence factor
The equivalence factor (EF) of an axle is its pavement damaging effect in relation to a standard axle which has a load of 80 kN. The EF values for each axle are summed for each vehicle type, and an average vehicle equivalence factor can be calculated for each vehicle type or group. This is then used with traffic count data to produce the equivalent standard axle (ESA) loading on the road. *(see Chapter 9).*

Traffic category	Typical traffic mix on road types (para 2.3.2) urban	inter-urban	rural access	rural infrastructure	Observations
Non-motorized personal:					
Pedestrian	▲	●	▲	▲	
Bicycles	▲	●	▲	▲	Endemic in many cities
Animal drawn vehicles	●	●	▲	▲	Still used in some cities
Motorized personal vehicles:					
Scooters/Motor cycles	▲	●	●		Endemic in many cities
Cars	▲	▲	●		
Vans/light vehicles	▲	▲	●	●	
Non-motorized public transport:					
Bicycles	●	●	▲	▲	
Rickshaws	▲				Still used in many cities
Animal drawn vehicles	●	●	▲	▲	
Motorized public transport:					
Motor cycles	●		●	●	
Auto-rickshaws	▲	●	●		Includes tuk tuks, scooters, etc
Taxis	▲	●	●		May want to distinguish shared taxis separately
Mini-buses (< 20 seats)	▲	●	●		Includes jeepneys, matatus, etc
Large buses (20+ seats)	▲	▲	●		
Non-motorized freight and delivery vehicles					
Porter	▲		▲	▲	Important in some regions and cities
Hand-carts	▲		●	●	Still used in some cities
Cycle-powered carts	▲		●	●	
Animal drawn vehicles	●		▲	▲	
Motorized freight and delivery vehicles					
Light goods	▲	▲	●		
Medium goods (2 axles, twin tyres at rear axle))	●	▲	●		More than 1.5 tonnes unladen weight, but not exceeding 8.5 tonnes gross vehicle weight
Heavy goods (3 axles)		▲			Larger trucks with three axles
Heavy goods (4+ axles, trailers included))		▲			Exceeding 3 tonnes unladen weight, or 8.5 tonnes gross vehicle weight
Miscellaneous					
Tractors, road rollers, etc		●	●	●	

● likely to be in evidence ▲ likely to be significant numbers

Table 4.2: Typical traffic categories used in road counts

Traffic counts (see Figure 4.1) 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, expressed as a percentage, 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

Figure 4.1: Manual traffic counting

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 AADT providing sufficient hours are covered by the daily counts. Box 4.2 gives specific advice on count durations.

Traffic counts and classifications have traditionally been undertaken manually but there are a variety of traffic counters which are available for automating the task for vehicular traffic. Modern counters also have detectors that are capable of automatic classification of the count.

Box 4.2: Advice on traffic count durations

In order to reduce the magnitude of errors, it is recommended that traffic counts to establish AADT 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. ‘Abnormal’ in this context means less than 12 times in a year.
- If possible, the seven-day counts should be repeated several times throughout the year.

4.2.3 Axle load surveys

The aim of an axle load survey is to estimate the number of ‘equivalent standard axles’ currently using the existing road. To do this, a survey is undertaken to determine an average equivalency factor for each vehicle type (see also section 9.3.3). Axle load surveys can be undertaken using fixed or portable weighbridges, as well as weigh-in-motion equipment.

4.2.4 Secondary sources of information

Secondary sources provide useful information that may be relevant to the forecasting process. These sources fall into two main categories, namely transport information and economic background.

Transport information covers material that adds to the general picture of existing highway use and trends. These materials support both the forecasting process and the understanding of current problems. They include:

- Vehicle registration statistics, which indicate scale and trends, as well as detail of fleet composition and specific growth trends in class of vehicle by location
- Traffic volumes on key roads may be collected routinely; this source provides a global view of traffic growth, and may also indicate seasonal fluctuations
- Accident statistics, which might be location specific, but are likely to be more general in nature
- Transport prices and trends, which may be used in forecasting models, particularly if mode choice is a component
- Land-use activity mapping.

The economic background describes the general development potential of the area, and key economic indicators are likely to be used as independent variables in trip forecasting models. In urban areas it may be possible to develop zonal values of the economic indicators where household studies are available. The key indicators are:

- Income, usually measured by gross national product (GNP) per capita
- Population, which will be based on census information
- Vehicle ownership levels
- Employment levels.

4.3 TRAFFIC FORECASTING

4.3.1 Normal traffic

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) i.e. 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.

As an alternative to time, growth can be related linearly to GNP (or gross national income). 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 GNP is needed. The use of additional variables such as population or fuel price brings with it the same problem. If GNP forecasts are not available, then future traffic growth should be based on time series data.

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. These events could lead to different growth rates for different types of vehicle. It is also quite common for vehicle import restrictions to change or for licence fees to be altered to encourage vehicle operators to choose particular types of vehicle, e.g. types that are less damaging to the roads.

Whatever the forecasting procedure used, it is essential to consider the realism of forecast future levels. Few developing countries are likely to sustain high rates of growth, 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.

Box 4.3: Advice on price elasticity of demand

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.

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.

4.3.2 Diverted traffic

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.

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.

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

4.3.3 Generated traffic

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 head-loading to motor vehicle transport and, in this case, generated traffic could be the main component of future traffic flow.

'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.

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 (Box 4.3). 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.

4.3.4 Outputs

Outputs from the traffic forecasting process will be tailored for the specific project to meet the needs of the design team and the appraisal processes. For each option under review (including the base case), and for the project lifetime, the outputs from the forecasting process will include:

- Traffic volumes (by category of vehicle) and person movements on links
- Travel times (by category of vehicle) on links
- Where applicable, forecasts of diverted and generated traffic
- Peak hour traffic volumes and AADT on links
- Cumulative axle-loadings
- Turning movements at key intersections.

4.4 UNCERTAINTY OF TRAFFIC ESTIMATES

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 percent and, typically, an error this size will give an error of a similar order of magnitude in the economic worth. Errors in estimation of traffic growth will increase the uncertainty in the project's economic return even further.

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, sensitivity testing should always be carried out to determine the effects of errors in traffic counts and forecasts on the final recommendations. Projects should normally be analyzed using both 'optimistic' (high) and 'pessimistic' (low) levels of future traffic in addition to the scenario of the best estimate.

4.5 SPECIAL CONSIDERATIONS FOR URBAN ROADS

4.5.1 Introduction

Forecasting traffic on urban roads is complex because of the nature of the urban network and transport modes in use. Here the estimation of future traffic volumes has two basic elements:

- Predicting travel demand (typically presented as a trip matrix) within the study area
- Assignment of total trips to the road network and, in particular, to the scheme under review.

The process of forecasting travel demand has as its output the level of trip-making over the project life on the scheme or network under review. The process can involve several steps, depending on the complexity of the problem:

- Generation of trips
- Distribution of trips
- Modal choice.

Table 4.3 gives an overview of the forecasting process for urban roads.

4.5.2 Generation of trips

Travel prediction models are used to forecast how travel demand responds to changes in the transport system. They are based on mathematical relationships that are derived using simple statistical techniques and relate observed trip-making to one or more independent variables. The model should accurately reproduce observed trip-making, and can subsequently be used to forecast flows in the future using changed inputs reflecting assumptions about growth in the independent variables. Thus, the growth in the explanatory (independent) variables must be forecast in order to 'drive' the forecasting model. However, these variables are often the subject of detailed national planning, and may be either readily available or relatively easy to generate.

4.5.3 Trip distribution

Trip distribution forecasts the patterns of movements between specific areas or zones given the demands for travel to and from these areas developed as part of the trip distribution model. Matrix estimation techniques are used to estimate the existing trip pattern or matrix from count data, developing the origin-destination patterns that are the most consistent with the observed flows. These techniques can also be used to update older observed or estimated matrices in the light of more recent traffic counts. By using the readily available data more extensively they can permit a significant reduction in the data collection exercise, by removing or reducing the need for roadside interviews.

4.5.4 Modal split

The upgrading of the road network may lead to changes in the modes which travellers use for their journey. This may arise, particularly in the urban context, when travellers switch between public transport and private transport, or between road-based and other forms of public transport.

In the absence of any policy measures designed to influence mode choice, significant switches between modes are unlikely unless schemes are large, and there are substantial volumes of travellers using non-road based modes within the area of influence of the scheme.

4.5.5 Assignment

Traffic assignment is the process in which the demand for travel between origins and destinations determined by the trip distribution model are assigned to specific links on the highway network.

Where a road project has little 'competition' from other roads or transport mode, for example, in the case of a simple on-line upgrading or bypass close to the existing road, the assignment can be manual. But where competition does exist, the issue of diverted traffic becomes important. A simple approach to this problem is the use of 'diversion curves'. These estimate the amount of switching between two competing roads, based on comparative journey times and distances for the two options.

For very complex networks (essentially the urban context), models have been developed which assign traffic to individual links in the network using criteria like generalized costs of travel or origin-destination trip times. These models have mechanisms that reflect the congestion

A range of model types is available to handle the differing levels of complexity associated with road development, including:

- Simple growth factoring of the existing flows, with total assignment to a single road
- Use of diversion curves in an 'either/or' situation
- Complex 'four-stage' models.

The main categories of complex (computer-based) models that are likely to be used in an urban road feasibility study are:

1. Transport demand models, which predict the amount of travel that would take place under a given set of assumptions. These broadly reflect population and transport system characteristics. The four-stage model (trip generation, trip distribution, modal split and traffic assignment) is the classic example.
2. Land-use/transport iteration models which forecast changes in both travel and land-use, in response to changes in the accessibility provided by the transport system. These models are highly specialized and urban focussed and are not in common use.
3. Traffic assignment models that focus on the supply side of the transport system (i.e. the way in which the predicted demand for travel impacts on the proposed network). These models can be part of a more complex modelling system (transport demand models), or stand-alone. These models can also provide information that supports the design of junctions within a network.
4. Junction design packages are a further set of models, some using simulation techniques that are used to optimize individual junction layouts and signal settings (both isolated and linked). These will be of value when undertaking analyses of major junction improvement schemes. As in traffic assignment models, traffic forecasts are an input variable to these models.

Forecasting approaches for typical projects

	Replacement project (new road, road widening)	By-pass	Project within a network
Complex network model	Probably not relevant, unless evidence of strong diversion due to scheme (>1000 vehicles per day).	Applicable (but use coarse network model unless the by-pass has a major network function).	Applicable
Diversion curves	Applicable	Can be used where size of town is small	May be applicable in small towns with limited network.
Simple analysis	Can be used if no competing roads or modes	Not applicable	Not applicable

A major junction improvement within the urban context may be treated as a 'scheme within a network', though the scale of modelling should be restricted to the immediate area of the junction (i.e. not city-wide). The use of junction design software would also be appropriate.

Table 4.3: Application of the forecasting process for urban roads

levels that accumulate on individual links as the assignment proceeds.

4.5.6 Scale of analysis

The scale of forecasting analysis in a feasibility study is based on three main factors:

The nature of the area, the size and variety of alternative choices (roads and other transport modes) and their market shares
The availability of data and resources
The forecasting approach adopted.

Urban road projects are likely to require some form of complex modelling, while inter-urban and rural roads are likely to merit a more simplified forecasting process. As a result, the urban process is likely to 'consume' larger amounts of data; as a minimum it requires:

- A trip matrix
- Classified traffic counts on links
- Travel time speeds over the network
- Zonal information relating to socio-economic characteristics
- Referenced road network and item inventory.

Where these do not exist or are out-dated, new surveys must be implemented to either furnish the information or to update the historic sources. Thus the estimation of the resources required to fulfil the forecasting process must be based on a good understanding of the robustness of existing data sources.

4.6 SPECIAL CONSIDERATIONS FOR RURAL ROADS

The volumes of traffic on rural transport infrastructure are likely to be extremely low and this has an impact on the reliability of limited duration traffic counts. The recommendations given in Box 4.2 for traffic count durations may be applicable in this situation though, for some rural access roads, the levels of traffic may be so small as to make counting uneconomic. In this situation, estimating traffic levels should be undertaken as part of the social enquiry.

Low traffic volumes also make it hard to develop an economic justification for improvements to rural transport infrastructure; there are insufficient benefits (that can be valued in money terms) to off-set the costs involved. The main source of benefit is likely to be developmental (i.e. generated traffic), but the estimation of these benefits is difficult to quantify in monetary terms.

The current trend in the appraisal of rural transport infrastructure is to estimate the nature of social benefits, and to combine these benefits with any quantifiable economic gains through some form of multi-criteria analysis (see Chapter 15). This approach takes the emphasis off traffic counting, and focuses more on social enquiry using participatory techniques.

DETAILED SOURCES OF INFORMATION

Bennett, C R and I D Greenwood. *Modelling road user and environmental effects in HDM 4.* Volume 7 of the HDM 4 series. PIARC, World Road Association, Paris.

IT Transport (2001). *Appraisal of investments in improved rural access. DFID Economists Guide.* IT Transport, Ardington, UK.

Transport Research Laboratory (1993). *Urban road traffic surveys.* Overseas Road Note 11, TRL Ltd, Crowthorne, UK.

TRL (2004). *A guide to axle load surveys and traffic counts for determining traffic loads on pavements.* Overseas Road Note 40, TRL Ltd, Crowthorne, UK.

5. Geotechnical Investigations

5.1 PURPOSE

From both an engineering and an economic point of view, geotechnical investigations are of fundamental importance because they have a large impact on many elements of the design and construction of a road. Geotechnical investigations:

- Help to determine the best route between the origin and destination (horizontal alignment), avoiding (if possible) difficult or unstable ground
- Determine the likely bearing capacity of the soils on the route and thereby have a strong influence on the thickness of the pavement
- Identify the type, strength and quantity of suitable materials for building the road
- Help to determine the best construction methods
- Have an important role to play in assessing the effects of the project on the environment, both close to the road and remote from it, and in designing measures to minimize any adverse impacts.

Geotechnical investigations comprise three principal elements; data gathering, data interpretation and reporting. Inadequate attention paid to these activities at the planning and at the feasibility stage of projects have been responsible for large errors in the estimation of the final cost of projects and hence their economic justification.

The amount and type of geotechnical investigation that is needed will depend on the nature of the proposed project and the geotechnical environment in which it is to be built (Box 5.1).

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Box 5.1: The geotechnical environment

The geotechnical environment is a combination of inter-related geological, topographic and geotechnical factors that directly influence the performance of civil engineering structures constructed within it. Key factors are; the engineering properties of the individual soils and rocks; natural instability; rainfall; hydrology; topography; and seismic activity

For new road projects, geotechnical investigations are used to select and compare alternative routes for the road and then to provide design and cost information on a wide range of factors for the selected route. For upgrading and reconstruction projects, geotechnical requirements may be limited to determining the choice and properties of materials that are available for pavement construction. Where existing roads have been damaged or are threatened by ground instability, geotechnical information is needed to design and build the necessary repairs or provide suitable protection.

The extent of the geotechnical work required will be greatest for roads traversing difficult or complex geotechnical environments (see Figure 5.1) and for roads that will carry high levels of traffic. Difficult geotechnical environments can range from, for example, remote mountainous terrains to low-lying areas underlain by thick, soft or organic soils. In such cases geotechnical investigations need to be comprehensive. Identifying the ideal route will be crucial and relatively sophisticated techniques of aerial photography and remote sensing will often be required. In comparison, upgrading a low volume road in an urban area may need almost no geotechnical input at all apart from some basic material testing.

Geotechnical investigation is an iterative process and surveys are usually carried out at four stages in the preparation of a project. The geotechnical information that is obtained and reported is conveniently described (Figure 5.2) as a 'preliminary geotechnical review (PGR)' at the problem identification stage, as a 'geotechnical review (GR)' at the pre-feasibility stage, and as a 'geotechnical assessment (GA)' at the feasibility stage, but other terminology is also used. The 'detailed geotechnical design (DGD)' at the final design stage is beyond the scope of this Road Note.

Figure 5.1: Difficult terrain

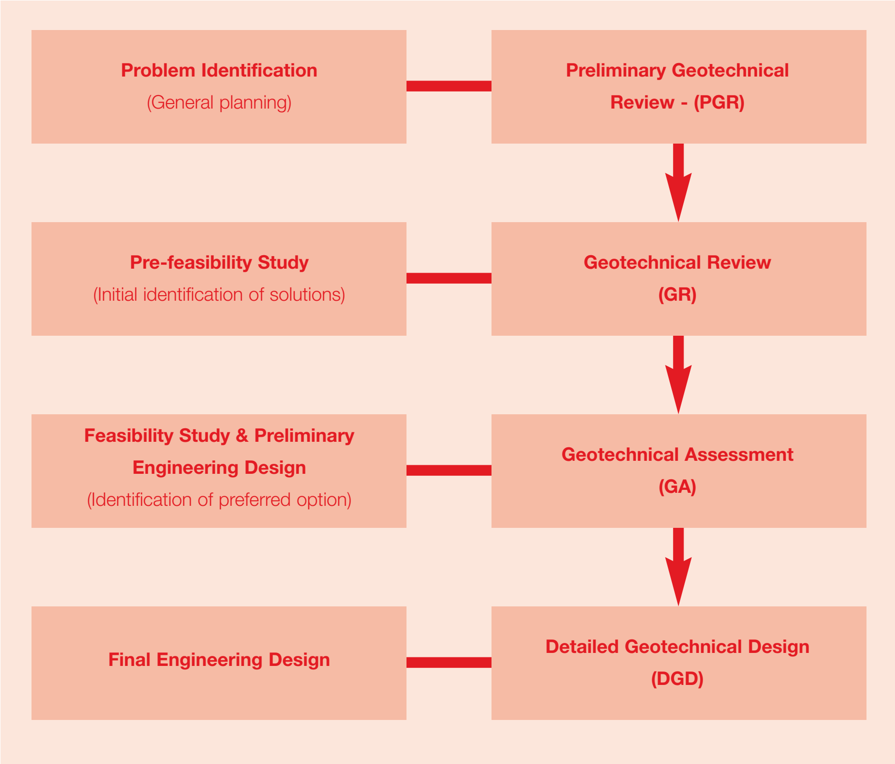

Figure 5.2: Stages of a geotechnical investigation programme

As the project proceeds through these stages, geotechnical information is collected at greater levels of detail. It is essential that key geotechnical problems or constraints are identified at the planning or pre-feasibility stages in order that they may be either (a) avoided by route selection or (b) so that later work can be focussed on providing suitable engineering solutions to them. Essentially a geological or geotechnical 'model' is built up and the staged refinement of the 'model' should be the central theme of the geotechnical investigation process (British Standard BS:5930, Site Investigation).

The outputs from each of these phases are described in detail in Section 5.2 below. First, the engineering issues that the geotechnical surveys are designed to resolve are described and the techniques that are used are introduced.

5.2 THE ENGINEERING ISSUES

5.2.1 Route location

Route location consists of selecting the best compromise between 'demand' factors and the 'geotechnical environment'. Demand factors determine the areas to be served by the road and the standard (or class) of the road, the geotechnical environment influences the engineering cost. The principal road engineering issues governed by the geotechnical environment are:

- Need for structures
- Impact of natural or man-made hazards
- Subgrade conditions
- Surface and sub-surface drainage, including erosion
- Materials used in construction
- Earthworks (the volume and stability of cuttings and embankments).

The emphasis placed on these different factors will vary with the stage of the survey and the standard of the road.

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. Potentially any one (or more) of these key factors could be critical. For example, in some areas construction materials may be abundant but the subgrade soils may be relatively weak thereby requiring a stronger, thicker pavement. In other areas, the soils may be fairly strong, but known sources of materials might be scarce, and so the emphasis should be on finding alternative sources to minimize the cost of haulage.

5.2.2 Engineering structures

One of the first factors to consider in selecting the route of the road is the need for major structures such as bridges, large culverts and tunnels. The very high cost of such a structure can be reduced by locating it at the most favourable point within the route corridor. The cost savings thus produced may be sufficient to justify shifting the road alignment away from the route that would otherwise be the most desirable. 'Nodal points' such as this must be identified at an early stage because they will have a significant effect on the cost of the whole project.

5.2.3 Natural and man-made geotechnical hazards

The occurrence of natural or man-made hazards can have major cost implications for road projects and adjustments to the alignment may be economically justified to avoid or reduce their impacts. Typical hazards to be aware of are:

- Natural slope instability
- Seismic activity
- Volcanic activity
- Mining.

Hazards such as these must be identified early in the development of the project. If major hazards are uncovered only at a late stage or, worse, during construction, the costs of the project will increase substantially (see Figure 5.3).

Figure 5.3: Some areas are prone to landslides

5.2.4 Subgrade conditions

To carry out the structural design of the road pavement (Chapter 9) it is necessary to predict the strength of the subgrade soil under the road after the road has been constructed. This depends on the type of soil and how wet it is likely to be, and its importance depends, to some extent, on the standard of the road. Thus, for a low volume road, construction costs may be lower if an area of difficult soil is avoided, even though the route will be longer, and this may also be the most economic option. Conversely, on a heavily trafficked road, where the shortest route will produce the highest road user benefits, it may be more economical to import additional material to the road line to strengthen areas of weak soil rather than to avoid them.

Particular attention needs to be given to defining areas of expansive or erodable soils which may have significant impact not only on road construction but also on future maintenance costs.

5.2.5 Drainage

Drainage is vital to the successful performance of a road, and many aspects of this are dealt with in Chapters 9 and 11. Understanding the interaction of hydrology with the proposed structures such as cuttings and embankments, and designing them accordingly, is very much the role of the geotechnical expert and is investigated as part of the geotechnical programme.

Similarly, the identification of springs and perched water tables that may cause local recurrent failures in the engineered structures is also the responsibility of the geotechnical expert. However, estimating the maximum flow in rivers or through culverts often requires the services of a hydrologist and such studies are often the subject of separate reports (see Chapter 11 and 12).

Allied with drainage is the problem of erosion. 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 until vegetation grows and establishes stability, or it may be necessary to install permanent solutions to long-term problems.

5.2.6 Materials for building the road

Sources of road-building materials have to be identified within an economic haulage distance and they must be available in sufficient quantity and of sufficient quality for the purposes intended (Smith and Collis, 1993). Previous experience in the area may assist with this but a survey is usually essential.

> *Two of the most common reasons for construction costs to escalate, once construction has started and material sources fully explored, are that the materials are found to be deficient in quality or quantity. This leads to expensive delays whilst new sources are investigated or the road is redesigned to take account of the actual materials available.*

Thus the material investigation often requires an extensive programme of site and laboratory testing, especially if the materials are of marginal quality or occur only in small quantities.

If the project is in an area where good quality construction materials are scarce or unavailable, alternate solutions that make use of the local materials should be considered to avoid long and expensive haulage (see also Chapter 9). For example consideration should be given to,

- Modifying the design requirements
- Modifying the material (e.g. lime or cement stabilization)
- Material processing (e.g. crushing and screening)
- Innovative use of non-standard materials (particularly for low traffic volume projects).

The materials investigations should also take into account any future needs of the road. This is particularly important in the case of gravel roads where re-gravelling is normally needed every few years to replace material lost from the surface. Sources of good material could be depleted with the result that haul distances and costs will increase. Furthermore, good quality material may be required at a later stage in the road's life when the standard needs to be improved to meet increased traffic demands.

Water is also a vital construction resource; many projects have been delayed because of an underestimate of the quantity of water that is conveniently available for construction. Sources of water may therefore need to be identified and used with care. Construction can be phased to make best use of natural moisture in the materials.

5.2.7 Earthworks

Earthworks always form a significant part of the cost of road construction; 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, both embankments and cuttings may be required, and can greatly affect the cost of the project (Figure 5.4).

In projects involving significant earthworks, geotechnical investigations are an essential part of the design process to provide the following information:

- Embankment side-slopes and drainage
- Cutting slopes and drainage
- Excavation methods
- Spoil disposal
- Special geotechnical protection and hazard mitigation works.

Figure 5.4: Major cuttings are sometimes unavoidable on trunk roads and on rural access roads

The cost of earthworks becomes a dominant cost item in areas of steep terrain and the early phase of the geotechnical investigation has an important role to play in the selection of suitable routes to minimize costs. For example, if the road is shorter the increased cost of earthworks may be offset by reduced pavement costs, reduced road user costs and shorter construction time. Thus there ought to be an optimum solution that minimizes total transport costs. Such a solution will be very dependant on the expected traffic and must be selected within the constraints of minimum acceptable standards and road safety.

In some geotechnically fragile areas, increased earthworks can lead to an increased risk of landsliding. The higher the standard of road, then the higher is the cost of repairing such damage and also the higher the cost of delays to traffic if the road is cut completely. In such circumstances expert advice is required and risk analysis might be useful.

Key information required from the geotechnical investigations are:

- The character of the soil-rock profiles to be excavated, including strength, ease of excavation and potential for deterioration on exposure
- The nature and orientation of significant joints sets, faults foliation or bedding within proposed cuts
- The character of the in situ materials below proposed embankments.

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 strong 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. Some types of rock, particularly fine-grained sedimentary rocks, are very prone to rapid weathering and local enquiry and observation of existing road cuttings should be made to identify them.

An important consideration for earthworks, especially in steep terrain or areas where there is evidence of former landslide activity, is that construction work could upset a delicate natural equilibrium (Turner and Schuster, 1996). Rainfall can trigger landslips, either by draining into the slope or by causing erosion, and it may be necessary to design special measures to prevent such failures. The heterogeneous nature of soils and rocks, as well as a shortage of time available to obtain comprehensive geotechnical data, often makes it difficult to apply theoretical design methods for cut slopes and full advantage should be taken of the observed performance of other slopes in similar conditions in the region.

A particular difficulty in steep terrain is the disposal of excess material (spoil), therefore every effort should be made to balance the cut and fill. Where this is not possible, suitable stable areas for the disposal of spoil must be identified. Spoil can erode, or may become very wet and slide in a mass. Material is carried down-slope and may cause scour of watercourses or bury stable vegetated or agricultural land. Material may choke stream beds causing the stream to meander from side to side, undercutting the banks and creating further instability. These topics are dealt with as part of the environmental assessment (Chapter 6), underlining the need for the technical specialists to work in a coordinated team.

5.3 GEOTECHNICAL TECHNIQUES AND SOURCES OF INFORMATION

5.3.1 Introduction

Information for geotechnical investigation is obtained from desk studies, fieldwork and laboratory programmes. The effort and the level of detail required depends upon the nature, scope and scale of the road project and the geotechnical complexity of the terrain itself. This is dealt with in section 5.4.

5.3.2 Desk studies

Existing geotechnical information may be available 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. More specific engineering information may be available from other reports on road projects in similar areas. Some desk study information may be of questionable quality and particular care should be taken to avoid over-reliance on such information in drawing *critical* conclusions.

Information from maps can be considerably enhanced by the use of aerial photographs and satellite imagery (see Box 5.2). The use of such remote sensing techniques should never be overlooked because they provide information very efficiently. They can also provide information that may be very difficult or impossible to obtain in any other way. Aerial photographs and satellite imagery are essential where the area of interest is unmapped or remote, and their use will result in considerable savings in time spent in the field. It is usually advisable to employ a skilled interpreter with geological training for this task but engineers without formal training in air-photo interpretation can often obtain valuable information.

As an extension of air photo and satellite image interpretation, terrain evaluation methods (see Box 5.3) have been developed which enable all types of engineering information to be incorporated into a systematic mapping scheme describing the terrain and its attributes (Lawrance et al., 1993).

5.3.3 Fieldwork

Fieldwork activities include surface mapping, test pits, boreholes, material sampling, and *in situ* testing. Surface work may include geological, geomorphological, geotechnical and hydro-geological mapping. Technical information may be obtained rapidly by the examination of surface terrain, geology and mass engineering behaviour.

A variety of established sub-surface sampling procedures appropriate for different materials are used to recover samples for laboratory testing. The depths and locations of boreholes and test pits will depend on project details and the depths of ground influenced by an earthwork or structure. Samples may also be recovered from natural or man-made exposures, for example, existing road cuttings provide an excellent opportunity to obtain good quality samples of material that would otherwise be difficult to obtain.

Box 5.2: Aerial photographs and satellite imagery

Aerial photographs may be available (or may need to be commissioned) as part of the feasibility or pre-feasibility studies. They are generally flown at scales ranging from 1:20,000 to 1:60,000. 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 3-dimensional relief. Even sub-surface features, such as tilted or folded rock strata or buried gravel deposits, can he identified from aerial photographs by the effect they have on surface features.

Satellite imagery is available for the whole world apart from persistently cloudy regions. The colour images depict terrain and drainage systems over relatively large areas (e.g. 185 x 185 km per image). They are commonly studied at scales of 1:100,000 to 1:1,000,000 and are therefore most useful at desk study and project identification (pre-feasibility) stages of investigation. By repeated coverage of the same area they also show changes in surface features. Changes in major river flow patterns, retreating coastlines, or deforestation can be observed in this way and such information could prove vital.

Box 5.3: Terrain evaluation and classification

Terrain evaluation is a distillation of geomorphological, geological and geotechnical mapping into a presentation that is easier for a road engineers to understand. Such mapping usually goes hand in hand with air photo interpretation.

Terrain or land system classification is a procedure by which the landscape is divided up into components having fairly uniform characteristics. The premise is that where the terrain possesses the same physical characteristics, it will also have uniform soil or rock features that affect engineering design. The concept of uniformity also implies that a terrain unit has uniform potential for hazards of particular types to develop.

Box 5.4: Quality of laboratory testing

The quality of the testing programme depends upon the procedures in place to ensure that tests are conducted properly using suitable equipment that is mechanically sound and calibrated correctly. The condition of test equipment and the competence of the laboratory staff are therefore crucial. There needs to be a robust Quality Assurance (QA) procedure (overseen by a competent geotechnical engineer) in place that will reject data that does not meet acceptable standards of reliability Head, 1992).

Box 5.5: Tropically weathered soils

The behaviour of some tropically weathered material can be noticeably different from the behaviour of temperate sedimentary soils. The approach to the laboratory investigation of tropical materials in terms of the range of tests employed, their detailed procedures and their interpretation should take this into account (Fookes, 1997)

5.3.4 Laboratory testing programmes

Any laboratory testing programme should be part of a rationally designed programme (see Boxes 5.4 and 5.5). It should be staged such that maximum use can be made of early data to plan the bulk of the testing. It is also important that the relationships between in situ conditions and laboratory conditions are considered when designing and developing the test regime.

Early phases of the laboratory test programme will generally concentrate on gaining clues to unusual soil behaviour, e.g. swelling or collapse potential. Bearing in mind the difficulties of sample recovery, statistical sample sizes and the cost of laboratory testing, most testing programmes will be based around relatively simple classification tests that can be done quite quickly; more sophisticated tests will only be used if absolutely necessary. However, even at the stage of final design, there is always the problem that natural materials show high variability in their properties and therefore obtaining design parameters at the ideal level of statistical reliability is very difficult. As a result, considerable engineering judgement and skill is required and the services of an experienced specialist should always be used.

5.4 INFORMATION THAT SHOULD BE OBTAINED AT EACH STAGE OF THE GEOTECHNICAL INVESTIGATION

5.4.1 The scope and cost of geotechnical investigations

The scope, and hence the cost of geotechnical investigations, varies widely depending upon the nature of the road project, its geotechnical environment and the amount of risk that is acceptable to the promoters or owners of the road. At one end of the range, for example, on a flat alignment underlain by a strong subgrade, the investigation may comprise a few trial pits that may take only a few days to complete. On the other hand, in complex, steep topography underlain by complex soil-rock profiles, detailed design investigations could take many months.

The actual costs of geotechnical surveys therefore varies greatly depending on

GDR No.	GDR Definition	GDR Description
1	No geotechnical difficulty	No further geotechnical input required beyond standard design advice. No special geotechnical measures required for construction.
2	Very low problem area	Some further minor geotechnical input required at final design and construction stages to confirm geotechnical assumptions. Standard geotechnical precautions may be required within typical designs.
3	Low problem area.	Some further geotechnical input required to provide data for design confirmation. Some limited input at construction stage. Standard geotechnical preventative measures required.
4	Moderate problem area	Geotechnical input required to define extent of problem and provide final design data. Problems likely to be overcome at construction stage by means of standard geotechnical remedial and preventative processes without significant delay.
5	Moderately severe problem area	Geotechnical input required to establish geotechnical parameters and solutions for problems that have potential to cause delay or increase cost.
6	Severe problem area	Geotechnical input required to establish detailed nature and extent of problem. Construction solutions likely to involve significant geotechnical measures with likelihood of delay and cost penalty
7	Major problem area.	Major input required into problem definition and solution. Specialist advice recommended. Several alternative solutions may have to be examined, including minor shifts of horizontal and vertical alignment. Solutions likely to impose significant delay and cost penalties which are not yet definable in detail.
8	Geotechnical obstacle	Feasibility of alignment compromised. Solutions likely to include significant shift of alignment.

Table 5.1: Geotechnical difficulty rating (GDR)

many factors, especially the standard of road to be built and the complexity of the conditions encountered, but sums between 0.5 and 3 percent of the total project cost are typical. The criteria for assessing the suitability of an investigation should not be based on its budget but rather on its professionalism and whether or not all geotechnical questions have been adequately addressed in a manner appropriate to the stage of the project.

As an aid to the effective design of a complex investigation it may be appropriate at an early stage to assign a geotechnical difficulty rating (GDR) to sections or terrain units along the proposed alignments. This will aid in the identification of key areas for investigation and in the more effective targeting of investigation resources. Table 5.1 presents an example of GDR definitions that could be used for this purpose

5.4.2 Problem identification or planning - the preliminary geotechnical review (PGR)

The objectives of the PGR are identification of any geotechnical constraints or hazards within the area of interest and preparation of a terms of reference for the geotechnical review (GR) that forms part of the pre-feasibility study. These are achieved primarily through desk study and will include the following:

- Identifying relevant geological maps, terrain evaluation maps and general geological/geotechnical review documents
- Extraction and summary of significant general geological/geotechnical information with particular attention to identifying geotechnical hazards (e.g. landslides) or areas that are likely to have significant engineering impact (e.g. zones of swampy ground)
- General identification of the geotechnical environments or terrain units associated with the planning area.

5.4.3 Project identification or pre-feasibility study - the geotechnical review (GR)

The main purpose of the GR is to ensure that any project that progresses to feasibility study stage is likely to be acceptable from a geotechnical point of view and will not be compromised by the later discovery of any foreseeable, fundamental geotechnical problems which cannot be solved satisfactorily.

During this phase possible alternative routes in terms of the ‘corridors’ within which they lie, or series of alignments within the area, will generally emerge as a focus for geotechnical investigations. 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.

Air photo mosaics at a scale of approximately 1:100,000 and satellite 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.

A site reconnaissance (walkover survey) should be carried out on at least parts of the routes or corridors under consideration to confirm and supplement information collected during the desk study. Such a reconnaissance is very valuable; it takes very little time and allows a rapid geotechnical evaluation of the environment. It should produce:

- A record of the key geological and geotechnical features, with particular attention to signs of ground instability and other hazards identified from the desk study
- A record of any available hydro-geological and drainage information (e.g. groundwater seepages and standing water levels)
- A record of the geometry, nature and condition of any existing man-made earthworks in the area
- Results of selected samples of exposed soil and rock for field identification. If there are limited opportunities for such sampling then consideration must be given to using hand augers or digging shallow pits.

Finally and most importantly, the geotechnical review should determine the requirements for the feasibility study.

5.4.4 Feasibility and preliminary engineering design - the geotechnical assessment (GA)

The objective of the GA is to assess in detail the impacts of the critical geotechnical issues that influence the design of a highway project, confirm the feasibility of the project and identify the best options to be taken through to detailed design. A number of key topics form the core of this programme. These are,

- A review and revision, if necessary, of the objectives and scope of the ground investigation (GI) works recommended in the geotechnical review that was conducted as part of the pre-feasibility study.
- Ground investigation works to the level of detail required by the project. Essentially the road corridors are investigated to select the best route. This should be carried out mainly using aerial photographs for all detailed interpretations, ideally at a scale of 1:20,000 - 1:60,000 (these can be supplemented by colour information from satellite images). If more detailed information is required, air photography may need to be commissioned at a scale appropriate to the size of the task and the complexity of the ground (approximately 1:10,000 - 1:30,000). If necessary, a more detailed terrain classification of the area should be made. Further details of specific issues are discussed below.
- Analysis/interpretation of the data produced during the GI and updated knowledge of the general geological, geotechnical and hydro-geological conditions along the proposed alignment(s) thereby defining the geotechnical environment governing the project and providing geotechnical evaluations of the various corridor and alignment options.
- Geotechnical input to the preliminary engineering design (PED). This should include general earthworks design, outline structure foundation designs and details of construction materials and related costs.
- A programme of any supplementary GI required to enable the final engineering design to be completed.

The various detailed aspects of the GI are as follows:

Structures

Preliminary structure foundation designs in terms of foundation types and detail of typical designs should be developed in close liaison with the structural engineer. The geotechnical assessment should provide details of the relevant soil-rock profiles and their geotechnical characteristics. These should be sufficiently detailed so that typical foundation widths, founding levels and, where appropriate, estimated pile lengths, may be developed in conjunction with the bridge engineer.

Subgrade

The GI should provide site-specific data on the subgrade conditions along a final alignment. Particular attention should be paid to:

- Identifying and defining the extent of weak soils and severe problem areas for pavement foundation. These include: swelling soils, collapsible soils, very weak, soft or peaty soils
- Identifying appropriate mitigation options.

Road-building materials

The GI must identify and prove that there are adequate and economically viable reserves of natural construction material. The materials required are:

- Common embankment fill
- Capping layer (imported subgrade)
- Sub-base and road-base aggregate
- Road surfacing aggregate
- Aggregates for structural concrete
- Filter/drainage material
- Special requirements (e.g. rock-fill for gabion baskets).

The location of construction materials, either borrow pits or quarries, should be defined and material quality and variability clearly established. For large projects involving the use of aggregate processing plant there may be a requirement to undertake quality assurance laboratory tests on trials of the processing procedures.

For projects with bridge structures requiring high quality concrete aggregate there may be a requirement to undertake specialist laboratory work.

On large projects, with significant fill and aggregate requirements, mass-haul diagrams should be drawn to augment cost-benefit decisions with respect to utilizing any alternative materials.

If the project is in an area where good quality construction materials are scarce or unavailable, consideration should be given to developing appropriate solutions to counter the shortfall, for example by modifying the design requirements, modifying the material (eg, lime or cement stabilization) or by material processing (e.g. crushing and screening).

5.4.5 Timing

The fact that so many aspects of the overall feasibility study depends on the geotechnical information means that the early initiation of the geotechnical work is usually vital. It is essential that the geotechnical work is underway and feeding back information during the engineering assessment process. The GI must be completed and the results analyzed in time to contribute to the preliminary engineering design. In projects where there are a number of options to be considered at feasibility stage, the design and programming of the GI should be sufficiently flexible to enable resources to be concentrated on the preferred route options, when identified. The final geotechnical assessment report must contain any necessary recommendations for further ground investigation if this is deemed necessary for the final engineering design.

5.4.6 Design for project implementation

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. The details of this are outside the scope of this Road Note.

A geotechnical investigation relies a great deal on the interpretation of a limited amount of information. It is important, therefore, that a suitably qualified geotechnical engineer is responsible for the geotechnical work. The geotechnical engineer should take professional responsibility for all geotechnically-related recommendations. He should scrutinize all information collected and carry out the review/assessment personally. He should maintain a close liaison with highway planning and engineering personnel and the environmental specialist at all times during the investigation phases.

5.4.7 Reporting the geotechnical information

Providing a retrievable archive of all the geotechnical data collected as part of a project is vital. The final geotechnical assessment report serves as the means for collating and presenting all the geotechnical findings. In addition to geotechnical interpretation and analysis, the final report should include all factual data including borehole logs, field and laboratory test results and so on (Table 5.2). If any of the factual data is the subject of a separate contractor's report it should be included within the main geotechnical report, possibly as an appendix.

Geotechnical information is expensive to obtain and, in general, does not lose its value with time, hence it is important that it is reported properly and archived in such a way that it can be retrieved and used for future projects.

Item	Preliminary Geotechnical Review	Geotechnical Review	Geotechnical Assessment
A clear statement of the geological setting and geotechnical environment(s)	P	II	II
Descriptions of anticipated geotechnical hazards, including earthquake hazard	P	II	II
Definitions of the geotechnical character of the soils and rocks likely to be encountered	P	II	II
Summaries of the soil-rock geotechnical properties		II	II
Borehole and test pit logs		II[1]	II
A schematic geological profile		P	II
An Index-Properties profile		P	II
Geotechnical profiles and sections		P	II
Details of geotechnical design relating to earthwork and structure (with plans and sections)			II[1]
Description of design methods used and typical calculations			II[1]
Definition of geotechnical design assumptions			II[1]
Definition of construction materials sources, including volumes and quality			II
Construction recommendations			II
Monitoring recommendations			II

P = Preliminary II[1] = If appropriate

Table 5.2: Typical geotechnical reporting requirements

DETAILED SOURCES OF INFORMATION

British Standards Institution (1981). *Code of practice for site investigations.* BS 5930. British Standards Institution, London.

Dearman, W R (1991). Engineering Geological Mapping. Butterworth-Heinmann Ltd, Oxford

Fookes, P G (1997). *Tropical Residual Soils.* A Geological Society Handbook, Geological Society, London.

Head, K H (1992). *Manual of Soil Laboratory Testing. Vol 1 Soil Classification and Compaction Tests (2nd Edition).* Pentech Press

Geotechnical Engineering Office (2000). *Highway Slope Manual.* Civil Engineering Department, Government of Hong Kong.

Lawrance, C J, R J Byard and P J Beaven (1993). *Terrain Evaluation Manual.* State of the Art Review No 7. Transport Research Laboratory. HMSO, London.

Smith and Collis (eds) (1993). *Aggregates: Sand, Gravel and Crushed Rock Aggregates for Construction (2nd Edition).* Geological Society, UK.

Turner, A K and Schuster R L (eds) (1996). *Landslides: Investigation and Mitigaton. Special Report 247,* Transport Research Board, National Academy Press, Washington, DC.

6. Environmental Impact Assessment

6.1 THE PURPOSE OF ENVIRONMENTAL IMPACT ASSESSMENT

Environmental impact assessment (EIA) is the process for examining and reducing the likely environmental impacts of a project prior to its implementation. EIA is a legal requirement in many countries for certain types of development project. EIA is commonly required for new roads and road improvements because of the range of potential environmental impacts associated with these projects (see Table 6.1). This table is illustrative and it is likely that the impacts will differ from project to project.

Even when a full EIA is not required, such as in the case of some smaller scale road improvement projects, an appropriate level of environmental analysis should be undertaken based on the likely effects of the project. Within this guidance EIA is referred to as encompassing the formal process as well as similar environmental analyses.

In most contexts EIA addresses more than just the natural or ecological environment. For example, most EIA's address aspects of the built environment and many consider wider community and socio-economic impacts. For this reason, the EIA needs to be managed as an integrated component of the overall project appraisal process. Chapter 7 of this document on the social impacts of road projects is particularly relevant to those involved in the EIA.

This chapter provides general advice for EIA of road projects. It supplements and should be read alongside more detailed EIA guidance listed at the end of this chapter and Appendix A providing topic-by-topic advice on the baseline data, likely impacts and mitigation measures.

6.2 OVERVIEW OF THE ENVIRONMENTAL IMPACT ASSESSMENT PROCESS

The basic EIA process involves a series of stages of examining and acting upon relevant environmental information. Figure 6.1 shows how the EIA stages support the activities associated with the feasibility work on a road project. In practice, the EIA process should be flexible rather than strictly linear, for example re-examining some environmental baseline information in light of discussions over possible mitigation measures.

EIA should be undertaken by appropriately qualified individuals working as a multidisciplinary team. Where a wide range of environmental impacts are anticipated, the role of managing and coordinating the environmental specialists will also be of critical importance to the success of the EIA and the overall project appraisal.

		Road Life Cycle Stages				
		Pre-construction	**Construction**	**Associated development projects and land use changes**	**Operation**	**Maintenance**
		e.g. Sources of materials; quarrying; borrow pits	*e.g. Earthworks; site clearing; drainage works; use of construction equipment; construction camps*	*e.g. Ribbon residential development; commercial and industrial developments using transport links*	*e.g. Traffic; accident management and diversionary routes*	*e.g. Resurfacing; drainage; lighting; embankment and bridge repair; gritting*
Environmental Resources	**Water resources**	▲	▲	▲	▲	●
	Soil & geology	▲	▲	▲	●	●
	Local air pollution	●	▲	▲	▲	●
	Regional air pollution	●	●	▲	▲	●
	Landscape, natural resources and waste	▲	▲	▲	●	●
	Biodiversity	●	▲	▲	○	●
	Cultural heritage	▲	▲	▲	○	○
	Noise and vibration	▲	▲	●	▲	●
	Community severance	●	▲	○	●	●
	Land acquisition and resettlement	●	▲	▲	○	○
	Wider socio-economic impacts	●	●	▲	▲	○

Key:
Potential major impact (positive and/or negative) ▲
Potential minor impact (positive and/or negative) ●
Unlikely impact ○

Table 6.1: Key Environmental Impacts Associated with Road Projects

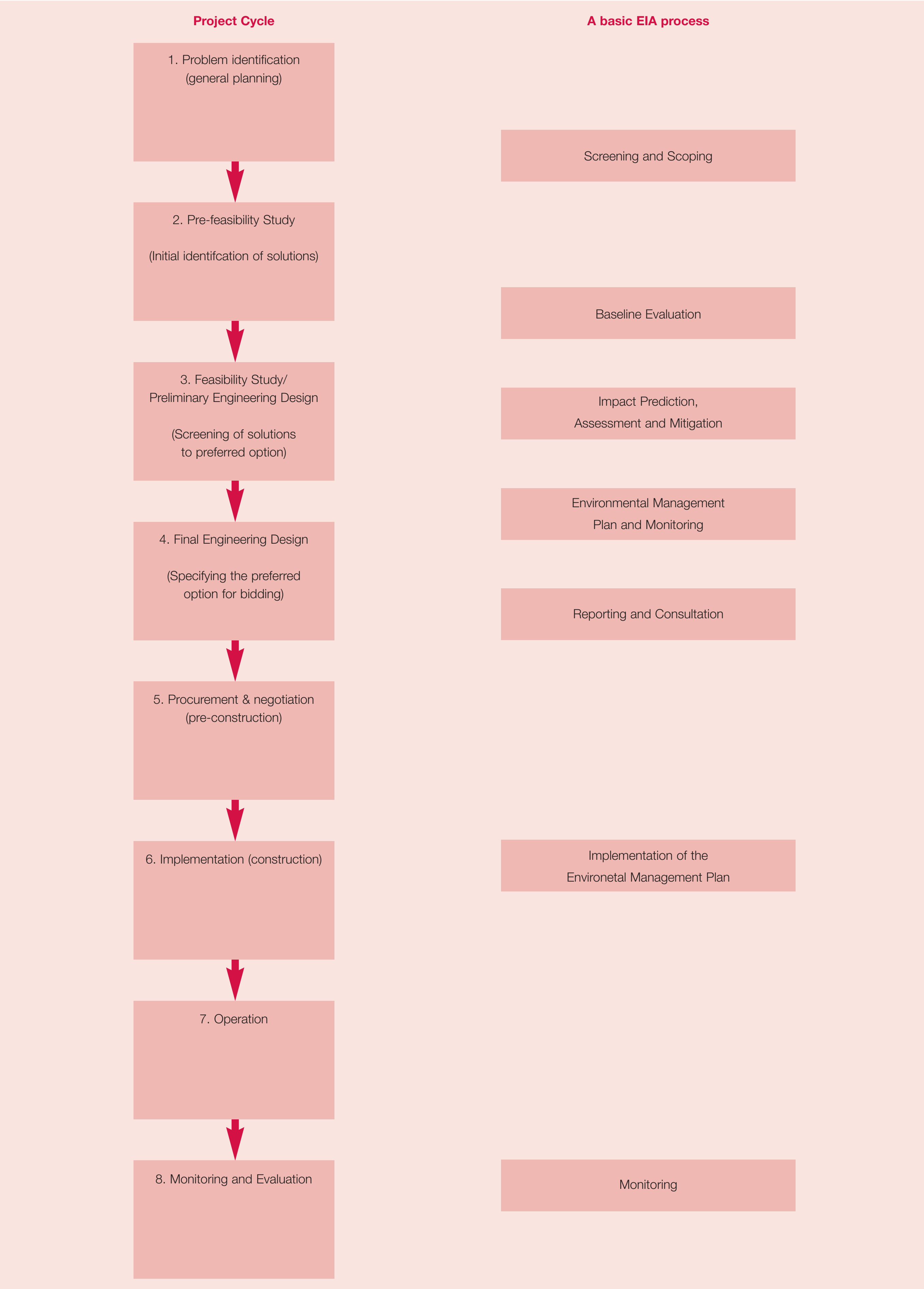

Figure 6.1: The EIA process alongside the road project cycle

6.3 SCREENING & SCOPING

In conducting an EIA it is important to examine relevant information from prior studies. In some cases a Strategic Environmental Assessment (SEA) may have been undertaken. An SEA is different from EIA because an SEA applies to policies, strategies, plans and programmes rather than individual projects. An SEA seeks to provide a broad environmental assessment of the strategy for the transport network from which individual projects can then be chosen.

Even where there has not been a formal strategic plan, there may have been a preliminary environmental analysis during a project identification phase. All such preliminary information should be obtained and reviewed as this will save time and resources in conducting the new EIA.

The first stage of environmental assessment is screening to determine whether a full EIA is needed. If not, some form of environmental analysis will usually be necessary and this should be proportional to the scale of the road project and its likely environmental impacts.

A full EIA must be undertaken in certain circumstances including:

- Where national/regional EIA regulations apply
- Where a project funding agency requires EIA.

The environmental screening decision should be made in consultation with relevant parties such as the environmental regulatory body and any funding agencies. The screening decision should also be made available to the public.

Environmental scoping is carried out alongside or soon after screening. Scoping involves identifying the most important environmental issues associated with the project. For example, a new road involving land take in or near a national park is likely to give rise to ecological impacts. By contrast an urban road widening scheme may have particular impacts in terms of local air quality. Good scoping will lead to a streamlined EIA and avoid the project team spending a lot of time on environmental issues which are relatively insignificant (see Box 6.1).

Scoping should involve:

- Collaboration between environmental topic experts as relevant to the project and its location
- Consultation with relevant parties including environmental regulatory bodies (e.g. the Ministry for Environment)
- Developing a work plan for the EIA
- Proposing the assessment techniques for particular EIA topics (e.g. a desktop assessment, modeling and/or site surveys)
- Defining the criteria for determining the significance of the impacts
- Identifying the timing and arrangements for consultation/involvement in the EIA.

Box 6.1: Screening and scoping: hints and tips

- Provide an opportunity to involve other relevant parties in the screening and scoping decisions – it is better to debate the issues at this early stage rather than holding up the project later
- The EIA team should not try to assess all of the environmental issues to the same level of detail – the scoping process should be used to focus on the most important ones.

6.4 BASELINE EVALUATION

Following screening and scoping, the next stage in the EIA process involves formulating a complete view of the environment that may be affected by the project. This is known as the evaluation of the environmental baseline and requires collection of data on the main ‘environmental or community resources’ (also known as valued ecosystem components (VECs) in some contexts). The current environmental baseline conditions may be subject to change through natural events and trends, or human activities other than the proposed road project. For this reason the likely future state of the environment should also be examined i.e. assuming that the road project does not happen. Consideration of the future environmental baseline situation is particularly important where the construction is not due to be completed for a number of years.

Sources of environmental baseline data for a road project may include (see also Box 6.2):

- Topographic maps
- Vegetation maps
- Aerial photographs
- Scientific and technical reports
- Other environmental impact assessment documents
- Technical, social, demographic and economic information from local, regional, and national government
- Professional and non-governmental research organizations, and development agencies
- Consultation with local residents and professionals.

Box 6.2: Baseline evaluation: hints and tips

- As part of project planning, ensure that the project team has identified additional surveys where needed to supplement existing baseline environmental information. Note that some environmental surveys may need to be repeated and/or carried out at a particular time of the year
- Consider whether the project team has selected appropriate ‘assessment years’ for developing the future environmental baseline. The assessment years will need to be chosen in consultation with the project engineering design team. Typically these are the opening year of the road and a design year, routinely defined as 10 years after road opening.

Where data do not exist for key environmental community resources, new environmental surveys may need to be conducted.

Collection of environmental baseline data can be a time consuming process. The activity should therefore be restricted to those data sets that are most relevant to the project i.e. the main environmental or community resources that could be significantly affected by the project.

Spatial scale is an important consideration in compiling the environmental baseline. For some topics the spatial area for which baseline data are collected will coincide with the geographic extent or 'footprint' of the road project. However, the nature of some environmental and community resources will require baseline data to be collected working to different spatial boundaries. For example, impacts on groundwater resources may arise many kilometres from the source of pollution.

6.5 IMPACT PREDICTION, ASSESSMENT AND MITIGATION

Impact prediction and assessment involve considering the baseline environment in the light of the expected changes associated with the project. The prediction and assessment should be carried out early enough to provide an input to the technical and economic comparison of alternative options for the project.

Impact prediction and assessment should be undertaken for all relevant environmental topics (see Box 6.3). It is also important to consider the interrelationships between them. For example, identifying when a community may be affected by a number of negative or positive environmental impacts. For further information on the topics listed in Box 6.3, except those indicated as being part of the SIA process, the reader is referred to the Appendix for topic by topic environmental advice.

There are numerous techniques available for conducting the impact prediction and assessment such as predictive modeling, mapping/geographical information systems and forms of qualitative analysis. These techniques are summarized on a topic by topic basis in Appendix A. Appropriate techniques should be used to characterize impacts against various parameters:

- Whether the impact is positive or negative
- Magnitude of the impact, in quantitative terms where possible (e.g. the scale of change resulting from the project)
- The timing in terms of the project life cycle (see Table 6.1) as well as the calendar month/season
- Whether it is permanent or temporary and the duration of its effects
- Whether it is direct or indirect in nature
- Any regulatory considerations associated with the impact
- The reversibility of the impact
- Whether the impact might be cumulative in association with other projects (e.g. housing and commercial development near to the new road alignment, with the projects collectively causing a major impact on a wetland habitat).

Once a potential impact has been characterized, consideration should be given to its significance. Put simply, significance is a factor of the magnitude and other characteristics of the expected impact and the sensitivity of the receiving environment or community. Determining significance is an important part of EIA and should be considered from the outset of the process. Where no significant impact is anticipated, this should be stated and explained in the environmental impact statement (EIS). The consistent and robust determination of significance can be assisted through the use of significance criteria which may have been developed for similar projects or on a region/country-wide basis.

EIA is an active process and is intended to help to improve the nature and design of the project. This is achieved through considering how the impacts may be avoided, reduced or remedied alongside the process of prediction and assessment. Avoidance of the impact is the preferred approach through selecting an alternative option or design.

Where an impact cannot be avoided, reducing or remedying the impact is the preferable approach. This is known as mitigation. Mitigation may be achieved through:

- Changes in the design, construction practices, maintenance, and operation of the project
- Additional actions taken to protect the biophysical and social environment, as well as individuals who have been impacted adversely by the project.

Finally, where mitigation cannot be achieved, some form of compensation may be considered, such as creation of a new area of equivalent wetland away from the project itself. Compensation is not always appropriate where an environmental feature is irreplaceable (e.g. an archaeological feature or unique habitat).

Mitigation and compensation measures must be realistic and achievable bearing in mind the issues such as capital cost, maintenance, land ownership and institutional responsibilities. The feasibility of mitigation and compensation measures should therefore be carefully considered and reported as part of the EIA and project appraisal processes.

Even with excellent baseline environmental data and a well-specified and designed project, EIA still involves

Box 6.3: The key topics for an EIA of a road project

- Water resources
- Soil and geology
- Local air pollution
- Regional air pollution
- Landscape, natural resources and waste
- Biodiversity
- Cultural heritage
- Noise and vibration
- Community severance*
- Land acquisition and resettlement*
- Socio economic*

* primarily covered within a social impact assessment (SIA) where one is undertaken

making predictions based on many variables. As with other aspects of project appraisal, there will be residual uncertainty associated with the impact predictions and mitigation measures. To provide a credible assessment, all areas of uncertainty should be identified and communicated as part of the EIA.

Impact assessment and mitigation in EIA can be supplemented by additional supporting analyses (see also Box 6.4). The need for such analyses may be driven by project funding agencies or through contact with other stakeholders. Any such analyses will need to be closely integrated with the results of the EIA. They may include:

- Socio-economic impact assessment (see Chapter 7)
- Distributional analysis examining in detail which communities/social groups are affected by the various impacts identified in the EIA)
- Sustainability tests, e.g. consideration of issues such as intergenerational equity and the precautionary principle (which seeks to promote a precautionary policy response where preliminary objective evaluation indicates that there are reasonable grounds for concern that potentially dangerous effects on the environment/communities may occur, even where there is a degree of uncertainty)
- Health impact assessment.

6.6 ENVIRONMENTAL MANAGEMENT PLAN AND MONITORING

Implementation of mitigation and monitoring the impacts are often the weak links in EIA. A project environmental management plan (EMP) (also known as an environmental action plan, a construction management plan or an environmental protection plan) should be prepared as it is the main mechanism to achieve continuity between project planning/appraisal, detailed design, implementation/construction and operation/maintenance (see Box 6.5).

An EMP should be drafted towards the completion of the impact assessment. It should be published as one chapter of the environmental impact statement and then updated later at key points prior to and during construction. Finally, a handover EMP should be prepared as the project enters the operation and maintenance phase at which time responsibility is often handed over to a different department or organization.

The contents of an EMP should complement other project documents such as the design drawings showing the designs for the environmental mitigation measures. The main elements of an EMP are:

- A list of all project-related activities and impacts, organized by the construction and operation/maintenance periods
- A list of regulatory agencies involved and their responsibilities
- Details of specific mitigation/remedial measures and monitoring measures associated with:
  - The construction period activities and impacts
  - The operation and maintenance period activities and impacts
- A clear reporting schedule, including discussion of what to submit, to whom, and when
- Cost estimates and sources of funding for both one-time costs and recurring expenses for EMP implementation.

Monitoring measures for the project may take a variety of forms such as:

- Compliance monitoring to enforce the implementation of agreed mitigation
- Effects monitoring/evaluation to consider the accuracy of the EIA predictions. This can provide a basis for identifying further mitigation measures for the project and/or capture issues of relevance to improve future projects.

6.7 REPORTING AND CONSULTATION

A key reporting and consultation stage will occur towards the end of the completion of the project appraisal and EIA to inform the decision whether to proceed with the project. However, it is also beneficial to consult other parties at earlier stages of the process to improve the assessment and avoid possible expensive changes to the design and mitigation at a later stage.

Typically, consultation is beneficial at the following stages of EIA:

- At the scoping stage of the SEA to identify sources of baseline environmental information and potential significant impacts
- During the impact assessment and mitigation

Box 6.4: Impact prediction, assessment and mitigation: hints and tips

- The project team should consider and report on the less obvious environmental impacts as part of the assessment, even if they are later ruled out and found to be insignificant.
- The project team will need to be creative in considering ways to avoid and reduce impacts through selecting alternatives and changing the project design.
- When proposing additional mitigation, the project team should examine the feasibility and cost of implementing and maintaining the measures.
- To bring credibility to the assessment, areas of uncertainty associated with the predictions should be clearly identified.

Box 6.5: Environmental management plans and monitoring: hints and tips

- The EMP is the most important output from the EIA – the project team should treat it as a live document through the construction phase
- To save time and resources, the project team should try to make use of environmental monitoring systems and data collected for other purposes (e.g. by environmental ministries or agencies).

- When the environmental impact statement (EIS) is published
- During the design stage and as the project enters the construction phase and the EMP is updated.

During consultation, the following stakeholders should be involved:

- Government ministries
- Project designers
- Local officials
- Associations
- NGOs
- Community representatives
- Local residents.

It is important to highlight what is expected of the consultees (i.e. what is being asked – questions within the documents can be useful triggers), and who to contact when responding to the consultation.

Public disclosure is an important aspect of all road projects. Internationally, one of the main drivers for improving environmental reporting, consultation and public participation techniques in EIA is the Aarhus Convention (2001). The convention provides for:

- Access to environmental information - the right of everyone to receive environmental information held by public authorities;
- Public participation in environmental decision making - the right to participate from an early stage in decision making;
- Access to justice - the right to challenge in a court of law, public decisions that have been made without respecting the two other rights.

The EIS is a key reporting output and its format and publication arrangements should be coordinated with other project documentation. The required contents of the EIS may be specified in relevant legislation and/or guidance. An EIS will typically include the following subsections:

- A non-technical summary
- Methods and issues including identification of the environmental assessment team, and introduction of policy, legal and administrative framework
- A project description including the need for the project and a summary of any off-site works
- Description of the environmental baseline
- Discussion of alternative solutions and designs
- Predicted environmental impacts (this might also include identification of mitigation measures)
- Consultation (a complete record of consultation undertaken)
- The environmental management plan including monitoring provisions.

The EIS can also be useful for conveying positive aspects of project. If the project or secondary developments are enhancing any social or environmental resources, it is a good opportunity to gain public approval. Equally, the reporting process should be seen as a chance to clear up misunderstandings and identify conflict areas early on in the planning process. This allows the detailed project design to be modified (see Box 6.6).

Box 6.6: Reporting and consultation: hints and tips

- Organized groups may be able to contribute specialist knowledge to the EIA process. However, it is often the local directly-affected community, who although sometimes lacking in technical, financial and educational resources, are the ones who may be able to make the most valuable contributions during consultation
- The EIS should not be overly 'wordy' or long. It should present the necessary information clearly and concisely, in a format that can be understandable to the public. The use of maps and graphics, along with GIS, can be useful in helping readers visualize the project's effects.

DETAILED SOURCES OF INFORMATION

Asian Development Bank (1997). *Environmental impact assessment for developing countries in Asia*. Asian Development Bank, Manila

DFID (2003). *Environment guide*. Department for International Development, London

EBRD (1996). *Environmental procedures*. European Bank for Reconstruction and Development, London

EBRD (2003). *Environmental policy*. European Bank for Reconstruction and Development, London

World Bank (1997). *Roads and the environment handbook*. Technical Paper 376, World Bank, Washington, DC.

World Bank (1999). *Environmental assessment sourcebook*. World Bank, Washington, DC.

7. Social Impact Assessment

7.1 THE PURPOSE OF SOCIAL IMPACT ASSESSMENT

Social impact assessment (SIA) is a technique that can be used to examine the various positive and negative effects on social welfare of a transport intervention. SIA can be applied at both the project appraisal phase, and in monitoring and evaluating implementation of the intervention. Its primary purpose in a feasibility study is to:

- Identify and mitigate risk
- Measure the social costs and benefits of a road project.

SIA usually involves a high degree of community participation. Analytically it provides an understanding of the social context, institutions and coping strategies that affect social behaviour and policy impacts. This includes:

- The ways people cope with life through their economy, social systems, and cultural values
- The ways people use the natural environment for subsistence, recreation, spiritual activities, cultural activities, etc
- The ways people use the built environment for shelter, making livelihoods, industry, worship, recreation, community associations, etc
- The ways communities are organized and held together by their social and cultural institutions and beliefs
- Ways of life that communities value as expressions of their identity
- A group's values and beliefs about appropriate ways to live, family and extra-family relationships, status relationships, means of expression, and other expressions of community.
- The aesthetic and cultural character of a community or neighbourhood.

In identifying risk and social mitigation measures, SIA involves characterizing these social attributes, forecasting how communities may be impacted by the planned intervention, and hence developing mitigation measures. Table 7.1 indicates the range of potential social impacts associated with road projects.

The measurement of social costs and benefits attributable to a road intervention are particularly important for justifying development of rural transport infrastructure. Because of the low traffic volumes, the economic rate of return (see Chapter 15) on improvements to these roads is typically insufficient to commit investment. Inclusion of social costs and benefits in the analysis will support the case for these roads and hence avoid marginalization of poor rural communities. The application of social costs and benefits to the appraisal of roads is discussed further in Chapter 15.

		Road Life Cycle Stages				
		Pre-construction	**Construction**	**Associated development projects and land use changes**	**Operation**	**Maintenance**
		e.g. Sources of materials; quarrying; borrow pits	*e.g. Earthworks; site clearing; drainage works; use of construction equipment; construction camps*	*e.g. Ribbon residential development; commercial and industrial developments using transport links*	*e.g. Traffic; accident management and diversionary routes*	*e.g. Resurfacing; drainage; lighting; embankment and bridge repair; gritting*
Environmental Resources	**Community severance***	●	▲	○	●	●
	Community displacement*	●	▲	●	○	○
	Labour based works*	●	▲	○	○	▲
	Road safety*	○	●	▲	▲	●
	Traffic volume	○	●	▲	▲	●
	Crime	○	●	○	▲	○
	Prostitution	●	▲	●	▲	●
	HIV/AIDS*	●	▲	●	●	●
	Pollution / respiratory health impacts	▲	▲	○	●	●

Key:
Potential major impact (positive and/or negative) ▲
Potential minor impact (positive and/or negative) ●
Unlikely impact ○

* Appendix B contains additional information covering these topics

Table 7.1: Key social impacts associated with road projects

7.2 SIA IN ROAD PROJECT APPRAISAL

7.2.1 Overview

SIA should be fully integrated in the project cycle. Each step in the planning phases of the project cycle includes SIA-related tasks (see Figure 7.1). Setting up baseline control surveys and a timeframe for follow-up surveys should be part of project identification and pre-feasibility work. By the time the project is ready for feasibility appraisal, the impact indicators will have been selected and are used to estimate the social costs and benefits of alternative project options.

For evaluation work, baseline surveys should be completed prior to the start of project implementation. During project implementation and supervision, the preparation for the follow-up survey needs to be made (the latter needs to be undertaken following completion of the project). The impact evaluation is then part of the post-completion activities.

Table 7.2 provides a checklist of social issues that should be covered at any of the planning stages

7.2.2 Problem identification and SIA

Transport interventions are often undertaken without a full understanding of the transport needs and constraints of rural communities. Thus there is sometimes little appreciation of the problems faced by organizations trying to deliver improved rural access. Collection of appropriate data from the village to national level can help to identify these attributes. A poor transport network will affect all other sectors and, in particular, access to:

- Transport and mobility services
- Health and education services
- Farms and markets
- Income earning opportunities
- Social networks and leisure activities.

A baseline survey is used to identify the nature of community access problems and the priority that is placed upon access and its improvement. The potential social benefits of a road intervention can also be assessed covering such changes as:

Responsive to needs of people affected	■ Have patterns of current road use, and forecast usage been established? Are the needs of users reflected in project design? (e.g. need for the new road to accommodate motorized vehicles, oxcarts, drivers, cyclists and pedestrians) ■ Have other local concerns been taken into account e.g. for safety, especially for children, and for security? ■ Are there legal provisions in force to mitigate the cost of accidents if they occur (e.g. seat belt laws, insurance schemes, checks on the road-worthiness of vehicles etc)? Are these laws consistently and fairly applied? If not, how will the project address this issue (e.g. through policy dialogue at ministry level)? ■ Do farmers feel that levels of compensation proposed for land lost to road widening is adequate?
Reaching poor and disadvantaged populations	■ Will the construction of the road be undertaken by local people, thereby bringing employment to the area (see Figure 7.2)? ■ If the project is financed as part of a 'food for work' campaign how will contractors ensure labour opportunities go to the poorest? ■ Does the potential benefit from the road depend on other facilities also being available e.g. transport, credit? Will/could the project facilitate their provision (e.g. through discussions with the Ministry of Transport on the need for a subsidized public bus service)?
Recognizing the roles and needs of women	■ For what purposes do women currently use the road? Will they be in any way disadvantaged by the new road (e.g. with regard to road safety, personal security, displacement etc)? Can/will the project attempt to offset any negative effects? ■ If local labour is used to build the road will women labourers be employed on equivalent terms and conditions as men?
Encouraging participation	■ How are local communities to be informed/consulted about the road? ■ Will indigenous knowledge be used in project design? ■ Will local labour be used to maintain the road? Will local contractors be asked to tender for maintenance and building work? ■ Where the Public Works Department is the implementing agent: is the department equipped to find out local needs and use local knowledge in project design? How can the project support the department to adopt a participative approach?
	Adapted from DFID (1993)

Table 7.2: Checklist of social development objectives of road infrastructure projects

- Improved social networks and enhanced social capital from people finding it easier to maintain links with family members outside of the immediate rural area. Such links provide for social interaction and access to help and resources in times of need.
- Enhanced community development may arise from the community working together to maintain or improve their own transport conditions. This depends upon how changes in transport conditions are brought about and how they are maintained.
- Increased confidence in an ability to travel to access services and opportunities.
- Improved health and education through easier access to services, particularly in areas such as maternal mortality and girls' education.
- Reduced vulnerability to unexpected events and shocks from crop failure, accidents and poor security. This is often due to an increased ability to access assistance and to secure income from an alternative source.
- Greater reliability of clinics and schools in securing secure staff for clinics and schools and easier to maintain these services because drugs can be supplied and school supplies replenished.
- Reduced time burdens from engaging in mobility due to the improved environmental impact of roads (e.g. less dust) and increased transport service frequency.

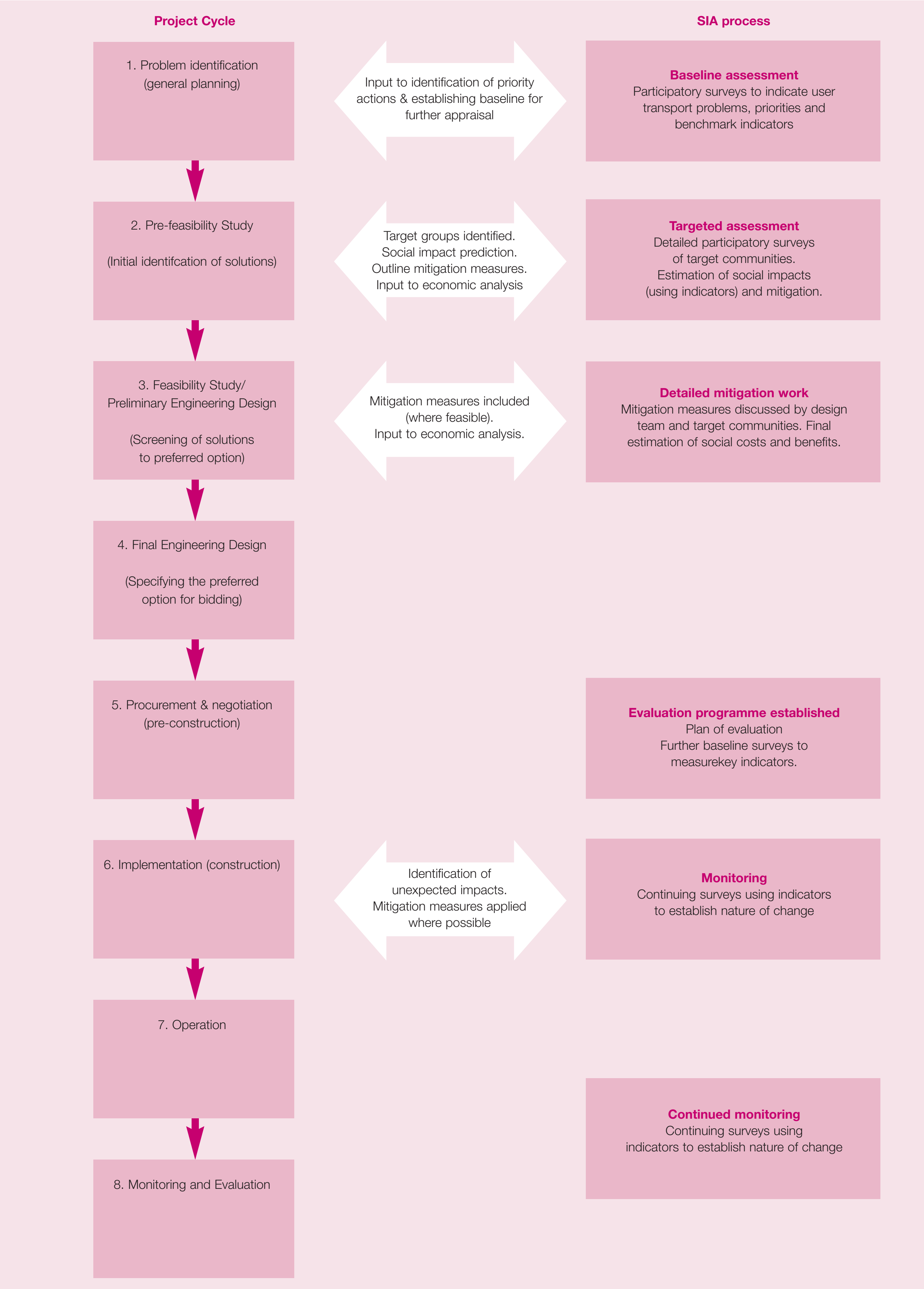

Figure 7.1: Outline of SIA process

Figure 7.2: Labour-based road works, Tanzania

At this stage, the set of social impact indicators used to compare options may be fairly coarse to reflect the broad nature of the investigation. A framework for these indicators could be based on the dimensions of poverty used by the World Bank, as shown in Box 7.1.

7.2.3 Pre-feasibility and SIA

At the pre-feasibility stage it will be clear as to which communities are most affected by the proposed intervention. These are the 'target' groups for more detailed surveys and analysis. The measurement of the benchmark indicators and development of mitigation measures is focused around these groups. Social costs and benefits largely relate to the impact of the transport intervention on these communities.

A socio-economic impact assessment of rural roads needs to cover an exceptionally large array of issues, with a large set of variables to quantify them. Table 14.3 provides a comprehensive list of social benefits and suitable indicators.

7.2.4 Feasibility and SIA

In the final stage of the project planning phase, the feasibility study finds the most suitable road improvement project for addressing the identified transport problem before preliminary engineering designs are developed. Potential social impacts are again forecast from baseline data and further in-depth surveys, including any adverse impacts caused by the road intervention. Mitigation measures are developed in a consultative process between the target groups, the SIA team and the engineering design team. This will involve compromise, as well as additional costs (for the agreed mitigation). Despite mitigation measures, there will still be social costs that need to be estimated for inclusion in the final project analysis.

7.3 CONDUCTING A SOCIAL IMPACT ASSESSMENT

7.3.1 Overview of the social impact assessment process

SIA is a type of social analysis that may be undertaken as part of a project design and is often continued during implementation as part of an evaluation process. An SIA helps to make the project responsive to social development concerns and to ensure that the project objectives are acceptable to the intended beneficiaries. Development initiatives informed by social assessment help to alleviate poverty, enhance inclusion and build ownership while minimizing and compensating for adverse social impacts on the vulnerable and poor. Table 7.3 summarizes the characteristics of SIA and the resources required to conduct SIA in the field.

The World Bank advocates use of a conceptual framework (World Bank, 2003) which comprises:

a. Asking the right question
b. Analyzing stakeholders
c. Understanding transmission channels
d. Assessing institutions
e. Gathering data and information
f. Analyzing impacts
g. Contemplating enhancement and compensation measures
h. Assessing risks
i. Monitoring and evaluating impacts
j. Fostering policy debate and feeding back into policy choice.

***a. Asking the right questions*:** At the country level, identifying the problem statement for analysis is a matter of judgment. It will likely depend on factors such as:

- expected size and direction of the poverty and social impacts
- prominence of the issue in the government's policy agenda
- timing and urgency of the proposed intervention.

The formulation of the key questions for analysis requires an understanding of the underlying problems that the intervention is intended to address, both in the short and the long term. The formulation can be done with a problem diagnosis, which organizes the chain of cause and effect from demand for the intervention, underlying constraints and potential impacts. It is also important to define a

Box 7.1: Effect of transport on key poverty dimensions

Roads can contribute to creating opportunity, facilitating empowerment, and enhancing security as follows:

- Opportunity: better access to markets creates economic opportunities for poor people to sell their labour and products. Better transport infrastructure and services facilitate access to schools and health clinics.
- Empowerment: the presence of roads can empower the poor by facilitating their access to information and their political and social participation by making it easier to hold public consultations in poor communities and making it possible for constituents to get to meeting places and town centres. Better access to government officials may serve the same objective. If roads are designed and implemented with local community involvement, the process may strengthen community capacity overall.
- Security: a reliable road system can enhance security by making it possible to respond better to economic and natural shocks. At the micro level access to transport facilitates job search and can contribute to easier diversification of income, thus reducing vulnerability of households to external shocks. Roads can also improve access to health care facilities, thus making it easier to respond to medical emergencies.

Grootaert (2002)

Tool Name		Social Impact Analysis
What is it?		An analytical framework to identify the range of social impacts and responses to capital road projects by people and institutions, including those that are vulnerable or poor. Often undertaken as pre- and post- impact assessment to forecast potential benefits and disbenefits and measure actual impact.
What can it be used for?		Can be used in all sectors to identify social impacts. In the transport sector it is an increasingly important tool to complement environmental impact assessment (EIA) by addressing the socio-economic effects of the road works as well as the subsequent effects of increased traffic associated with the upgraded road.
What does it tell you?		Provides a socio-economic baseline against which costs and benefits of the road intervention can be measured. Also provides insight into coping mechanisms and social risks, suggestion from stakeholders on most appropriate means to mitigate negative impact of the type of road intervention and potential effectiveness in local context.
Complementary tools:		Used in conjunction with stakeholder analysis. Other tools such as institutional analysis and risk analysis complement and draw heavily on SIA. Also draws on participatory appraisal techniques.
Key elements:		Characterized by use of mixed methods and direct consultation of those potentially affected that can include a wide range of data collection techniques: open-ended community discussion, key informant interviews, focus groups, quantitative survey, observation, ethnographic field research, participatory appraisal. Proper structuring of qualitative methods and interpretation of both qualitative and quantitative research requires sufficient knowledge of local customs and cultures and thus normally requires partnership with local consulting, NGO or research firms. Typically, SIA uses purposive surveys to collect quantitative information from a sample representative of a particular region or beneficiaries of a particular intervention.
Requirements	Data/Information:	(1) The degree of diversity of the groups likely to be affected by the intervention (from the stakeholder analysis) based in part on detailed country level contextual information (cultural, ethnic, regulatory and institutional issues relevant to the reform or affected groups), typically from existing studies, press reports, and key informant interviews. This determines the sampling strategy for fieldwork. (2) Direct data on stakeholder perspectives, typically from field research. (3) Quantitative data typically on income, expenditures, behavioural responses, coping mechanisms or other variables relevant to the intervention to compare with results from qualitative data. Typically, SIA uses purposive surveys to obtain quantitative information relevant to a particular transport intervention expected to have disproportionate impacts on a specific region or known population groups. The sample will then be representative of that region but not nationally representative. This is particularly useful for situations when national household data do not exist or do not contain the specific information needed.
	Time:	SIAs can vary greatly in length depending on the scale of research and the number of sample areas (which will be, in part, a function of the diversity or complexity of the groups involved and the size of the population affected). As this is typically combined with stakeholder analysis, a minimal time for both exercises is approximately 3 person months.
	Skills:	Often requires either a team with mixed skills (in qualitative techniques and in quantitative data collection and analysis, and preferably with someone with sector knowledge), or two teams or individuals working together. The coordination, and iterative analysis of both qualitative or participatory data collection methods and quantitative analysis is paramount.
	Software:	N/A
	Financial cost:	Varies according on the depth and purpose of analysis. A 'mixed methods' SIA costs approximately can cost in the region of US$80-100,000. The pre-intervention baseline study and post-intervention evaluation study may cost more where local capacity is low and needs to be supplemented by international consultants.
Limitations:		Justification for a road capital project will be made on the cost-benefit analysis of alternative interventions. In scenarios where the SIA is not mandatory, nor considered necessary, the socio-economic impacts should be considered as part of the EIA (see Chapter 6).

Adapted from the World Bank (2003b)

Table 7.3: Characteristics of SIA

counterfactual, i.e. what the social and poverty impact of not having the intervention would be (the 'do-nothing' scenario).

***b. Identifying stakeholders*:** Stakeholder analysis identifies the people, groups and organizations that are important to consider when looking at the poverty and social impacts of alternative transport interventions. It describes their characteristics and assesses their interests in relation to the type of intervention. The analysis should examine the following:

- Stakeholders who may be affected by the intervention, positively or negatively
- Stakeholders who may affect the intervention, by supporting or resisting it.

Stakeholder analysis helps to manage the needs and expectations of all stakeholders likely to be involved in the project, thus pre-empting conflict (see Figure 7.3). The principle is that different stakeholder groups are managed according to their level of influence on the project outcomes. Key players are those with a high level of influence and high interest in the project. Conversely, stakeholders which appear to have low influence and power require continuous monitoring in case they oppose any project objectives. These might include pressure groups or NGOs whose influence can grow and become a potential threat. The direct beneficiaries (including poor and vulnerable groups) tend to have a high interest because the road intervention will facilitate their mobility and access to basic services; equally they have low levels of political power or influence in the community decision-making process.

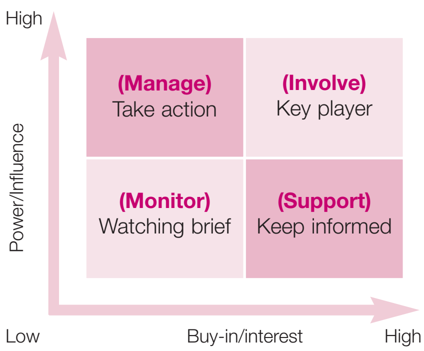

Figure 7.3: Stakeholder analysis diagram

***c. Understanding transmission channels*:** After analyzing stakeholders, SIA identifies the channels through which a particular intervention and subsequent change in transport condition is expected to affect them. The expected impacts of transport change on the welfare of different stakeholders will manifest themselves through various transmission channels, which include:

- Employment
- Prices - production, consumption, and wages
- Access to goods and services
- Assets - physical, natural, social, human, financial
- Migration.

The transmission channels will convey different impacts on stakeholders, depending on the intervention selected. Impacts may differ along two key dimensions. First, impacts can be direct (when they result directly from changes in accessibility brought about by the intervention) or indirect (when they result from the intervention through other channels). Second, the nature of impacts may vary over time, and so will net impacts on various stakeholders.

***d. Assessing institutions*:** Institutions can have a major influence on the decision-making involved in selecting alternative transport projects. Institutions are the formal and informal rules of the game that affect the behaviour and incentives of stakeholders, and are the main arenas in which stakeholders interact with one another. In this regard, SIA needs to consider:

- How institutions and interests mediate the suitability of a road improvement project and its impact on resolving the transport problem
- How the analysis of markets and organizational structures reveals the necessary conditions for the benefits of interventions to reach the poor

***e. Gathering data and information*:** Once the policy issues, stakeholders and likely transmission channels have been identified, the analyst should assess the available data and, if necessary, collect additional data (see Figure 7.4) to determine what type of analysis is feasible and plan future data collection. Four steps are suggested:

- Mapping out desirable data and information for SIA (includes both quantitative and qualitative data)
- Taking stock of available information and prior analyses
- Adapting SIA to data and information limitations ex ante (includes selecting a feasible analytical approach and collecting additional data)
- Planning to prevent limitations in the future (includes developing a strategy for data collection, monitoring and ex-post analysis that builds national capacity for SIA).

***f. Analyzing impacts*:** The choice of approach and tools employed to analyze impacts will depend on the types and importance of the expected impacts (direct and indirect), and the availability of data, time and local capacity.

The methodology selected may include a combination of the following tools:

- Social tools (social impact assessment, participatory poverty assessment, beneficiary assessment, and social capital assessment)
- Direct impact analysis tools (such as average and marginal incidence analysis, poverty mapping, and tools to assess public service delivery)
- Behavioural models (including supply and demand analysis, behavioural incidence analysis, and household models).

For comprehensive and effective impact analysis, the SIA approach advocates the integrated use of both quantitative and qualitative tools and methods.

Figure 7.4: Data collection, India

***g. Contemplating enhancement and compensation measures*:** If the ex-ante analysis reveals adverse effects on the living standards of the poor or other vulnerable groups, the following could be considered:

- An alternative design that includes enhancement or mitigation measures, or a different sequencing of public actions
- Direct compensatory mechanisms that compensate on poverty, equity, or political economy grounds (e.g. in the event of land acquisition and displacement)
- Delay or suspension of the project: if the benefits of the intervention are lower than the costs of mitigating or compensating the poor.

***h. Assessing risks*:** Risk assessment addresses the risk that some of the assumptions underlying the analysis may not be realized. This provides further insights into option choice and design. In addition, when combined with careful monitoring, risk analysis can help anticipate and address major unintended consequences by adjusting the option design during implementation.

There are four main types of risk in SIA:

- Institutional risks: risks that assumptions regarding institutional arrangements and/or organizational performance were incorrect (for instance, unexpected market failure, reform complexity exceeding institutional capacity, vested interests in the agency)
- Political economy risks: risks that groups may block implementation or capture benefits
- Exogenous risks: risks of shocks such as conflict, financial crisis, terms of trade shocks, or natural disaster
- Other country risks: risks of political instability, conflict or social tensions preventing implementation of the road improvement project.

***i. Monitoring and evaluation*:** Monitoring and evaluation play an important role in the analysis of poverty and social impacts of transport interventions. Monitoring impact indicators (and the assumptions underlying the analysis) helps to signal unexpected developments during implementation. Monitoring and evaluation are also central in the promotion of accountability and ownership. In order to enhance their impact, monitoring and evaluation systems are best set up during the initial stages of the project. They should also be integrated with existing systems in order to strengthen national capacity.

***j. Fostering debate and feeding back into choice*:** SIA is an integral element of the dialogue on the country's poverty reduction strategy. Fostering and drawing upon public discussion of policy can be useful at various points of the SIA process. At an early stage, the debate can inform the choice of option for which analysis should be undertaken. During the analysis, discussions can help analyze stakeholders, understand transmission channels, and validate technical impact analysis. Policy debate among stakeholders is also essential to develop consensus, build ownership and to create leverage of social accountability, since it enhances the understanding of the potential poverty and social impacts of the project. Finally, it can also be useful for monitoring and evaluation purposes.

A sensible approach to SIA is both country and context specific, dependent upon available data and capacity as well as the road improvement project under scrutiny. The tools and techniques used for SIA are likely to vary greatly across countries and interventions. However, regardless of the chosen methodology, there are some key components that should be addressed in this kind of analysis. Table 7.3 presents a summary matrix that captures and integrates these key components. The matrix itself can serve as a useful tool during the SIA process.

7.3.2 Summary of Social Impact Assessment Principles

The following principles should structure any SIA:

1. Involve the diverse public. Since SIA is all about determining and addressing the concerns of the public, public involvement is essential. Public involvement should be an active and interactive process, in which members of the public are full participants in the SIA enterprise. It is essential that all potentially affected segments of the public have opportunities to participate. One aspect of social assessment involves determining who the affected segments of the public are, and how they are organized. Public involvement must reach out to groups that do not routinely participate in government decision making because of cultural, linguistic, and economic barriers.

2. Analyze impact equity. A basic part of SIA is to analyze who wins and who loses with each alternative considered. It is especially important to analyze whether an alternative may have high and disproportionate adverse environmental or health effects on a low-income or minority population. Impact equity must be considered in close and sympathetic consultation with affected communities, neighbourhoods, and groups, especially low-income and vulnerable groups (elderly, young, infirm, poor). Analysis should begin during scoping to ensure that important issues are not left out.

3. Focus the assessment. This is a matter of scoping. Scoping during the feasibility study should seek to ascertain what issues are really important to affected communities and groups. The analysis should not focus only on economic issues or demographics.

4. Identify methods and assumptions. The SIA must report the assumptions on which it is based, and describe methods employed.

5. Define significance. An SIA should discuss how the significance of a social variable or an impact is represented. In one case, emphasis may be given to impacts on agricultural land use and life style, while in another it may be given to impacts on small family-owned businesses in the vicinity of the project. There are obviously reasons for regarding one variable as more significant than another in a given case; these reasons need to be made explicit. Similarly, the reasons for considering one kind of impact to be more significant than another must be defined and weighted.

6. Provide feedback to project stakeholders. An SIA should not be something a consultant does in isolation, producing a final deliverable without involvement of the client or the local population. There should be participatory stakeholder consultation throughout the project cycle and, in particular, at the project's inception when stakeholders 'buy-in' is required. There should be active feedback between the SIA contractor, planners and community leaders throughout the assessment and planning processes. These processes should be carefully co-ordinated so that planners can be informed of potential problems and opportunities before it is too late to do anything about them.

7. Use SIA practitioners. Trained social scientists, using appropriate professional methods, will provide the best results. Generally speaking, such practitioners include cultural anthropologists, sociologists, cultural geographers, and members of related professions. However, practitioners of other disciplines (e.g. economics, social history) may be effective social impact analysts if they have the right interests and training.

8. Establish monitoring and mitigation programmes. An SIA should not only provide an analysis of impacts, but also the basis for setting up programmes to mitigate social impacts and monitor how these programmes work.

9. Identify data sources. As a matter of good practice, an SIA should identify the sources upon which the analysis is based. In some cases, community groups may desire confidentiality and such desires should be accommodated to the extent practicable and consistent with law. If confidentiality cannot be guaranteed, informants should be told and given the opportunity not to provide information, or to provide it in abridged form.

In summary, the following should be considered when planning a social impact assessment as part of feasibility studies for capital road projects:

- Identify the target beneficiaries and stakeholders – where has demand for the intervention originated from?
- Gather data and information to identify the access issues affecting local populations and potential impacts of investment alternatives
- Assess the risks of undertaking alternative road projects on the community (i.e. displacement of the population, use of local labour during construction, disbenefits of the road intervention such as increased traffic speed and risk of road traffic accidents etc)
- Conduct the social impact assessment and measure the social benefits of the proposed intervention in conjunction with an environmental impact assessment and cost-benefit analysis.

7.3.3 Reporting and consultation

A detailed schedule of the social assessment activities described in the terms of reference should be prepared describing the types of outputs the social assessment plans to produce. Relevant charts, graphs, statistical and qualitative analysis, along with raw data where appropriate, can be provided in the SIA report. In addition to the outputs of the SIA, a note on the social assessment process itself can be included, stating any difficulties faced by the practitioners conducting the SIA and recommending the most appropriate dissemination strategy for the findings. The analytical report format could be structured as follows:

- Background to the country area and characteristics of provinces, districts and villages to be affected by each investment alternative
- Institutional framework and planning of roads in the area under assessment with perceived (pre-intervention) and actual (post-intervention) impacts described
- Findings from the participatory appraisal and questionnaire analysis
- Recommendations for prioritizing investment alternative(s) based on their relative social impacts on local stakeholders and beneficiaries, and support for a specific road improvement project based on its social costs and benefits, and the implications for poverty reduction objectives.

DETAILED SOURCES OF INFORMATION

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TRL (2004b). *A guide to pro-poor transport appraisal*. Overseas Road Note 22, TRL Ltd, Crowthorne, UK.

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8. Road Safety Design and Audit

8.1 INTRODUCTION AND PURPOSE

Road safety considerations are integral to the project appraisal process:

- At the problem identification stage to measure accident rates
- At the pre-feasibility stage to undertake a safety audit of each design option with estimates of likely accident rates both with and without the intervention
- At the feasibility stage to undertake a comprehensive safety audit of the design work.

Although human failings and road system deficiencies mean that crashes are one of the inevitable costs of road transport, it is well established that highway engineering can have a major role to play in contributing to (and hence preventing) a significant number of crashes that occur (see Box 8.1).

Road safety should be a primary consideration in the design of a road, with the safety engineer taking a strong lead in the identification of potential hazards and techniques for their mitigation. This process could be effected though a road safety audit (see Box 8.2), which should be undertaken by experienced practitioners. The role of the safety auditors (like those of both the environmental and social specialists) is continuous throughout the planning and design stages of a new scheme, working as an integral part of the planning and design team to produce a safe road. Audits prove to be an invaluable safety management tool in providing formalized checking procedures that all aspects of safety have been considered and appropriate provision or amendments made in the current plans to cater for any issues found.

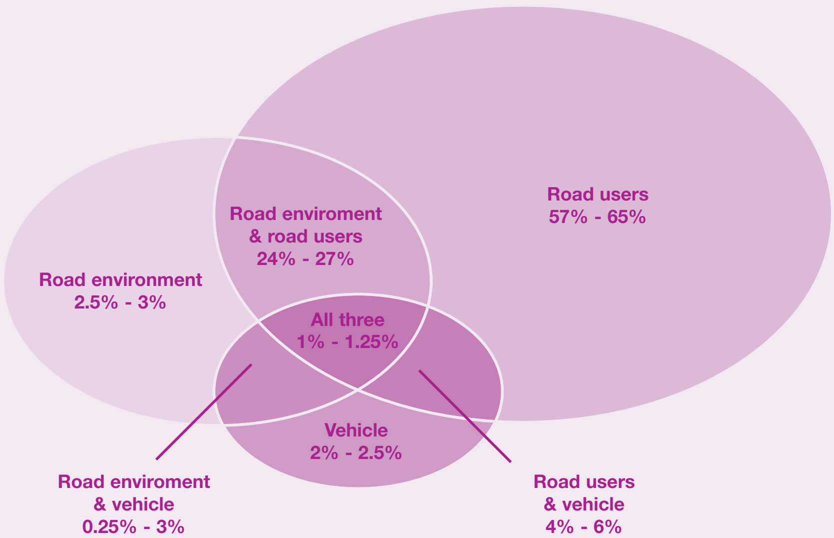
Issues relating to the institutional framework for national road safety, education, enforcement and vehicle engineering approaches to safety improvement fall outside the scope of this Note. It must be appreciated, however, that these factors do interact, and a coordinated approach to road safety at national, regional and local levels is essential. Thus this Note concentrates on the highway engineering aspects of road safety, and the role of the road safety engineer in the feasibility process.

8.2 THE ROAD SAFETY ENGINEER'S ROLE IN THE FEASIBILITY PROCESS

In the feasibility process the road safety engineer, working closely with the other members of the design team, has to identify three main elements:

1. Potential safety hazards and the consequent need for safety features to be included in the road design.
2. The costs associated with the installation of any necessary road safety features (including all associated audit and maintenance costs). Box 8.3 highlights the key elements that might be covered.
3. A forecast of the impact of the road development, with all its associated safety features, on road accidents.

The road safety engineer will also advise the design team on any aspects of traffic



Box 8.1: Contribution of the three main factors in road crashes

This Venn diagram illustrates the typical percentages of the main causation factors involved in road crashes as judged by experts in on-the-spot accident research studies. The areas where the ellipses overlap denote multi-factor causes. In these studies, the road environment and road user was shown to be a factor in about 24% to 27% of crashes, yet this figure can be directly affected by the feasibility study.

Box 8.2: Road Safety Audit

What is a Road Safety Audit?
Road safety audit is a formal, systematic procedure for checking the safety of new road schemes or schemes for the improvement of existing roads. Specific aims are to

- minimize the risk of accidents occurring on the scheme and to minimize their severity
- minimize accidents on adjacent roads, ie. to avoid creating accidents elsewhere on the network
- recognize the importance of safety in highway design in meeting the needs and perceptions of all road users
- reduce the long-term cost of a scheme bearing in mind that unsafe designs will be expensive to correct at a later stage
- improve the awareness of safe design practices by all those involved in the planning, design, construction and maintenance of roads.

What should be audited?
Schemes eligible for audit cover a wide range of different classes of road in both urban and rural areas, including:

- Major highway schemes
- Minor improvements
- Traffic management schemes
- Maintenance works
- Safety improvement schemes

When to audit in the project cycle?

- Appraisal (pre-feasibility, feasibility and preliminary design)
- Final engineering design
- Implementation (pre-opening of the road or scheme)
- Monitoring (post-opening)

Who should audit?
At the appraisal stages, a specialist who is independent of the design team is usually required to undertake the audit, working to a detailed brief provided by the Project Manager/Design Engineer. He or she should have general roads safety engineering experience and should have received recognised road safety engineering training as well as safety audit training.

Checklists
The use of checklists can be a very valuable aid, particularly for those new to the audit process. Examples of these are given in some of the following general references on the subject:-
IHT(1990), AustRoads
(1994), TMS Consultancy (2001), HA (2003).

Box 8.3: Road scheme safety elements for economic appraisal

Capital cost. The additional costs of specific road safety features factored into the road design. If the implementation is expected to span two or more financial years then the annual breakdown of expenditure is also required. It should also include the cost of carrying out road safety audits at the appropriate stages of design and implementation.

Annual maintenance and operating costs. An estimate is also required of the expected regular maintenance required due to the type of road safety feature installed; for example, simple kerb line alterations will probably not require maintenance, whereas roundabouts may do (particularly if their centre is landscaped) and traffic signals certainly incur regular maintenance costs.

Service life of scheme. For the economic appraisal, account should also be taken of how long the installation is likely to last; that is, before major rehabilitation or replacement is necessary.

Terminal salvage value. It is possible that some safety features or countermeasures may have a residual value if they are removed, e.g. if a junction is temporarily signalized for a number of years until a by-pass is completed and, after completion, lower subsequent traffic flows mean that the signals can be removed. If the signal system could be used elsewhere then the recovery of this cost should strictly be taken into account in the calculation; however, in most cases, any residual value is likely to be negligible.

Estimate of any disbenefits. Some accident countermeasures will inevitably produce secondary effects on traffic movement, which could be considered as negative effects. For example, road closures necessitate drivers choosing alternative routes and speed reducing measures may incur penalties in terms of increases in journey time, fuel consumption and emissions. The additional costs associated with these should strictly be calculated and deducted from the benefits due to the scheme.

management that have safety implications. This will be most important in the design of roads in urban areas where traffic management techniques may be extensively deployed in association with the design of the road improvement.

8.3 ENGINEERING SAFETY MEASURES

The road engineering factors in road safety can be broken down into six categories:

- Geometric design
- Road surfaces
- Road markings and delineation
- Road signs, streetlights and other road furniture
- Traffic calming measures
- Traffic management.

These factors may be further categorized into either of the two approaches to improving safety, that is:

- Accident prevention, in which improved and appropriate standards of highway design and planning are applied to new or upgraded roads
- Accident reduction, in which problems on the existing road network are dealt with by means of in-depth investigation and implementing (normally low-cost) engineering counter measures to improve the safety of specific sites.

8.3.1 Accident prevention through highway design

There are a number of principle design measures that can be used in the prevention of road traffic accidents on rural and urban roads which can be summarized as follows:

- Footpath – separating pedestrians from the carriageway
- Wide road shoulders – to allow drivers to stop safely at the road side
- Increased carriageway width
- Correct road gradient and curvature – to lessen the risk of collision
- Appropriate pedestrian crossings – comprising refuge islands, zebra and pelican crossings
- High skid resistant surfacing
- Separate lanes for two wheeled vehicles
- Appropriate street lighting – with frangible columns that collapse on impact

These are discussed in turn for rural and urban roads.

Rural Roads. Traffic flow is the most important determinant of the number of all accident types. Segregating pedestrians from traffic through the introduction of a separate footpath is a most effective measure for reducing pedestrian casualties. When included in new construction, this can produce first year rates of return in excess of 200% (see Chapter 15). The cost-effectiveness (and hence the rate of return) is reduced significantly if this safety feature is introduced as a post-construction countermeasure.

The width of the road shoulder is another design feature which can have a significant effect on safety. Wide shoulders (which, ideally, should be sealed) not only provide an escape area for drivers needing to take evasive action to avoid a collision but also tend to be preferred by pedestrians to the alternative of walking close to fast-moving traffic. For this segregation to be encouraged, shoulders need to be kept in good condition and vegetation kept well under control. Reduced accident rates tend to be produced with wider shoulders up to an optimum width of 1.5m. Surprisingly, increasing shoulder width beyond 1.5m often increases accidents. This may be because wider shoulders are often associated with different land use involving increased pedestrian and other road user activity.

Increasing the width of the carriageway also reduces accident rate. Thus for example, if the carriageway width and shoulder width (in excess of 1.5m) are increased by, say, 0.5m the *net* effect is a reduction in accident rate.

Safety studies have confirmed that a reduction in the severity of accidents involving errant vehicles is achievable by ensuring a maximum side slope of 1:4.5 and/or increasing the recovery area adjacent to the carriageway.

Other variables such as gradient and curvature are also important, with the risk of collision increasing as these features increase in severity (see Chapter 10). Where steep gradients or sharp curves cannot be avoided owing to difficult terrain and particularly if, for example, a sharp bend occurs after a long straight section, warning signs should be correctly designed and sited to alert drivers from their perceptual inertia. Crash control devices like guard rails (crash barriers) should also, ideally, be included in the design.

Urban Roads. In urban areas, where speeds are usually lower than in rural areas, the accidents resulting in the most severe injuries tend to involve the vulnerable road user groups. Collisions between vehicles and pedestrians in urban areas tend to occur chiefly as the pedestrian is crossing the road. The task of crossing the road is often quite difficult, especially where city traffic volumes are high, and particularly where streets are very wide (e.g. 15m) with multi-lane traffic streams where the pedestrian has to make a decision about what constitutes a ‘safe gap’ in order to cross.

Ways of making the road-crossing task easier must be considered and it is usually recommended that pedestrians are channeled to cross at designated crossing points. The decision over choice of crossing to install, i.e. whether by refuge islands (see Figure 8.1), zebra crossing or signalized (pelican) crossings, is dependent on traffic level and pedestrian use (e.g. TRL, 1994). However, in choosing a signalized crossing, the engineer needs to be aware of the high costs of the installation and maintenance of signals as well as the likely level of compliance to the signals by both drivers and pedestrians.

Care should be taken with the siting of pedestrian crossings to try to ensure that they are located where most pedestrians are currently choosing to cross. Also, when installed, drivers’ attention needs to be drawn to these locations. Pedestrians who cross elsewhere can often be at greater risk therefore it may thus be necessary to prevent this by physical means, i.e. by physical barriers, though it is important to ensure that such barriers do not inhibit drivers’ ability to see clearly.

It is good practice to lay high skid-resistant surfacing on the vehicle approaches to a crossing, the length depending upon the approach speed of vehicles and collision potential. Similarly the need for advanced warning signs for a crossing also depends on approach speed. Drivers must be able to see pedestrians clearly and visibility must not be obscured by street furniture. As a guide, for 85th percentile speeds of 50km/h the desirable minimum visibility distance should be 65m; for 70km/h the minimum visibility should be at least 100m.

Figure 8.1: Pedestrian refuge design, Nepal

Note: Low height and sloping profile of edge kerbing to avoid adverse effects of night time collisions

If the criterion for a crossing cannot be met, the use of pedestrian refuges can improve safety by:

- Splitting the pedestrian's gap acceptance decision into two parts namely judging an appropriate gap in only one direction of traffic at a time,
- Having a psychological effect on drivers, making them slow slightly or at least be more wary.

Although the recommended minimum width for a refuge is often 1.2m, this should be related to actual use at peak times. Also, where handcarts or wheelchairs are likely, the refuge should be at least 2m wide.

Two-wheel users (cyclists and motorcyclists) are another vulnerable road user group. Generally, the best way to deal with this group is to segregate them from heavier traffic in some way. The construction of completely separate lanes for two-wheelers is, however, likely to involve high cost but it is possible that, if roads are wide enough, simply painting a solid line as a cycle lane marker can provide a significantly safer environment.

Figure 8.2: Cycle lane treatment on minor arm of a T-junction, UK

The main difficulty with special cycle lanes tends to be how best to deal with them at junctions (see Figure 8.2). It is generally advised that the lane is designed to deviate away from the actual junction mouth so that emerging motorists cross the cycle lane before having to make decisions on gaps in the heavier traffic streams.

Shared pedestrian/cycle ways should be divided by means of a (raised) line and surface marking to designate clearly which side is for cyclists. The width of these special lanes needs to be decided on the basis of use (i.e. number of motorcyclists, cyclists, rickshaws, carts etc.) and whether the lane is to be used as one or two-way. As a guide, cycle tracks along the carriageway should be 2-3m wide on both sides of the road.

If designated motorcycle lanes are being constructed, it is important to design the lanes to high standards (particularly junction design and sight distance at bends) otherwise relatively high numbers of motorcycle collisions are still likely to occur. Again, if such separated bicycle/footways are constructed to the side of roads, it is important to ensure that the surface is constructed and maintained to a high standard. If they are not, cyclists and pedestrians will still tend to choose to use the road where their risk of being struck by a vehicle is obviously greater.

Medians are usually installed on multi-lane highways where speeds are relatively high, but drivers will make U-turns wherever there is a break in that median. The U-turn is unfortunately a relatively slow manoeuvre where the chances of conflicts (and hence collisions) are high. The basic design philosophy should be to minimize gaps in the median. Drivers wishing to make a U-turn would then have to do so further downstream at an existing (or new) roundabout or a crossroads where side roads can be used to help drivers re-join the preferred major road direction safely.

Many collisions occur during the hours of darkness where drivers' vision is impaired and the effect of alcohol, i.e. drinking and driving, is likely to be more prevalent. The situation for vulnerable road users is thus more hazardous during this time as they are much harder to see, particularly if they are not wearing light-coloured clothing. Street lighting, although expensive, is generally regarded as creating a much safer environment in terms of both road safety and security. However, street lighting should be designed to a high standard otherwise variable lighting and deep shadows can be produced creating their own safety problems. Lighting columns and wall or other mounted fittings need to be resistant to vandalism and be in positions that minimize the risk of damage by vehicles. Lighting columns should also be frangible to minimize injury to occupants

Figure 8.3: Frangible lamp post after vehicle collision, Australia

Source: AustRoads (1994)

when vehicles collide with them and located away from busy pedestrian areas (see Figure 8.3).

At urban junctions collisions involving turning or crossing vehicles are usually the most common type of accident, and right-angle collisions can result in very serious injury. The geometry of both major and minor roads can have a great impact on safety and generally the shape of a junction should be made as simple as possible. Complicated junctions with large numbers of turning lanes increase the possibility of incorrect manoeuvres, and wide empty areas encourage drivers to take shortcuts and increase the accident risk. Drivers emerging from the minor road at a priority junction must have adequate visibility (in both directions on a two-way undivided road). Channelization physically separates the traffic streams and guides vehicle movements, alerting drivers to the junction ahead. It can also help pedestrians to cross the carriageway. Raised islands are likely to be more effective than road markings or 'ghost' islands but they can be a hazard at night time (i.e. they should also be well marked with reflective paint and signs to minimize the risk of collision).

Roundabouts generally have a good safety record when compared with priority junctions or signalized junctions. Conversion of a hazardous priority junction to a roundabout may provide a good countermeasure since the approach speeds of vehicles on all arms, including the major road, are slowed. Roundabouts with more than four arms are generally not desirable owing to possible driver confusion, and the larger roundabout size will permit higher circulating speeds.

At signalized junctions at least two signals should be visible from each approach and duplicate signals may be necessary either at low level (for drivers waiting close to the signal) or high-mounted on poles. The latter is perhaps of most use for multi-lane approaches where there is a risk of obscuration by traffic. The use of high intensity signal aspects, or yellow backing boards around the signal heads, and median islands all help to draw drivers' attention to the signal. It is also important that the road surface on the approach to the signals on each arm of the junction is kept in good repair and has a high skid resistance value.

8.3.2 Accident reduction through low-cost countermeasures

The combination of detailed local accident investigation with relatively low cost engineering remedial measures, can be highly cost-effective. Driver behaviour and knowledge are poorer in developing countries than in industrialized countries, so engineering measures that are 'self enforcing', such as median barriers, guard rails, pedestrian segregation, etc. can be effective, whilst measures such as improved signs, road markings and speed limits may be less so unless coupled with improved enforcement techniques.

The following low-cost design measures can be used in the prevention of road traffic accidents on rural and urban roads, and are summarized as follows:

- Village 'gateway' comprising chicanes, road narrowing or rumble areas – to notify the driver of a change in speed and approaching built up area
- Bus lay-bys – to protect alighting passengers
- Raised pedestrian crossings – to slow traffic
- Cushioning of street furniture – to absorb energy dissipated on impact by a vehicle
- Improved warning signs and road markings at road bends or where bridges are located

These are discussed in turn for rural and urban roads.

Rural Roads. Pedestrian accidents are a major problem on rural roads. Most occur where major roads pass through rural villages or settlements. Conflict occurs because pedestrian activity is high, and drivers do not reduce their vehicle speed as they pass through the village.

Indeed, major rural road links built to fairly high standards tend to encourage high vehicle speeds. It is important to provide physical means of indicating to the driver the change in road nature as a village is entered. A gateway can be provided, like the one shown in Figure 8.4. This is highly visible and reminds drivers of the lower speed limit through the village.

There are many types of traffic calming measures such as chicanes or road narrowing (with a combination of raised kerbs and hatch markings), which can be used on rural roads in appropriate places to discourage high speeds and make a safer environment for pedestrians. However, any raised speed reducing device or sudden deviation from the natural road path needs to be well lit to avoid night time collisions. Devices such as road humps are not recommended for potentially high speed approaches into villages: rumble areas (see Figure 8.5) or transverse bar line markings (which can nowadays be slightly raised above the road surface) are preferred.

Many of the countermeasures discussed above to improve the road environment for pedestrians also apply to two-wheeled and non-motorized vehicles.
In particular, wide sealed shoulders can be used by these vehicles and, indeed, could be marked by signs and surface markings to encourage this. Care is needed, however, in the way segregated 'lanes' are handled at junctions. Edge lines are particularly useful for two-wheeler riders to distinguish edge of carriageway at night time if visibility is poor or the rider is 'blinded' by oncoming headlights.

Bus stops on rural roads often have poor safety records. This may be a result of poor siting of the stop (e.g. after a sharp bend with relatively poor visibility for approaching drivers), or where there is little or no provision for bus parking such that drivers stop in the carriageway. There is usually more pedestrian movement in the vicinity of bus stops and thus greater chance of pedestrian accidents. Wherever possible bus lay-bys should be provided which have adequate length and width for buses to pull in off the carriageway and adequate space for waiting passengers to queue without using the road or bus pull-in area. The lay-bys should be positioned on straight, level sections of road clearly visible from both directions. Bus stops on each side of the road should be sited offset downstream from each other such that alighting passengers wishing to connect quickly with a bus in the opposite direction will tend to cross behind the waiting bus. In these situations safety is also improved by:

- Improving the visibility for pedestrians crossing the road
- Highlighting the presence of crossing pedestrians to approaching drivers from the same direction as the waiting bus.

Figure 8.4: Gateway into village, UK

Figure 8.5: Rumble areas on entry to village, Indonesia

Figure 8.6: Raised zebra crossing, Pakistan

Figure 8.7: Crash cushion, China

Urban Roads. Many of the features mentioned above under '*design* considerations in urban areas' could be applied as accident *countermeasures* e.g. pedestrian crossing facilities, particularly raised crossings and refuges. Raised crossings (Figure 8.6) have the advantage that they become the slowest points on the road for vehicle traffic, such that drivers' attention is focused on the hump ahead. Also, by needing to slow down for their own comfort, drivers are more likely to be aware of (and give way to) pedestrians about to cross.

Where both traffic and pedestrian flows are so high that a pedestrian footbridge can be justified, then this must be made as easy to use as possible in order to attract pedestrians to cross at this point (e.g. consider use of ramps rather than steps with an overhead cover for protection against the weather), and the use of pedestrian barriers may also be necessary. In busy city streets linking shopping malls at first floor level can be a useful way of encouraging more pedestrians to cross here rather than at street level.

Driver error, where the driver fails to take evasive action, is a major factor in single vehicle accidents. It is difficult to devise ways of preventing such accidents other than by surface treatment or traffic calming features generally designed to reduce speeds.

The engineer has an important role to play in making the road environment as 'forgiving' as possible. This normally means accepting that accidents will occur but ensuring that the energy dissipated on impact is spread over as long a time span as possible and, preferably, absorbed more by the object struck so that any human injuries are minimized. Street furniture should be set back from the edge of the road at a minimum of 1m for a design speed of 50km/h. Solid objects should be cushioned where there is any chance of them being hit by a vehicle.

Where a bend in the road or a bridge has a single vehicle accident problem and it is not economic to change the geometric design, then warning signs, road markings and the use of guard rails or crash cushions (Figure 8.7) should be introduced. It is also worth investigating whether more accidents than expected are occurring at night time or during wet weather conditions, possibly revealing a need for specific improvements to provide for these conditions.

8.4 FORECASTING ACCIDENT REDUCTIONS

For project appraisal purposes it is necessary to estimate the likely change in accidents that may be expected following a road improvement. Table 8.1 presents a range of percentage reductions for a variety of engineering design improvements and accident countermeasures. The figures come from many different countries and should be taken as indicative if no local accident database is available. It should also be noted that where an accident countermeasure is an integral part of an overall site improvement, it will be difficult to isolate the effects of the particular countermeasure from the effects of the other improvements i.e. if several types of measure are introduced at a site or area then the individual expected percentage reductions in casualties cannot be aggregated.

Road feature	Accident category*	Percentage reduction in accidents
Road standard		
Improve to higher standard	I	19-33
Increase no. of lanes	I	22-32
Horizontal alignment		
Improved geometry	T	20-80
Curvature: improving radius	I	33-50
Vertical alignment		
Gradient / removing crest	T	12-56
Superelevation improvement/introduction	T	50
Passing lane	I	11-43
Climbing Lane	T	10-40
Road structure		
Lane widening	T	12-47
Skid resistance improvement	T	18-74
Shoulder widening	T	10-40
Shoulder sealed	T	22-50
Road verge widening	T	13-44
Junction design		
Staggered (from straight) crossroads	I	40-95
T-junctions (from Y-junctions)_	T	15-50
Roundabouts (from uncontrolled)	T	25-81
Roundabouts (from traffic signals)	T	25-50
Mini roundabouts (from uncontrolled)	T	40-47
Turning lanes	T	10-60
Traffic islands	T	39
Traffic control		
Regulatory signs at junctions	T	22-48
Guidance/directional signs at junction	T	14-58
Overhead lane signs	T	15
Side road signs	T	19-24
Brighter signs and markings	T	24-92
Signs and delineation	T	29-37
Bend warning signs	T	20-57
Stop ahead sign	T	47
Speed advisory sign	T	23-36
Speed limit lowering - & sign	I	16-19
Yield/Give Way	T	59-80
Stop sign	T	33-90
Signals from uncontrolled	T	15-32
Signals - modified	T	13-85
Junction channelization	T	10-51

Road feature	Accident category*	Percentage reduction in accidents
Visibility		
Lane markings	T	14-19
Edge markings	T	8-35
Yellow bar markings	T	24-52
Raised reflective pavement marking	T	6-18
Delineator posts	T	2-47
Flashing beacons	T	5-75
Lighting installations	T	6-75
Sightline distance improvement	T	28
Channelization medians	T	22-50
Crash amelioration		
Median barrier	T	14-27
Side barriers	T	15-60
Frangible signs	I	30
Pedestrian facilities		
Pedestrian walkways	T	33-44
Pedestrian zebra crossings	T	13-34
Pelican crossings	T	21-83
Pedestrian refuges	T	56-87
Footbridges	T	39-90
Cycling facilities		
Cycle schemes	T	35-56
Marked cycle crossing at signals	T	10-15
Cyclist advanced stop line at junctions	T	35
Traffic calming		
30km/h zones (incs. humps, chicanes etc.)	T	10-80
Rumble strips	T	27-50
Rail crossings		
Flashing signals	I	73-91
Automatic gates	I	81-93

*I = Injury accidents
T = Total accidents

Table 8.1: Results from review of accident counter measures research

DETAILED SOURCES OF INFORMATION

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PART 3

Engineering Design

9. Pavement Design

9.1 INTRODUCTION AND SCOPE

9.1.1 Type of project

The majority of road projects will consist of some kind of maintenance, rehabilitation/renewal, upgrading or reconstruction rather than new construction. This is particularly so for projects for principal roads but even for ‘new’ low volume rural road projects there will often be a track of some kind in existence already. Nevertheless the terminology and the engineering principles are largely the same and both types of project are covered in this chapter.

The structural or pavement design of a 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, and this is essentially the output of the structural design process.

9.1.2 Structural classification

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.

The aims in designing a pavement are to protect the natural ground (i.e. the subgrade) from the high and concentrated load stresses that, without the pavement, would be applied directly to the subgrade by the wheels of vehicles. At the same time it is also necessary to ensure that the layers of the pavement itself are strong enough to support the traffic loads. Since the imposed load stresses are higher nearer to the wheel (and therefore to the road surface) the traditional type of construction consists of various layers of material with the weakest (cheapest) layer at the bottom and the strongest layer (likely to be the most expensive) at the top.

There are various ways of describing the pavement layers and this has often led to confusion. Figure 9.1 illustrates the most common method. The most important layers are the surface layers and the roadbase since these need to be the strongest.

9.1.3 Earth Roads

Earth roads have no added pavement and are therefore not *structurally* designed. Their performance depends very strongly on their cross-sectional shape (Figure 9.2) (Chapter 10), material properties, location in the terrain (Chapter 5) and the drainage facilities incorporated in the design (Chapter 11). 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 gravelling and improvements to provide all-weather access where appropriate. The engineering aspects of earth roads are not discussed further.

9.1.4 Gravel Roads

Roads may be surfaced with gravel to provide traction for vehicles in wet weather. Surfacing with gravel also retards the increase in deformation of the surface, but regular reshaping is needed as part of routine maintenance activities. Even when badly deformed, gravel roads can normally carry traffic successfully because drivers try to avoid deforme

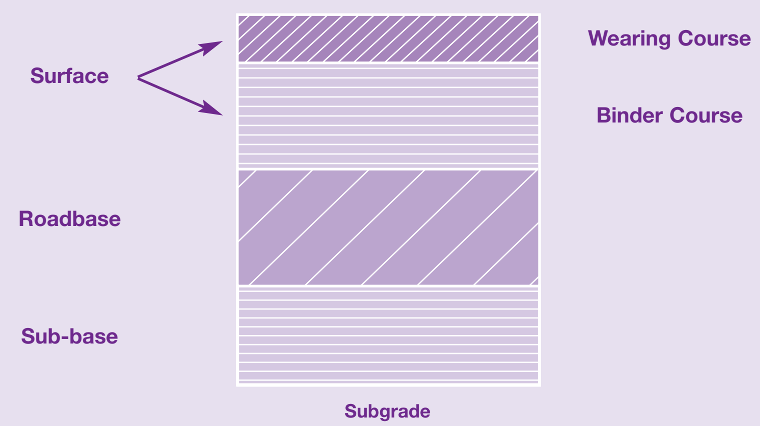

Figure 9.1: Pavement layer description

Figure 9.2: Well shaped earth road

areas by choosing different wheel-paths, but vehicle operating costs will be increased considerably as gravel roads deteriorate. Compared with earth roads, gravel roads generally have properly designed (and built) drainage structures and are usually able to provide all-weather instead of seasonal access.

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, 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 for every 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 e.g. Tables 3 and 4 of Overseas Road Note 2 (TRL, 1985).

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 seal on the road surface (e.g. a surface dressing). Considerable information is available on the performance of gravel roads under a variety of conditions. Using road investment models (Chapter 15) it is possible to estimate the total transport costs associated with a gravel road, including, vehicle operating costs, maintenance costs and re-gravelling costs, under a variety of traffic, climatic and maintenance conditions.

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 25-500 vehicles per day. In recent years it has been apparent that gravel is becoming scarce in many areas and, taken together with environmental, social and sustainability considerations, it has been found justifiable to provide a bituminous surface (or other 'bound' surfacing) at considerably lower traffic levels than previously. It is not possible to give general guidelines for this and each case must be studied individually on its merits with the help of an investment model.

As with earth roads, the performance of gravel roads depends very strongly on their positioning in the terrain (Chapter 5), their cross-sectional shape (Chapter 10) and the adequacy of drainage facilities (Chapter 11). The engineering aspects of gravel roads will not be discussed further.

9.1.5 Choice of paved road construction type

Where a paved road is necessary, there are two basic types of construction that can be used namely flexible and rigid. In the past, flexible pavements with an asphalt surfacing have normally been used in most tropical countries. However, there are wide differences in the relative price of bitumen and cement and so the cost of using rigid pavements constructed with Portland cement concrete can sometimes be favourable (Figure 9.3), particularly in those countries that import bitumen but manufacture their own cement. The choice between flexible and rigid pavements should be made on considerations of the likely cost of construction and maintenance, the pavement life and effect on road user costs.

9.1.6 Rigid pavements

The potential for building in concrete should always be considered in feasibility studies. 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 and this might be particularly attractive for countries experiencing difficulties maintaining their road network to an economic standard. 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 (Figure 9.3).

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

Figure 9.3: A typical rigid concrete road in the Philippines

introduction of concrete technology in the road building sector can also do much to develop local skills and offers scope for fostering local contracting industries.

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 concrete road that has deteriorated badly 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.
No design methods have been produced for concrete roads *specifically* from research in and for developing countries in the tropics although several such countries have built extensive networks of concrete roads. Design methods that are applicable include AASHTO (1993), CPCA (1984) or the TRL (Mayhew and Harding, 1987) methods. In practice it is in the rehabilitation/renewal/upgrading of concrete roads that the main differences are likely to lie.

9.2 FLEXIBLE PAVEMENT MATERIALS

9.2.1 Thin surfacings

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 underlying structural layers.

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.

Surface dressing (or spray and chip).
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 (Figure 9.4). 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 thin surfacings.
Surfacings that fulfil a similar function to that of a surface dressing, namely to simply waterproof the road surface, are sand seals (sand plus bitumen), slurry seals (graded fine aggregate or sand plus bitumen emulsion), a combination of slurry seal and surface dressing (often called a Cape seal), and Otta seals (gravel aggregate and bitumen).

9.2.2 Structural surfacings

There are many types of surfacings which, as well as providing the waterproofing function, also provide substantial structural strength to a pavement. These consist of precisely defined mixtures of bitumen, coarse aggregate, fine aggregate, sand, and fine material (called filler). To make them properly, it is usually necessary to mix the constituents in specialized 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 to act mainly as an extender. HRA is slightly 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, as described in Overseas Road Note 19 (TRL, 2002). Provided that suitable sand is available, the use of HRA should be encouraged since it is resistant to cracking and therefore provides a more resilient waterproof surfacing than other mix types.

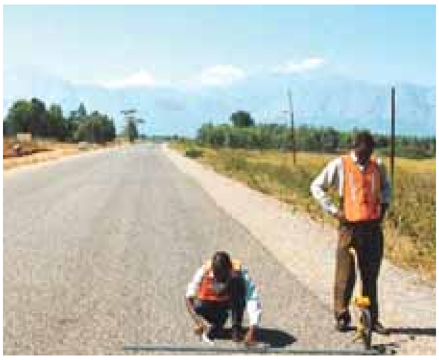

Figure 9.4: A good surface dressing

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 the 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 more brittle than HRA and liable to crack under heavy traffic loads, allowing water to penetrate the roadbase.

Bitumen macadams.
These mixes are similar to AC, differing slightly in the allowable range of particle sizes and 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 a binder course (i.e. lower layer of a surfacing) or as a roadbase (see Figure 9.1) and in other situations where their permeability is of no consequence e.g. regulating courses under strengthening overlays on roads which have deformed excessively.

Stone mastic asphalt.
This surfacing is designed to reduce the risk of deformation by making sure there are adequate voids in the mix when fully compacted by heavy traffic and also to provide good durability by incorporating plenty of bitumen. The bitumen often contains a modifier to improve its properties.

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 generally recommended for main roads but labour-based construction for lower volume roads can be cost effective in appropriate circumstances and should be seriously considered.

Discrete element surfacings.
Surfacings comprising concrete blocks, bricks, hand-packed stone, cobbles and the like can sometimes be appropriate in certain circumstances. Each situation will need to be assessed on its merits.

Proprietary thin surfaces.
In recent years a range of new proprietary surfacings have become available. Because they are proprietary products, their precise composition is unknown but many of them include

modified binders to improve performance. They are designed to replace the top 25-50mm of an existing surface that may be cracked or becoming deformed. They are normally more expensive than conventional materials but may last much longer. Each product should be tested locally to assess its likely cost and benefit.

9.2.3 Roadbases

The roadbase is generally the main structural element of a road. Roadbase 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 contain little or no clay. The most common type of unbound base is graded crushed stone, or 'wet mix' (Figure 9.5). Other types of unbound aggregate roadbase, such as dry-bound macadam and water-bound macadam, are frequently encountered. Despite their names, these are unbound materials; the names reflect the way that they are constructed and this, in turn, affects the exact combination of particle sizes from which they are formed.

Cement or lime stabilized 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 stabilization as clay minerals are necessary in the soil for the stabilization reaction to occur. For both cement and lime stabilization to be effective, the material to be stabilized should not be too uniform in size and should be free from organic matter.


Figure 9.5: Good quality crushed stone is the most common form of roadbase

Bitumen stabilized bases.
Bitumen stabilization is rarely used for lower grade aggregates in roadbases because other alternatives are usually cheaper and more reliable. If bitumen is used in roadbases 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, sand stabilized with bitumen is an alternative which can be used successfully for moderate traffic.

9.2.4 Sub-bases and other pavement layers.

The quality of material used for sub-base does not need to be as high as for roadbases. 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 stabilized 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.

9.2.5 Use of materials of marginal quality.

Specifications for pavement materials used in developing countries have often been copied from those used in the more industrialized 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. The results of international research and also local experience shows that, for some materials and for specific situations, standard specifications can often be relaxed to make use of materials that are marginal in quality according to the adopted specifications, but are abundant and relatively cheap to use (SADC Guide-lines, 2003). The need to do this will be dictated by a lack of conventional materials or a need to build a lower cost road.

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.

The use of marginal materials often requires a greater degree of control during construction and, in some circumstances, the rate of road deterioration may be higher, but there are many successful projects that have made use of such materials and the research documentation for their use is substantial. These materials should always be considered when carrying out pavement design in situations where their use is economic.

9.3 FACTORS AFFECTING FLEXIBLE PAVEMENT DESIGN

9.3.1 Introduction

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

- Strength of the subgrade
- Traffic loading
- Properties of the materials
- Variability and uncertainty in the above three items and in the quality control of the construction process.

It is important to understand that a road is only as good as its *weakest* part and so the designer is only interested in the weakest few per cent. This is well illustrated by the simple fact that a pot-hole every 20 metres is a very poor road indeed but the area covered by such pot-holes is likely to be only about 0.5% of the total surface area.

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.

9.3.2 Strength of the subgrade

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, therefore some care is often needed in assessing its value. 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 Overseas Road Note 31 (TRL, 1993).

9.3.3 Traffic loading

The second important factor to influence pavement thickness is traffic loading (Box 9.1). 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 axles, referred to as standard axles, using Equation 9.1. Multiple axles are treated as separate axles for this purpose.

Box 9.1: The importance of an axle load surveys

One of the most common causes of premature pavement failure is incorrect estimates of traffic loading. Overloading is common in most (if not all) developing countries and therefore very large errors are likely to occur if it is assumed legal axle load limits are upheld. It is also unwise to assume that axle loads on all roads in a country are similar. It is therefore essential to carry out independent axle load surveys when planning paved road projects.

$$\frac{D_L}{D_{80}} = \left(\frac{L}{80}\right)^{4.5} \qquad \text{Equation 9.1}$$

where D_L/D_{80} = the ratio of damage created by an axle load of L kN to that created by the standard load of 80 kN
= the number of equivalent standard axles for axle load L kN.

The equation 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 130 kN axle causes as much damage as the passage of nine 80 kN axles.

Guidance on how to carry out axle load surveys is given in Overseas Road Note 40 (TRL, 2004). 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.

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.

9.3.4 Materials

The third factor which influences pavement thickness is the choice of materials for the construction of the pavement layers themselves. This becomes particularly 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 that are available take this into account, but the subject is complex and specialist engineering advice should be sought.

9.3.5 Variability and uncertainty

It is essential that, as far as is possible, the design takes account of inherent variability in the materials used for construction, variability induced by the construction process itself, uncertainties associated with climate (in particular, rainfall and depth of water table), and uncertainties in future vehicle axle loadings and traffic flow levels.

Subgrade strength.
The subgrade strength normally varies both along the road alignment, from season to season and from year-to-year. Allowing for this in the design process is absolutely vital. Soil properties can change within a few metres, but it is quite impracticable 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 localized 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.

The variation of subgrade strength with time also needs to be taken into account.

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. Alternatively, if there is an existing road that has been built on the same subgrade in the area of the project, the strength of the subgrade can be measured underneath this road under the most likely adverse conditions (i.e. at or near the end of the rainy season). This will provide the best estimate of subgrade strength for design purposes.

Problems arise when road maintenance is very poor. The ingress of water through damaged or aged surfaces and shoulders, and the retention of this water through poor maintenance of the drainage systems, or poor choice of materials for the pavement layers, can have a drastic effect on the strength of the layers and their subsequent performance. It is not possible to compensate adequately for such effects by means of more conservative designs, although some designs are more tolerant than others to this problem.

Materials.
Additional problems of variability arise with the aggregates chosen for roadbases 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 to ensure that all materials are within specification, problems are inevitable (see Chapter 5). Lack of sufficient testing is likely to give rise to disputes during the construction phase, often with serious financial consequences.

The behaviour or performance of a road is complex and depends on many factors. As a consequence, it is often difficult to evaluate the effects of deviations from the specifications for the materials and so it is prudent to allow no deviations. Exceptions arise for some types of material of ‘marginal’ quality, as discussed Section 9.2.5, where these have been evaluated by means of reliable research programmes and appropriate specifications for their use drawn up and included in national standards or published by a reliable source. 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 such ‘approved’ marginal materials.

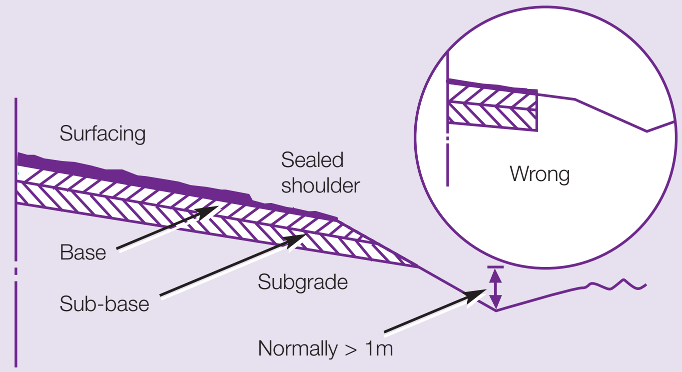

Figure 9.6: Drainage of pavement layers

Construction control.
The construction process itself is seldom as well-controlled as expected or desired. For example, 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, despite large uncertainties in traffic forecasts, small increases in thickness should ensure that the road carries the traffic satisfactorily provided that the natural variations in thickness arising from the construction process are properly accounted for in the design.

Sources of variability arise in all aspects of the construction process and some are inherently more serious than others, for example, the mix proportions of premixed bituminous materials and the degree of roadbase compaction achieved transversely across the road. Specifications should be set in such a way that only a very small proportion of test results are allowed to fall below the desired levels. Fortunately most specifications are set this way but they need to be enforced during construction.

9.3.6 Shoulders

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 1.5 metres wide. Narrower shoulders are acceptable for roads with bound bases (but see Chapter 10). 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.

9.3.7 Drainage of pavement layers

Good drainage is crucial to the performance of roads and either influences, or is influenced by, the structural design of the pavement itself, the geometric design of the roadway (Chapter 10), the design of culverts, bridges and water crossings (Chapter 12). Chapter 11 is specifically concerned with drainage.

Drainage within the pavement layers themselves is an essential element of structural design because 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, then 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, either by extending a permeable pavement layer right through the shoulder as indicated in Figure 9.6, or by including a permeable layer within the shoulder.

9.4 PREPARATION AND CHECKING OF FLEXIBLE PAVEMENT DESIGNS

9.4.1 Collection of information

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.

For most projects, a pavement design life equivalent to 15 or 20 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.

Information from the traffic and axle load surveys (Chapter 4) 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 (Chapter 5) 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.

9.4.2 Choice of design method

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 tropical and sub-tropical countries can pose serious problems.

Considerable advances have been made in the theoretical understanding of pavement behaviour and 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. However, in the meantime no roads administration will accept such designs until they have been empirically calibrated and verified through local research and demonstration trials.

9.4.3 Differences in structural designs using different methods

The mechanisms of deterioration of flexible pavements in tropical countries are often quite different to those in temperate climates. In addition, structural designs obtained by using different design methods usually differ quite significantly; total thickness variations exceeding 100 percent are common and, for heavily trafficked roads, even larger differences can occur. There are various reasons for this. Firstly, each *type* of structure behaves differently and therefore the same thickness design would not be expected to apply. Secondly, the assumed terminal conditions (i.e. the level of deterioration that is deemed to represent 'failure') which are inherent in each design method, are often very different. Finally, and most importantly, the level of *reliability* may be different using different methods (see Box 9.2). Unfortunately few design methods deal with this explicitly; ORN 31 (TRL, 1993) and the AASHTO (1993) method are two notable exceptions.

Thus the fact that there are differences in the thickness designs obtained using different methods should not, perhaps, be so surprising although, to the non specialist, the magnitude of the differences certainly is. Unfortunately, the in-built assumptions in most of the design methods are not usually described in the published manuals. Technical comparisons between the different structural designs are therefore difficult and economic comparisons often impossible unless properly documented design methods are used.

Overseas Road Note 31 (TRL, 1993) is a general design guide for bituminous surfaced roads in developing countries and emphasizes good engineering practice which applies universally. It is based on research by the International team at TRL but it cannot, of course, encompass all of the conditions likely to be encountered in all countries, particularly the more extreme or unusual conditions. 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 'in the right ballpark' (i.e. approximately correct).

Box 9.2: The importance of reliability in pavement design

In terms of traffic carrying capacity to a defined terminal condition, the performance of roads of nominally similar design is extremely variable and therefore factors of 'safety' are required to ensure that most roads last as long as desired. However, it is not economically justifiable to design minor access roads to the same level of reliability as important trunk roads therefore the concept of designing for different levels of reliability (or risk) is essential in any rational design method. This has a very significant effect on the structural design. For example, designing a road to carry 5.0 million standard axles at a reliability level of 85 percent requires, typically, an extra 200mm of roadbase material compared with a design for 50 percent reliability and a design for 95 percent reliability requires a further 130mm of material.

Figure 9.7: Dynamic cone penetrometer in use for measuring the strength of an existing pavement

9.5 STRENGTHENING FLEXIBLE PAVEMENTS

To strengthen existing roads that are wearing out so that they can continue to carry traffic successfully is usually done by constructing a new layer, or overlay, on top of the existing road. These 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 penetrometer (Figure 9.7) or benkelman beam deflection testing is used to assess the 'strength' of the existing road and to determine how much additional strengthening is required. TRL's Overseas Road Note 18 provides established recommendations for tropical condition based on considerable research experience. This method should be used either to prepare overlay designs or to check those submitted as part of project reports.

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 to overlaying under these circumstances, often militates 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 reliable results to be obtained. The results will need to be assessed, and preferably also carried out, by an experienced road engineer to determine the best remedies.

9.6 COSTING

Costing the design of the new pavement or overlay should be based on final achieved costs in other contracts, as described in Chapter 13 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.

The cost of road pavement is usually a relatively large proportion of the total project cost, hence the need for an estimate that is as accurate as possible. When using the unit rate method to estimate pavement costs it is important that the pavement of the source project is of similar traffic loading and similar ground conditions to the option under consideration. Where a project includes pavements of different types, different traffic loading or different ground conditions, then the source project or projects must offer a similar range of conditions.

When using the unit rate method to cost road pavement it will normally be appropriate to derive a suitable unit rate from the surface area of the wearing course. This can easily be measured from layout drawings.

9.7 INPUTS AND OUTPUTS

The inputs to the pavement structural design consists of the following information:

- Subgrade strength values along the road alignment
- Traffic
- Material quality details and volume of materials available
- Costs as-placed of the pavement layers.

The output is simply the layer thicknesses along the alignment.

DETAILED SOURCES OF INFORMATION

AASHTO (1993). *Guide for design of pavement structures*. American Association of State Highway and Transportation Officials, Washington, DC.

SADC (2003). *SADC Guideline for low volume sealed roads*. SADC, Gaborone, Botswana.

TRL (2002). *A guide to the design of hot mix asphalt in tropical and sub-tropical countries*. Overseas Road Note 19. TRL Limited, Crowthorne, UK.

TRL (2004). *A guide to axle load surveys and traffic counts for determining traffic loading on pavements*. Overseas Road Note 40. TRL Limited, Crowthorne, UK.

Transport Research Laboratory (1993). *A guide to the structural design of bitumen-surfaced roads in tropical and sub-tropical countries*. Overseas Road Note 31, TRL Ltd, Crowthorne, UK.

Transport and Road Research Laboratory (1985). *Maintenance techniques for district engineers*. Overseas Road Note 2. TRL Limited, Crowthorne, UK.

10. Geometric Design

10.1 PURPOSE OF GEOMETRIC DESIGN

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 to 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. 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 (TRL, 1988).

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 (Box 10.1). It is vital that decisions are not taken before this is carried out which prejudice the choice of geometric design standard.
There are few developing countries that have carried out basic research on traffic economics and safety in order to develop their own geometric standards. Therefore standards have been adapted from those used in industrialized countries. However, the needs of road users in the industrialized countries are usually very different from those in developing countries. In developing countries pedestrians, animal-drawn carts, bicycles, auto-rickshaws, for example, 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 motorized 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.

> Box 10.1: Choice of design standards
>
> 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.

10.2 ELEMENTS OF GEOMETRIC DESIGN

10.2.1 Sight distance

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'. Different aspects of sight distance are used in the selection of standards for horizontal and vertical alignment.

10.2.2 Horizontal alignment

The key elements are the 'minimum radius of curvature', the 'minimum stopping sight distance' and the 'minimum passing sight distance' (Figure 10.1).

10.2.3 Vertical Alignment

The key elements are the 'maximum gradient', 'length of maximum gradient'; 'minimum stopping sight distance' or 'passing sight distance on summit curves', and 'length of valley curves' (Figure 10.2)

10.2.4 Cross-section

The important factors are, 'width of carriageway (running surface) and width of shoulder', 'crossfall', 'camber and super-elevation', 'width of structure', and 'width of road reserve' (Figure 10.3).

10.3 RATIONAL BASIS FOR GEOMETRIC DESIGN

When choosing geometric design standards for a particular situation it is necessary 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.

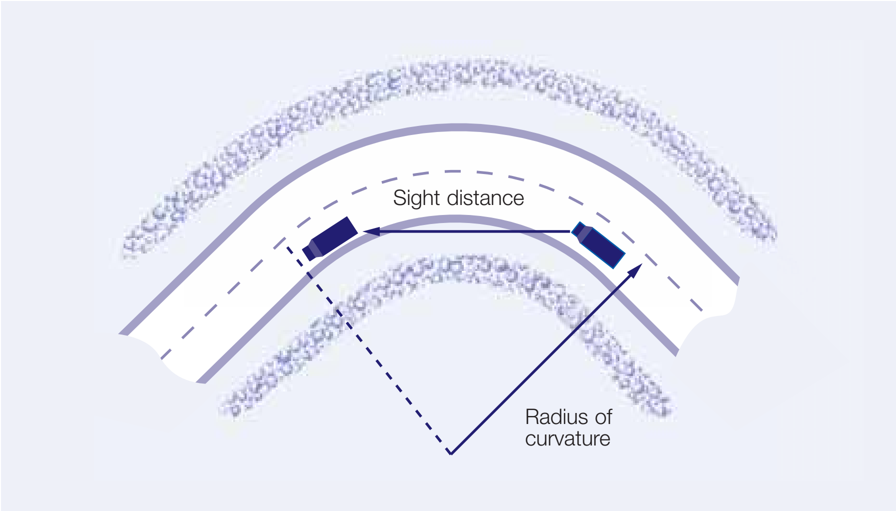

Figure 10.1: Horizontal alignment (plan view of road)

10.3.1 Access Roads

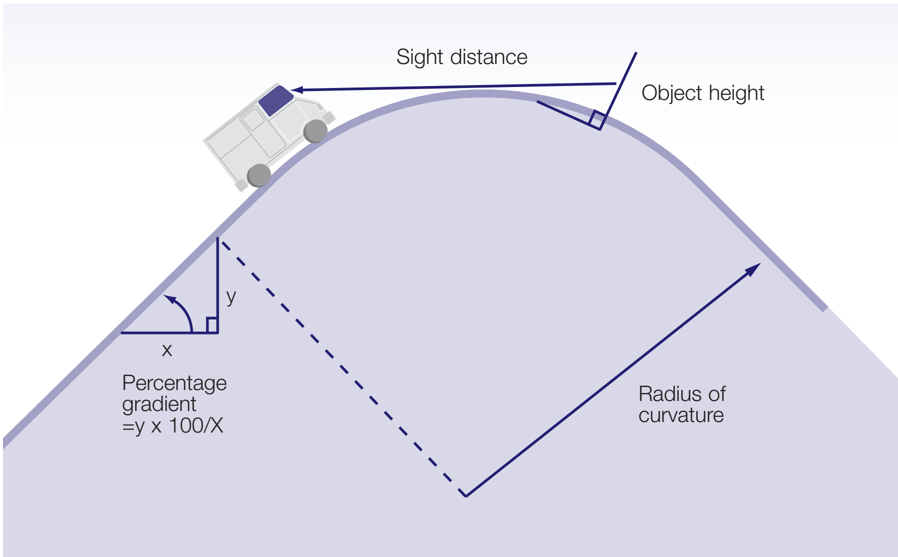

Figure 10.2: Vertical alignment (section through road)

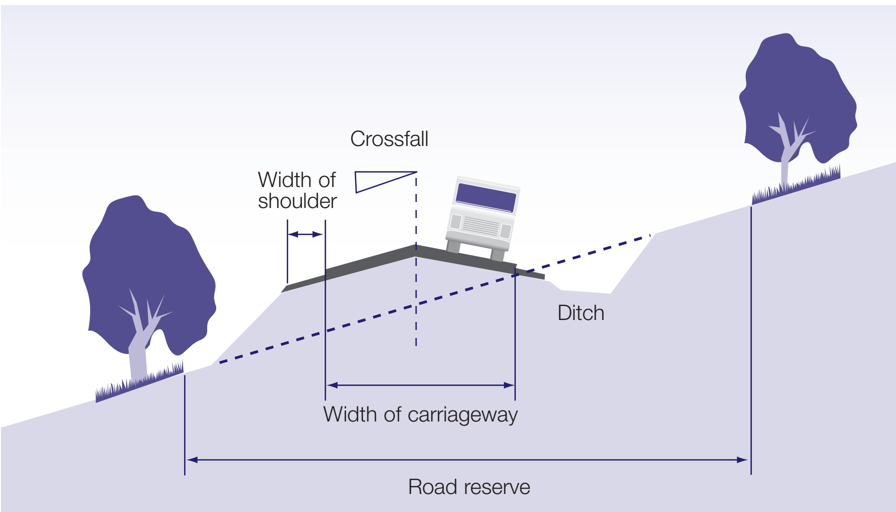

Figure 10.3: Cross-section (section through road)

10.3.1 Access Roads

These are lightly trafficked roads carrying up to, at most, a few hundred vehicles per day. They 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.

10.3.2 Collector Roads

On collector roads the volume of traffic is likely to be in the range 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.

10.3.3 Arterial Roads

Arterial roads will normally carry relatively high levels of traffic (>500 vehicles per day) 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.

10.4 DESIGN RELATED TO TERRAIN

In flat undeveloped terrain, the cost of a road is almost entirely independent of its alignment, so a relatively 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 earthwork cuts and fills are needed resulting in a higher 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.

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

The alignment should be chosen carefully to provide good drainage and to minimize earthworks. When locating roads in erosion-prone regions or areas where instability of slopes is a problem, careful attention must be given to minimizing the disturbance of the terrain caused by the road (see Chapter 5). The location of the road will also be affected by the availability of road-making materials and the distance that they have to be hauled.

10.5 HORIZONTAL ALIGNMENT

Suitable ranges of horizontal alignment standard are given in Table 10.1. 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.

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 the curves. The minimum radius should be chosen to be adequate for all likely vehicles, 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 will only be required to carry, say, light 4-wheel drive vehicles, this figure can possibly be reduced. However, consideration must be given to other special users of the road, such as the Roads Department, to allow access during road maintenance. It is desirable to flatten the gradient at any tight corner.

For collector and arterial roads, projects will often be for improvement rather than for 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.

It is preferable that lengths of horizontal curves should be close to the 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, with such designs, sight distances are restricted on the longer curves and a shorter length of alignment is available where overtaking is safe.

10.6 VERTICAL ALIGNMENT

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.

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 10.1 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, some 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.

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 in 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.

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 minimize the sum of these costs. Proposals should support recommendations 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 Chapter 15. Minimum values for the radii of vertical curves should be based on safety criteria; the standards in Table 10.1 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’.

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.

Road type	Access road	Collector road	Arterial road
Normal surface type	Unpaved/paved	Gravel/paved	Paved
Approximate range of traffic levels (vehicles per day)	< 200	100 - 1000	400 - 15000(2)
Carriageway width (metres)	2.5 - 5.0	5.0 - 5.5	6.0 - 7.0
Shoulder width (metres)	0(3) - 1.5(4)	1.5	1.5 - 2.5
Crossfall (per cent)	(5)	(5)	(5)
Stopping sight distance (metres)	25(6) - 85	50 - 120	65 - 230
Overtaking sight distance (metres)(7)	140(8) - 240	140 - 320	180 - 590
Minimum horizontal curve radius (metres)	0(9) - 190	60 - 210	85 - 450
Minimum crest curve K values (10)	0(9) - l6	5 - 30	10 - 120
Maximum percentage gradient	15 - 20(11)	10	8(12)

Notes

(1) Values are based on those recommended in Overseas Road Note 6 (TRL, 1988).
(2) For higher traffic volumes, use latest British 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 - 7 percent on unpaved roads; 3 percent 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) K = curve length/algebraic difference in percentage gradient.
(11) Where design is for animal-drawn carts, gradients may need to be restricted to a maximum of 4 percent; slippery soils may also restrict the practical maximum value to as low as 5 percent.
(12) 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.

Table 10.1: Guidelines for Geometric Design Standards(1)

10.7 CROSS-SECTION

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 decrease.

For access roads where traffic flows are so low that vehicles meet only occasionally, a single track road with intermittent passing places is the cheapest road to construct. For higher traffic flows, a single track road causes considerable inconvenience to traffic and is only 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. If the new road is to be constructed by machine, then the extra construction cost of building a wider road will often be quite small. However, for labour-based construction, significant additional construction costs will be incurred. If there is a large amount of pedestrian, animal or bicycle traffic, both shoulders should be increased in width. Visibility is reduced on bends and on summit curves and so the width of the carriageway should be increased.

For collector roads for relatively low traffic volumes, research has shown that carriageway widths in excess of the minimum values in Table 10.1 cannot be justified in terms of accidents or traffic operation but that there is benefit in widening from this value on bends and summit curves.

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 on 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 best practice. Arterial roads should normally carry centre line markings.

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 are expected, shoulder widths should be increased or it may be appropriate to segregate this traffic entirely from the vehicular traffic.

Crossfall is needed on all roads in order to assist the shedding of water into the side drains. Suitable values are given in Table 10.1.

10.8 ROAD RESERVE

For new road construction, most countries already have standards for the amount of land that will be bought or acquired for the road. Often this is much wider than in industrialized countries since the pressure on land space is not as great. The total width of the road reserve may be from 10 metres to more than 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. Firstly, 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 unplanned development. A wider road reserve will improve sight distance.

10.9 JUNCTION DESIGN

Conflicting vehicle movements at junctions are a significant contribution to accidents in many developing countries (Chapter 8). 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 channelization may be appropriate to improve vehicle flow and safety. Local widening at T-junctions combined with painted channelization (ghost islands) has proved highly cost effective in industrialized 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.

10.10 SIGNS AND ROAD MARKINGS

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 minimize confusion and delay.

Ideally, signs should be reflectorized, 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 and theft of road signs can be a problem.

10.11 COSTING EARTHWORKS

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.

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 level of accuracy.

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.

Methods of costing based on those in Chapter 13 should be used.

DETAILED SOURCES OF INFORMATION

Transport and Road Research Laboratory (1988). *A guide to geometric design*. Overseas Road Note 6. TRL Limited, Crowthorne, UK.

11. Drainage

11.1 THE IMPORTANCE OF DRAINAGE AND THE CONTROL OF WATER

Water is capable of causing considerable damage to a road. It has two principal effects. First its presence weakens most road building materials, especially unbound materials including the subgrade (see also Chapters 5 and 9), causing the road to deteriorate quickly. Secondly, flowing water erodes materials and transports them to somewhere where they are not wanted thereby damaging not only their place of origin and their final resting place but also the route taken by the flow of the water. In extreme cases, where water is not adequately controlled, it can cause landslides, wash away whole sections of road, and generally cause immense damage.

A properly engineered drainage system is the means whereby water is controlled. Falling rain, runoff and rising ground water need to be disposed of as rapidly as possible to protect the road and its environment from damage, and its disposal has important environmental implications. Drainage of one sort or another is one of the most important factors controlling road performance and the construction of the drainage system is always a significant proportion of the cost of a road project. Indeed, in mountainous terrain, particularly where traffic is not heavy, the costs of drainage and drainage related features can be the dominant costs. Drainage therefore needs to be considered during all stages of project development.

The 'output' of the design of the drainage system appears in almost all aspects of the design of the road, not merely in its most obvious features namely the design of the drains and culverts themselves. This Chapter describes the elements in a drainage system in sufficient detail to provide a sufficient understanding for appraisal purposes so that the extent of the work and the construction and maintenance costs may be estimated.

11.2 ROAD GEOMETRY

11.2.1 Alignment

The drainage of a road is significantly influenced by its alignment. For example, a road on a hill ridge is not affected by run off from adjacent land, it does not require any structures for crossing water courses, and the water table will be deep. However, it may be difficult to avoid steep gradients when building a road along a descending ridge. A ladder of hairpin bends on a hillside can lead to very large drainage flows with the risk of severe erosion. For a road in flat terrain, realigning it away from a low lying area can facilitate the disposal of water and reduce the problems caused by water rising from the water table.

11.2.2 Carriageway

Crossfall or camber is provided to permit water to flow from the carriageway into the side drains by the shortest possible route. Recommended camber is 3 percent for a paved road and 5-7 percent for an unpaved road (Table 10.1). If the camber is insufficient on steep roads, water will flow down the wheel-tracks and cause erosion. Super-elevation is sometimes constructed on a curved length of road, but this can increase transverse erosion of unpaved roads and should be avoided if the earth or gravel surface is erodible (Figure 11.1). It is recommended that the crown of the road is at least 750mm above the bottom of the side drains or the surrounding land to

Figure 11.1: Transverse erosion on a super-elevated curve

reduce the likelihood of ground water rising into the pavement. This figure is often increased in cuttings, where hydraulic pressure can cause the water table to rise and where there may be additional lateral water flow from the cut slopes.

11.3 STRUCTURAL CONSIDERATIONS

11.3.1 Internal Drainage

Water that enters the road pavement from any cause should be able to drain away as quickly as possible and therefore pavements should contain a drainage path that provides for this. Ideally, the permeability of the pavement layers should be such that lateral migration of water is encouraged and the sub-base, at least, should extend to the edge of the formation *underneath* shoulders that are as impermeable as possible. Under no circumstances should trench construction be used where the roadbase and sub-base are contained *between* impermeable shoulders. It is also recommended that the camber or crossfall of the lower layers of the pavement is *at least* as high as that of the finished surfacing unless the subgrade is, itself, free-draining.

11.3.2 Shoulders

Water flowing off the carriageway should continue smoothly over the shoulder and into the side drain. On a paved road, the shoulder should, ideally, be constructed with a camber of 4-6 percent. On an unpaved road the shoulder is often indistinguishable from the running surface and the camber tends to increase naturally from the centreline towards the edge. Extending a surfacing seal over at least one metre of the shoulder normally prevents water permeating back underneath the carriageway and weakening the pavement (Figure 11.2).

Figure 11.2: Sealed shoulders together with low embankment slopes ensure that the pavement remains dry and strong.

11.4 DRAINS

11.4.1 Side Drains

Side drains carry water parallel to the road to a mitre drain, water course or water crossing where it can be disposed of. They also help to lower the water table. Side drains are often not necessary on the downhill side of a road on side-long ground or alongside embankments.

Side drains should be large enough to carry all the carriageway water or the run off. Increasing the width of side drains allows water to flow more slowly with less risk of erosion. Side drains should not be deep and steep-sided because this can be dangerous to vehicles leaving the carriage-way, whether deliberately or accidentally. If land is available, very wide side drains can be constructed to act as safe pedestrian paths during the dry season.

It may be necessary to reinforce the slopes of the side drain if run-off enters the drain at high speed. The inside slope is also prone to erosion by water flowing from the carriageway and should be either protected with vegetation or very well compacted.

If practical, side drains should have a minimum longitudinal gradient of 0.5 per cent to ensure that water continues to flow in the desired direction and to prevent sediment from being deposited. This can be achieved in flat terrain by excavating side drains of variable depth.

Erosion in steep side drains (Figure 11.3) can be reduced by constructing a non-erodible drain lining or by reducing water speeds with masonry, concrete, wood, turf or bamboo scour checks with a well-profiled upper edge and a non-erodible apron (Figures 11.4 and 11.5). The spacing of scour checks depends upon the erodibility of the soil, the width of the carriageway, the gradient of the drain and the rainfall intensity, typically ranging from 2 to 50 metres.

The volume of water in a side drain can normally be reduced by excavating mitre drains, although this is difficult in side-long ground and impossible in a cutting. In such cases the side drains must be large enough for the increased water volume which will accumulate.

Side drains may be ‘V’ or ‘U’ shaped. The former can be maintained by a grader; the latter can be maintained by a back hoe or by labour and the flat base is less likely to erode.

11.4.2 Urban drains

Many urban roads have side drains below the carriageway and into which water flows through gully or kerb inlets at the edge of the carriageway or shoulder. It is important that there are sufficient inlets to drain the carriageway and prevent water ponding excessively on the carriageway or shoulder.

Figure 11.3: This side drain is eroding severely. Access along the road may soon be lost. Scour checks should be constructed

Figure 11.4: The short and steep access road has been constructed with concrete drains to prevent erosion

Figure 11.5: Scour check constructed from wooden stakes with a masonry apron

The spacing of inlets depends upon the width, gradient and camber of the road and the rainfall intensity, typically ranging from 5 to over 100 metres.

11.4.3 Sub-surface drains

Longitudinal and transverse sub-surface filter drains and pavement drainage blankets (i.e. a permeable pavement layer designed primarily to allow water to flow freely through it and to stop capillary action) can be used to reduce the level of the water table in the vicinity of the road. Since these can become blocked and cannot be inspected, it may be more practical to construct an embankment for the road or realign it away from areas of high water table.

11.4.4 Mitre drains

Mitre drains carry water from a side drain and dispose of it at a site away from the road where it will not flow back to the road or cause erosion. They are used to reduce the volume of water flowing in the side drain. It is often difficult to set out a mitre drain on the uphill side on side-long ground and a relief culvert or a soakaway may be necessary. The spacing of mitre drains depends upon the erodibility of the soil, the width of the carriageway, the gradient of the drain and the rainfall intensity, typically ranging from 5 to 50 metres.

11.4.5 Cut-off drains (interception ditches)

Interception ditches (or cut-off drains) are excavated approximately parallel to the road and on the uphill side on side-long ground or near the top of cut slopes. Their purpose is to trap run-off flowing over the ground (or in the top portion of the soil) and prevent it from compounding erosion and flow problems. However, if interception ditches are not maintained properly, and this is highly likely since they cannot be seen clearly from the road and access to them may be difficult, they can be a source of serious weakness because they can allow water to permeate the soil at vulnerable places and cause landslides. For this reason there use is not usually recommended.

11.5 EMBANKMENT SLOPES

11.5.1 Gradient

Embankment slopes are prone to erosion by water flowing from the carriageway. The gradient of the slopes should suit the soil from which the embankment is constructed and the slopes should be protected with vegetation wherever possible. In general, embankment slopes should be as flat as possible to increase the lateral support to the pavement and reduce the likelihood of lateral water ingress. Diagonal drains can be excavated to control the flow of carriageway water down the slope.

11.5.2 Bio-engineering

Bio-engineering is the use of live vegetation for engineering purposes. Bio-engineering is often used to prevent erosion on slopes and can be used in many places in a drainage system (Figure 11.6). In addition, live vegetation transpires and increases the rate at which the road dries out after becoming wet. However, such vegetation often requires maintenance; for example, in many circumstances it requires cutting and must never be allowed to become established in the base of drains because this will promote sedimentation.

11.6 WATER CROSSINGS

Structures are required to allow water to cross the road line. This may be because there is a natural water course crossing the road line or because it is necessary to transfer water from the side drain on one side of the road to the other side for disposal. These structures can be culverts, drifts, bridges or any other type of water crossing. The required flow capacity of the structure depends upon the rainfall, the water catchment area and the nature of the land from which the water will drain. These issues are essentially hydrological and are usually dealt with by a specialist engineer. Water crossings are considered in more detail in Chapter 12.

Figure 11.6: Turf is being placed on this embankment to prevent erosion

11.7 ADDITIONAL ITEMS

11.7.1 Soakaways

Soakaways are pits filled with porous material, often large rocks, into which water flows and gradually permeates into the ground. They are often located at the end of short mitre drains if the water cannot be disposed of safely in any other way. Soakaways should be maintained by removing any sediment and replacing the porous material. However, soakaways are often poorly maintained and block with sediment, causing the water to back up into the side drain.

11.7.2 Gutters, chutes and parallel drains

A number of other items can be used to drain a road. Gutters are equivalent to side drains on a paved road and are common in urban areas when the road is kerbed. They take water from the carriageway and carry it away for disposal. It is important that gutters are sufficiently deep that water cannot be shed back onto the carriageway.

Chutes are steep channels or pipes which carry water down the side of an embankment or cut slope. They are often constructed from pre-cast concrete units and empty into chambers at the base to prevent erosion.

Parallel drains are drains excavated alongside side drains and into which short mitre drains discharge water in order to prevent erosion close to the carriageway.

11.8 COSTS

A drainage system should be costed by estimating the required quantity of each of the above elements and multiplying by unit rates as in a normal bill of quantities. Side drain construction is normally included within the price of road formation. It may also be possible to make an estimate of cost by calculating a typical drainage cost per kilometre of road and adding this to a more detailed estimate of the costs of water crossing structures.

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PIARC (1998). Proceedings of the International Symposium on Sub-drainage in Roadway Pavements and Subgrades, Granada, Spain. The World Road Association (PIARC), Paris.

Watkins, L H and D Fiddes (1984). *Road and urban hydrology in the tropics*. Pentech Press, London.

12. Bridges and Water Crossings

12.1 INTRODUCTION

Bridges provide access over obstacles such as rivers, roads, railway lines, footpaths and ravines and are required for most road projects. The need for and the location of bridges may have a significant influence on general route selection as well as on local geometry. They therefore require careful consideration at the project planning stage.

For projects that are concerned with improving or up-grading existing routes, the structural engineering requirements for bridges and structures may be relatively minor unless the existing structures lack the capacity for the anticipated traffic and therefore need strengthening, widening or rebuilding. On the other hand, for projects concerned with new roads, bridges and water crossings can be an important and expensive component, both in terms of initial cost and long-term maintenance needs, and can therefore represent a significant fraction of the total investment.

The complexity of structures increases rapidly as the size increases such that if a large bridge (with a span greater than about 30m) is needed the costs of the bridge can form the major part of the project and the bridge itself may become a project in its own right.

The engineering design of a bridge is an inherently complex process that requires knowledge of structural engineering, geotechnical engineering and, for water crossings, hydrology and hydraulics. However, the sizes of bridges that are most frequently required are such that relatively straightforward basic designs can often be used for the superstructure, although the design of the foundations may vary considerably.

The treatment of bridges and structures for water crossings at each stage of project development depends on the type of road project and the number and size of the crossings required. The level of detail should be sufficient for decisions to be made with confidence and with an accuracy of the same order as other components of the project. For example, for the majority of road projects it is not envisaged that special geotechnical or hydrological information will be required at the pre-feasibility stage. However, for major bridge projects some preliminary design is required even at the planning stage to provide sufficient information to enable the normal project development process to progress logically. For most projects, however, some familiarity with the detail of bridge design is not required until the feasibility stage. For typical road projects, this might be provided by a competent highway engineer. Where major bridges are being considered, the services of an experienced bridge design team are necessary because of the significantly greater level of expert knowledge that is needed.

Rivers do not necessarily have to be crossed by a bridge. For low volume road projects it may be appropriate to consider the use of low level crossings such as fords and drifts. In order to choose 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 at any time of the year or if a single-lane bridge is likely to become a traffic bottleneck in future. The choice of structure will therefore depend not only on engineering considerations but also on total transport costs in the same way as for the other elements of the road.

For major rivers, it may be economic to provide a ferry service or improve an existing service instead of providing a major structure. These alternative solutions are particularly applicable where the river channel is constantly changing. Where traffic levels are low and the river is wide and slow-moving, they can be a cost-effective alternative. However, appraisals should take account of the delay to traffic introduced by the use of ferries and both their capital and maintenance cost. The value of time is discussed in Chapter 14. The information presented in this chapter is concerned with bridges (and other water crossings) but the same general principles are required for most other highway structures such as retaining walls, gantries, etc. However, tunnels require specialist knowledge and are beyond the scope of this document.

The key factors that control the choice and the design of a bridge, and therefore its cost, are the weight of traffic to be carried, the ground conditions of the site, and, for water crossings, the likely flow of water passing across the line of the road.

12.2 STRUCTURE TYPES

12.2.1 Fords and drifts

The simplest river crossing is a ford and this can provide a simple and economic alternative to a bridge in favourable conditions, i.e. where traffic volumes are low and water depths are generally less than 150mm. 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 would normally only be used for rivers that do not flood because this may cause the ford to be

Figure 12.1: A drift

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.

Fords are often used on low cost rural access roads but can also be effective on more sophisticated road systems in certain situations. An improvement on a ford is a concrete drift (Figure 12.1). This provides a permanent running surface for vehicle 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 percent, or 4 percent 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 3.5m to 4m, but should be delineated by graduated marker posts to show both the edge of the road and the depth of the water during floods. 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 a significant portion of the total.

12.2.2 Culverts

Culverts are used to convey surface water under a road. They are usually made from large diameter pipes, concrete boxes, or brick/stone arches. Culverts are, in fact, small-span bridges but generally do not have engineered abutments and are covered by fill material which supports the road surface. In most countries, large diameter concrete pipes are available and these may be cost effective provided that they can be transported and handled. Culverts should normally be at least 1m in diameter to reduce the likelihood of blockage and to make them easier to maintain. Corrugated galvanized 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. These large diameter culverts can be used to provide pedestrian access under the roadway. There should be little maintenance required for either steel or concrete culverts 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.

For larger volumes of water, it is possible to use several pipes in parallel under the road (Figure 12.2). Multiple pipes can also be used where the planned embankment height is insufficient to cover adequately a single pipe of sufficient diameter. Culverted drifts or vented fords may be used to cross perennial streams.

Reinforced concrete box culverts are also 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 pre-cast.

Cost estimates for culvert pipes are made on the basis of the length of pipe required, depending on diameter. Unit prices for concrete and for culvert pipes of various diameters which are appropriate to the road being analyzed should be readily available. Costs should be based on final achieved contract costs rather than current contract rates (see Chapter 13). Costs for headwalls and box culverts are normally determined 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.

Figure 12.2: Multiple culverts

12.2.3 Bridges

Bridges will be needed over rivers where high level crossings are required, where several culverts in parallel do not have sufficient capacity to carry the flow, where drifts are not suitable because of safety considerations, or because resulting traffic delays are unacceptable. Bridges are discussed in detail below.

12.2.4 Other structure types

Other highway structures include footbridges, subways, underpasses, retaining walls and gantries. The general information provided here can be applied to all of these structures.

12.3 BRIDGE DESIGN CONSIDERATIONS

12.3.1 Introduction

Most countries have established bridge or structural 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 are similar to, codes adopted in the USA (e.g. AASHTO, 2002), the United Kingdom (e.g. BSI 1990) or the Eurocodes. International design guidelines are also available e.g. Overseas Road Note 9 (TRL, 1992) which is applicable for the design of small span bridges. It is advisable that new structures are designed to the code adopted by the country concerned to avoid problems of lack of uniformity and to prevent either 'under' or 'over' design. An exception may be made where a temporary structure is envisaged or provision must be made for known exceptional loads, e.g. access to a power station or other structures known to require exceptionally heavy plant or equipment.

The objective of the design process is to produce a structure which satisfies the project requirements within the given constraints. As with other aspects of the road design, the scale of the task depends critically on the size of the engineering structures required. For most culverts, for example, 'off-the shelf' solutions will be acceptable based on relatively little field investigation. However, for larger structures the process should begin with a definition of the problem in terms of function, geometric layout and constraints and move towards a preferred solution after considering different options. The process is necessarily iterative, often involving additional site investigations to obtain more detail as the preferred solution is identified and more detailed design carried out.

Engineering assessment at the pre-feasibility stage should focus on the general technical and economic feasibility of providing bridges or water crossings. At the feasibility stage the objective is to select the structural solutions for each water crossing. The following information is required to enable an effective engineering assessment of different options to be carried out,

- Location
- Site conditions (topography, geology, hydrology)
- Geometry and alignment
- Environment
- Loading
- Aesthetics
- Costs

For many road projects it is likely that approximate locations, geometry and structural form will be sufficient to enable the solution to be evaluated and costs estimated. For major crossings, however, all of the above factors will need to be investigated to enable a proper assessment of the project.

12.3.2 Location

The location of a bridge, culvert or retaining wall is governed by the general route of the road and is often subordinate to the general alignment and grade. In schemes where several alternative routes are being considered, the general policy for the selection of a crossing site is to avoid horizontal and vertical curvature as these can lead to serious problems in analysis, design and construction. Selection of a bridge location should suit the particular obstacle being crossed and requires the consideration of engineering and social aspects as well as the appearance and cost of the structure. Locations should be chosen to minimize the overall cost of the project, including special investigations, initial design and construction, earthworks, and river training, if required. Future maintenance requirements should also be taken into consideration as these can represent a significant real cost to bridge owners.

A large number of interacting and often conflicting factors need to be considered. These include the following,

- Route and alignment of road.
- Access requirements and headroom under the bridge (navigation, railway requirements, pedestrian access, local requirements, etc).
- River hydrology (high water level, river debris, flood plain, scour, etc).
- General geography of site (faults, landslides, seismic activity, etc).
- Geotechnical conditions.
- Environmental conditions (climate, marine environment, pollution, etc).
- Availability of construction materials.
- Constraints on sub-structure.
- Time of construction.
- Access for construction.
- Aesthetics.
- Future maintenance and repair.

Thus a good bridge site should have the following characteristics,

- The bridge location should have suitable local geology with stable terrain.
- The bridge should be as close as possible to a direct alignment of the road
- Road approaches should be straight for maximum visibility.
- For economic construction, labour, materials and access should be available.
- The bridge should cross the obstacle at right angles, i.e. no skew, and should have a straight alignment to avoid complications in analysis.
- The bridge location should be chosen to minimize the width of the crossing.
- The soil around the bridge supports should have high bearing capacity to support the sub-structure, ideally with rock or other erosion resistant strata at foundation level.
- For economic foundations, the sub-structure should be located to avoid work in water.
- The river should be straight at the bridge location to minimize the risk of the river changing its geometry.
- The banks of the river should be high to allow sufficient clearance over the river for both flood height and navigation. It is also important to consider what the cost of disruption or damage would be if the river were to overtop the bridge.
- Abutments and supports should be away from the river water including flood plane to simplify construction, avoid scour and improve durability.
- Where piers are required in the river course, the disturbance to flow should be minimized.
- The river crossing should be located where the water flow is steady, with little turbulence and cross currents, and well away from the confluence of river tributaries.
- Ideally no river training works should be required to regulate the flow of the river around the bridge. 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.

12.3.3 General site conditions

An assessment of the conditions at the bridge site is required before the bridge is designed in order to:

- Determine the general suitability of the site for the proposed works
- Enable an adequate and economic design to be prepared
- Plan the best method of construction
- Determine changes that may arise in the environment as a result of the works
- Evaluate the relative suitability of alternative sites.

Bridges are an expensive and vulnerable component of road networks and should be resistant to earthquakes, flood and other environmental loads. Sufficient information should be obtained to ensure that the bridge environment is understood fully. This includes a topographical survey, a geotechnical survey (Chapter 5) and a hydrological survey. No reasonable estimate of cost can be made without this information.

Topographical survey

A topographical survey will be carried out as part of the feasibility study for most road schemes. This should highlight the locations where bridges may be considered as alternatives to road junctions, level crossings, etc, or may be required to cross geological formations such as rivers and deep valleys. Potential bridges sites will require more specialist information including geotechnical and hydrological surveys. The scope of the investigations for engineering design should be determined during the feasibility study stage on the basis of the particular project requirements.

Geotechnical survey

A geotechnical survey (see also Chapter 5) will be carried out as part of the feasibility study for most road schemes. This should provide information on the general geotechnical conditions and highlight the locations where crossings may be required. Particular bridge sites will require more specialist information, particularly for river crossings. The scope of the investigations required for engineering design should be determined during the feasibility study stage on the basis of the particular project requirements.

Water flow and hydrological survey

A hydrological survey will be carried out as part of the feasibility study for new road schemes. This will provide design information for the road drainage as well as for bridges, culverts and other water crossings. This may be undertaken by a highway engineer or a hydrological specialist as a component part of the other surveys that are required to determine the best road alignment. For a rehabilitation project of an existing road, the task becomes one of checking that the existing water crossings are adequate. The survey should provide general information on the hydrology within the project area but bridge sites will require more specialist information as hydrological conditions will have a significant effect on design criteria. The scope of the investigations need to be flexible and should be determined at the general planning phase on the basis of the particular project requirements.

To calculate the water flows, information will be needed on:

- Rainfall characteristics.
- Topography.
- Water catchment areas and their shapes.
- Vegetation and soils.
- Available storage for water 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). Peak flood volume is one of the most important design parameters for the potential structures and, in general, estimating its value is neither quick nor easy. For example, considerable engineering judgement is usually needed to perform the calculations because data may be either lacking or unreliable.

It is always worth reviewing local experience to find out about peak flood levels because the highest flood levels are usually associated with local misfortune (even disasters) and therefore tend to remain in the collective memory of local inhabitants.

Most bridges (< 30m span) should be designed to cope with a 1 in 50-year flood. For more important structures this should be increased to 1 in 100-year. For temporary structures, this can be reduced to 1in 20-year. Clearance above the high water line should be at least 1.0m. Navigational clearance should be considered where appropriate.

Figure 12.3: Scour induced failures of bridge pier or abutment

A significant reason for structural failure of bridges and high maintenance costs in tropical countries is erosion and scour leading to foundation failure (see Figure 12.3). Even at the planning stage, it is advisable to make sure that these aspects have been considered and appropriate protection provided. This may affect the preferred bridge solution because protection systems and/or because increased depths of construction may significantly increase construction costs. Similarly, the potential for stream migration should also be considered as should the influence of stream bed degradation, the need for scour protection systems, and the effect of tides (where appropriate).

Great care is required where catchment areas are large and high levels of rainfall are rare but intense. The resulting flash floods can wash away roads if the water crossings have not been designed to cope properly with such events, yet good statistical data may be lacking to carry out the necessary calculations.

12.3.4 Geometry and alignment

Geometry and alignment are dictated by the function/type of the structure, the general route selection and the traffic conditions. These can have a significant effect on engineering constraints and costs, and must be considered at an early stage in the design process.

The width of a proposed bridge will significantly affect the cost of construction. If a two-lane bridge is provided instead of one, material costs will more than double as heavier construction will be required to accommodate the additional traffic loads. Careful consideration should therefore 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, particularly where a long bridge is required (see also Chapter 14). In some cases, it may only be necessary to widen the carriageway sufficiently to ensure that motor traffic is unimpeded by non-motorized traffic rather than provide two standard traffic lane. But, ideally, the number of lanes provided on the bridge should be the same as specified for the road to avoid traffic bottlenecks and potential accident black-spots.

The proportion of pedestrians, bicycles, and animal-drawn vehicles should be considered carefully because this can be quite high (see Figure 12.4). The width of

Figure 12.4: Congestion on single lane bridge

the bridge itself should be sufficient to carry the full width of the roadway including auxiliary lanes, and/or pedestrian footways. A cheaper solution may be to provide light footways cantilevered out from the main structure.

12.3.5 Highway loading

Estimating traffic volumes and loadings is discussed in Chapter 4. The traffic loading for bridges is normally specified in the appropriate national design codes. The composition and volume of traffic using the road will be estimated as part of the feasibility study (Chapter 4) and this will be used to ensure that the appropriate codes are used. These take into account the heaviest loading expected over the service life of the structure. In addition, abnormally heavy loading can also be considered where appropriate.

Non-traffic associated loads such as wind, earthquake and temperature will normally be specified in the particular structural design code being used.

Bridges tend to be expensive components of a road network, therefore specific consideration should be given to the design loading from a strategic point of view. The over-design of bridges in anticipation of future developments may produce large economic savings in future years.

12.3.6 Environment

The construction of a river crossing will affect the environment around the bridge site both upstream and downstream, particularly where a major bridge is being considered. These effects should be considered as part of the environmental impact assessment for the road project (Chapter 6). The assessment should consider the effect the bridge will have on the river hydrology, the plant and animal life, and the living conditions of the local inhabitants.

12.3.7 Aesthetics

Aesthetic considerations are a very important aspect of major bridge projects and tend to be handled by specialist bridge designers. In many cases, architects and engineer have worked together to produce a functional work of art which is structurally sound and aesthetically pleasing. For most bridges, however, this is not required. Nevertheless, aesthetics have a role to play and should not be neglected.

Features may also be incorporated into the bridge structure to improve its architectural appearance or to adjust it so that it blends well with the landscape and is in harmony with the local environment. The added cost is usually small since an intelligent use of normal quantities of materials should be sufficient to meet aesthetic standards. However, costs sometimes increase considerably with the demand for a special aesthetic effect. These include:

- Close high abutments.
- Reduction in number of columns.
- Increase in span length.
- Decreased depth of superstructure.
- Curved soffit.
- Special architectural handrail.
- Extra length.
- Special layout of wing walls.
- Architectural concrete finishes.

While such features may be useful in some situations they should be used with care. The ideal bridge structure is straight-forward, elegant and pleasing to the eye. Additional features added just for visual effect can be detrimental. It is not possible to be prescriptive in what is a very subjective field and it is only through their own experience, and by observing the results of other designers, that engineers can learn what makes a bridge attractive.

12.3.8 Economics

In order to carry out a proper economic appraisal, it will be necessary to have sufficient information to enable costs to be determined for the different options to a sufficient degree of accuracy. However, detailed cost estimates will not normally be possible or desirable for all options at the feasibility stage. Methods of estimating costs are discussed in Chapter 13.

For major bridges, the cost will often be the main factor influencing the decision to proceed with construction and the selection of the type of bridge to be used. In this case a detailed comparison of options will be required and costs determined more accurately.

12.4 TYPES OF BRIDGE

12.4.1 General

The main elements of a bridge are:

- Deck
- Abutments, piers and foundations
- River training works
- Approaches.

Details such as joints, bearings, parapets, handrails, etc, are important but are not likely to influence significantly the choice of bridge type and therefore the costs. Maintenance costs may prove to be significant and need to be considered for each type of bridge.

Bridges are perceived in different ways by engineers and the public and this makes it difficult to devise a classification system. It is customary to use the following categories when describing bridge:

- Function (road bridge, railway bridge, etc).
- Material of construction (reinforced concrete bridge, steel bridge, etc).
- Form of superstructure (beam, beam and slab bridge, cantilever, arch bridge, cable-stayed bridge, etc).
- Length of span.
- Culvert: spans less than about 5m.
- Short-span bridge: span less than about 20m.
- Medium span: span between 20-100m.
- Long span: span greater than about 100m.

The following sections present a general description of the more common forms of bridge. This is not intended to be a concise classification and there is some overlap between the bridge types described.

12.4.2 Timber bridges

In many rural areas which are close to forests, the cheapest construction option for the superstructure of bridges may be parallel timber logs (Figure 12.5). 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, should be applied. To be effective, timber preservation

Figure 12.5: Log bridge

must be done thoroughly and may significantly increase costs. On top of the logs, cross beams should be used to support longitudinal running boards.

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.

Modular timber bridges (Figure 12.6) (Parry 1981, TRADA) 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 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 and are not common, they should be considered for use in appropriate situations. Various design guides are available including Overseas Road Note 9 (TRL, 1992).

12.4.3 Concrete bridges

Concrete superstructures are now common in most 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 pre-casting 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 (Figure 12.7). A bituminous wearing course may also be added. Alternatives to a beam and slab design are 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. Other more sophisticated techniques of pre-stressing may also be considered.

Post-tensioned beams and slab.

The deck is constructed in-situ in a similar way to the 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.

Pre-tensioned beams.

This method is applicable mainly to pre-cast 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.

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 replaces. 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.

Concrete box girder bridges.

For longer spans a concrete box can be used to produce a deck with low dead load. Segmental construction can be used for longer spans whereby separate units are manufactured using industrial processes either at site or in a factory (see Figure 12.8). 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 inexperienced contractors are employed.

Figure 12.6: Modular timber bridge

Figure 12.7: Pre-stressed beam and slab bridge

Figure 12.8: Concrete box girder bridge

12.4.4 Steel bridges

Steel superstructures are of three types, as follows.

Steel beam bridges.
These 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 beams can be either standard rolled steel beams or steel girders fabricated from steel plates. The length of the beams 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.

Truss bridges.
These are made from steel sections fabricated at a factory to form trusses and may be either part or fully assembled before delivery to site. Bailey bridges are a particular example of a truss bridge that is available in modular form and can be dismantled and re-used on other sites. 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.

Box girder bridges.
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 steel box girders because of their light weight.

Composite bridges.
Most modern bridges have concrete decks although timber, steel and, more recently, fibre reinforced polymers are also used. Composite bridges have decks consisting of steel beams spanning between supports with a concrete slab designed to act compositely with the beams. Studs welded to the top of the steel beams provide the shear connection to ensure full composite action. This is a very efficient form of bridge deck with the steel beam carrying the tension forces and the concrete acting as a top compression flange.

12.4.5 Arch bridges

Masonry and brick arch bridges and culverts are a traditional form of construction in some countries and may be competitive where skilled bricklayers or masons and appropriate materials are available. Some of the oldest bridges in the world are of this form and are successfully carrying modern traffic loads many times greater than the design loading envisaged when they were originally built. Structural analysis of this type of structure is less precise than that for steel or concrete, but arch bridges 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.

12.4.6 Cable structures

Cable structures are the most innovative form of bridge and are used for most of the long-span bridges in use today (Figure 12.9). Cable structures are light and efficient but are only economical for long spans due to the complex design and construction requirements. Suspension bridges support the deck load using a main cable draped between two towers: the cable spans the full length of the bridge and is anchored into the ground through massive anchor blocks at both ends of the bridge. The deck is suspended from the main cable using a series of shorter vertical hanger cables. Cable stayed bridges, on the other hand, transmit the deck loads directly to the towers through a series of inclined cables or stays. The cables in the back span are anchored to the ground through a tension pier. Cable bridges enable long clear spans to be crossed and so are ideal where navigation clearance is required, e.g. across estuaries, or where ground conditions prevent the use of intermediate piers.

12.4.7 Abutments, piers and foundations

Abutments and intermediate piers distribute the vertical and horizontal loads on the bridge to the foundations. Abutments must

Figure 12.9: Cable stayed bridge

also resist the horizontal forces of the soil which is constrained.

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.

Most of the information necessary for designing the foundations will be obtained during the geotechnical surveys (Chapter 5). 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. The piles support the load either by bearing onto bedrock or through friction with the soil along their length. Normally piles are more expensive than concrete footings and require specialist design and construction skills.

12.4.8 River training works

On large and medium sized rivers, bridge sites should be chosen so that training works are not needed. Unless very large sums of money are spent, such training rarely works successfully for long enough and may not be justified. Training works on small rivers and streams should also be avoided if possible but maybe justifiable if there is no other suitable bridge site available within an economic distance.

12.4.9 Approaches

Approaches to bridges, large culverts and other water crossings are essentially part of the road pavement but may deviate from the ideal horizontal and/or vertical alignment, requiring additional embankment material or cuttings. The additional costs, whilst significant, are unlikely to be sensitive to the type of bridge being considered although they will affect the differences in cost between one type of crossing and another.

12.5 MAINTENANCE COSTS

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

12.6 REPLACING EXISTING BRIDGES

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 and these should be considered in the analysis of a project.

A common problem arises where a two lane road includes a series of narrow single lane bridges (Figure 12.4). 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 having to give way to oncoming vehicles. A widening or replacement programme may be appropriate, but should be tested in the economic analysis.

Many large rivers 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.

12.7 COSTS AND DESIGN CHOICE

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

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 but 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 because this will determine whether locally available timber is strong enough.

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.

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.

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 available 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.

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.

A new bridge is usually evaluated in terms of the reduction in transport costs to existing and forecast traffic and the possible development benefits that might result. The reduction in transport costs will relate to the savings in traffic diversion from different routes or the savings in not having to use a ferry. Ferry costs may be either estimated from the physical costs of maintaining, running and, if necessary, replacing the ferry, or in terms of the commercial charges of running the ferry. For large ferries, particularly if a subsidy is involved, the former approach is preferable.

For small ferries run competitively by private enterprise the latter approach will usually be sufficient. There are no reliable standard methodologies for establishing the development benefits that may result from a new bridge. In general the development benefits that are likely to arise will be dependent upon the combined effect of the magnitude of the change in transport costs and the development potential of the area that has improved accessibility.

The costs to the economy of the total failure of a bridge are nearly always extremely high. It is sometimes necessary to quantify the benefits of a proposed investment from the reduced risk of bridge failure or the temporary closure of the bridge. In these cases the benefits will be calculated in terms of the savings of traffic diversion or use of a ferry. However in most instances the need for the bridge is not in question and any investment may be evaluated in terms of minimizing the total long term engineering costs of keeping a bridge in place (i.e. the lowest 'agency cost' solution) together with any traffic disruption involved whilst work is in progress. The benefits of bridge widening are usually identified in terms of passenger time savings and reduced vehicle operating costs associated with the reduced traffic delays forecast from the widened bridge.

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PART 4

Option Selection

13. Cost Estimation

13.1 INTRODUCTION

The purpose of the *final* cost estimate shortly before a contract is awarded for construction is to provide the most realistic prediction possible of the total cash expenditure and the cash flow requirements that will be necessary to complete the project. This will reduce or eliminate the problems that inevitably arise if the tendered contract bid prices are considerably higher (or lower) than expected or the costs of the project escalate during projection execution. However the level of accuracy required at this late stage of project development is much higher than is needed, or can be obtained, at the earlier stages of planning, pre-feasibility and feasibility. It is the purpose of this chapter to explain how cost estimation is best done at each stage of project development so that the expectations of all interested parties are realistic and can be satisfied, appropriate resources for the task can be assigned, and deficiencies can be identified and rectified.

It is important to remember that, as a general rule, costs are closely related to the time that it takes to complete a project and therefore anything that increases this will also increase costs.

13.2 COST COMPONENTS, DATA AND RESPONSIBILITIES

13.2.1 Cost components

Cost estimates for a road project need to include the costs of all factors necessary to enable the works to be completed. Thus the estimate should include the cost of:

- Engineering works included in the main contract
- Environmental mitigation works that are not included in the main contract
- Engineering works carried out by others, for example utilities diversions
- Supervision
- Land acquisition
- Resettlement
- Compensation
- Any surveys, investigations or other special contracts
- Value added tax and other taxes
- An allowance for contingencies

Simple methods are required at the earlier stages of project development but, in order to appreciate how a contractor obtains his bid price, it is worthwhile reviewing, from first principles, how the cost estimates for road works are built up.

Cost of the designed works

It is necessary to determine all of the inputs required on site to complete the work. For each input, the required quantity and its unit cost must be established. Inputs may be small scale, such as hours worked by a labourer (taking into account labour productivity figures), hours assisted by an item of plant (taking into account expected utilization and including fuel and other consumables) or the quantity of cement used in a culvert (taking into account wastage), or the inputs may be large scale such as the length of a constructed road or the number of culverts of a given size. In all cases, the quantity of each input is multiplied by its unit cost to give the total cost of that input. Although inputs such as concreting formwork and road detours are not permanent, they are also costed and assigned to the relevant item.

Cost to the contractor

There are other activities on site which have costs which cannot be related directly to a single input. These include supervisors, administrators, site transport, safety measures, first aid provision, training, insurances (public and site accident), mobilization including any import duties for equipment, site camp construction, gravel prospecting, production of drawings, maintenance of completed road lengths until the final handover and so on. The quantity and the cost of each need to be estimated.

Price charged to the client by the contractor

Next, there are costs which are added to give the likely figure which the client will pay to the contractor in order to obtain the designed works. These include risk (for example, in case the contractor incurs costs due to delays caused by bad weather, unavailable labour or poor sub-contractor performance), profit, tax and financing charges such as interest on loans when buying equipment.

It is normal for the client to include a contingency in a cost estimate to allow for error between the clients cost estimate and the final cost charged by the contractor (i.e. the contractors bid price plus variation orders and claims throughout the construction period). The contingency at the pre-feasibility stage will be higher than at the feasibility stage and this, in turn, will be more than at the final design stage because there are more assumptions and unknowns in the earlier stages. However, care should be taken to avoid adding contingencies to all components separately and inadvertently adding the same contingency more than once. In fact it is likely that some items will be underestimated and so the magnitude of a sensible contingency at each stage may not be as large as one might first assume.

The total cost to the client

Finally, there are additional costs which the client is likely to have to pay to other parties in order to allow the contractor to construct the designed works. These include the costs of feasibility studies, surveys, investigations, design, supervision, land acquisition, tendering, procurement, construction of associated works by others, environmental mitigation not included in the contract, resettlement and compensation, and final claims.

Long term costs to the client

Most cost estimates are carried out for capital costs but any investment in infrastructure requires investment in annual maintenance and consideration of whole life costs is recommended.

13.2.2 The role of the estimator

The key component of any cost estimate is the engineering designs that are being costed and therefore the cost estimate can be no more accurate than the designs themselves (see Box 13.1). Cost estimation requires very close liaison between the estimator, the other technical experts involved in the project and the project design organization, so the estimator will normally be part of this organization. The estimator must also communicate with the client and the funding agency.

It is essential that the estimator is able to appreciate the conception 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. Thus 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 site of the proposed project.

The estimator should be accountable for the estimate and should be involved in the subsequent monitoring of project costs against it. He (or she) should be responsible for employing the estimating technique most appropriate for the type of project and its stage of development. In reaching this decision, the estimator should note the strengths and weaknesses of the various estimating techniques employed and the sources of data.

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 organization. When a new estimator has to be appointed, for whatever reason, or when a check estimate is required from a separate estimator, it is important to ensure an orderly transfer of all relevant information so that the new estimator is able to become accountable for his estimate and the subsequent cost control against it.

Box 13.1: Accuracy of cost estimation

At the final engineering design stage the level of detail needs to be sufficient for the estimated cost to be within the required tolerances built into the financing. Thus the level of detail will increase through each stage of project development to ensure that the level of accuracy is appropriate at each stage of the process.

At the feasibility stages it is not practicable to estimate the costs of individual projects to a very high level of accuracy. However, good procedures at these stages should be subject to random rather than systematic errors so that when assessing a programme or portfolio of investments, such as a 5-year plan for example, the *total* cost should be known rather more accurately.

There is no point in producing detailed cost estimates of components of the project if there are major uncertainties that limit the achievable level of accuracy of the estimate as a whole. If these uncertainties cannot be resolved, the level of detail of the cost estimation needs to be adjusted accordingly.

13.2.3 Data collection

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

Project specific data are in two forms:

- Current costs of basic inputs to the work
- Productivity data relevant to the type of work, its location and the particular circumstances surrounding it.

The estimator needs to collect current cost data about a wide range of factors including labour, plant, materials and administration and financial matters. Section 13.7 summarizes all the sources of data.

13.3 METHODS OF ESTIMATING COSTS

There are three basic cost estimating techniques, summarized in Table 13.1.

13.4 THE UNIT RATE, SIMPLIFIED UNIT RATE AND GLOBAL METHODS

13.4.1 Common Features

The global and the unit rate methods are based on historical information from previous projects which, ideally, should be located in 'libraries' or databases of *achieved* costs. The information is used to determine the total cost of a project, or the major elements of a project, in terms of the overall cost for a unit of construction. In the global method the units chosen are very coarse (or global) and might, for example, be a cost per kilometre of single lane carriageway. The unit rate method uses a larger number of smaller units. This allows the cost estimate to be more detailed and more accurate. Thus the global and unit rate methods differ only in the size of the element used as the basis of the unit rate.

	Global rate	Unit rate and simplified unit rate	Operational
Project data required	Size/capacity Location Completion date	Bill of quantities Location Completion date	Materials quantities Method statement Programme Key dates Completion date
Basic estimating data required	Historical achieved overall costs of similar projects (adequately defined) Inflation indices Market trends General inflation forecasts	Historical unit rates for similar work items Preliminaries Inflation indices Market trends General inflation forecasts Plant data	Labour rates and productivities Plant costs and productivities Material costs Overhead costs Labour rate forecasts Plant capital and operating costs forecast
Application	Mostly used in the early stages of the project cycle (i.e. project identification and pre-feasibility)	Used in feasibility studies, particularly where the study adopts a process of early screening and evaluations of a number of options.	Always used for final design work and in tenders

Table 13.1: Cost estimation techniques

Cost item	Quantity	Unit	Rate Rp 10^3	Total Rp 10^6
Roadworks costs				
Drainage				
Rural 2 lane undivided carriageway	995	m	10.5	10.4
Urban 2 lane undivided carriageway	450	m	125.5	56.5
				66.9
Earthworks and demolition				
Clearing and grubbing	394,890	m^2	0.8	315.9
Common excavation	258,690	m^3	6.8	1,759.1
Embankment with materials from common or borrow	629,805	m^3	16.0	10,076.9
Demolition of masonry/concrete	1,735	m^3	17.9	31.0
Demolition of buildings	8,265	m^3	14.9	123.2
				12,306.1
Shoulders				
Shoulder	20,610	m^3	51.6	1,040.3
				1,040.3
Sub-base and base				
Aggregate base class A	31,635	m^3	54.0	1,708.3
Aggregate base class B	9,685	m^3	52.2	505.6
Asphalt treated base	35,355	m^3	254.5	8,997.8
				11,211.7
Surfacing and pavement				
Prime coat	257,810	l	0.8	206.2
Tack coat	53,130	l	0.9	47.8
Asphaltic concrete surfacing	236,295	m^2	12.2	2,882.8
				3,136.9
Roadwork costs				**26,721.6**

Table 13.2: Example of the simplified unit rate method

The unit rate method is based on the 'bill of quantities' approach to pricing construction work. In its most detailed form, a bill will be available containing the quantities of the different types of work 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 (e.g. price books for civil engineering), or 'built-up' rates from his own analysis of the operations, plant and materials required for the measured item.

When a detailed bill is not available or when less effort is required at the early stages of project development, the unit rate method is normally simplified so that the items in the bill of quantities are very much less detailed than those used in bid documents. The simplified bill of quantities must be chosen carefully so that it is based on items that can be measured or calculated directly from available information. 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 (an example is shown in Table 13.2). In extreme cases, the simplified unit rate estimates are essentially the same as the global estimates described below.

As an example of rolled-up items and rates, the pavement construction cost could consist of:

- All of the items that normally appear at the bidding stage in the section of the bill of quantities headed 'pavement' rolled-up into a single item called 'pavement'
- Alternatively, the costs of the various items that normally appear in the section of the bill headed 'pavement' may be split into categories relating to main carriageway, interchanges, side roads, and other items. The decision on how to roll up the various items should be made to reflect the circumstances of the project.

Rolled-up rates are produced by adding up the whole cost of all the items included in the rolled-up item, and dividing that total cost by the quantity of the individual item that is being used to represent the rolled-up item. For example, the rolled-up item 'pavement' might represent the cost of the wearing course, binder course, roadbase, sub-base, capping layer, kerbing, footways, and any other items that the estimator decides should be included in that rolled-up rate. The measured item might be the surface area of the wearing course because this can be easily measured from the simplest of conceptual design drawings.

Clearly it is important that the projects used as the source of information are similar to the proposed project in terms of traffic loading, ground conditions and any other features that might affect the pavement design. It is important that the total cost used to derive the rolled-up rate includes any percentage additions that are applied elsewhere in the original bill.

Since the estimate is compiled by the direct application of historical prices and does not require an examination of the programme of work and method of construction, it does not encourage consideration of the particular peculiarities, requirements, constraints and risks affecting the current project. Therefore, it does not provide an analysis of the actual costs of work of the kind that would be carried out by a tendering contractor for any but the simplest of jobs. Thus, when using unit rates from previous projects, great care is needed to ensure that account is taken of the actual completion costs of the project. The effective rates, taking account of subsequent claims, may be much higher than the bid rates. Failure to allow for such increases will result in major under-estimation of costs.

The global method is the 'broadest brush' approach and its approximate nature means that it is usually only suitable at the planning and pre-feasibility stages of project development; it is not suitable for the feasibility stage. However, if the method is refined and made more detailed, for example, by separating roadwork costs and bridge costs, it begins to approach the unit rate method which is the preferred choice for estimating costs at the feasibility stage.

13.4.2 Common problems

There are a number of potential problems with unit rates that affect the accuracy of the cost estimate and which need to be borne in mind at all times during the process. Since global rates are essentially rolled-up rates from more detailed unit rates (although they may never have been broken down in this way) the potential problems associated with detailed unit rates also apply to global rates.

Predicting the change in prices with time.

These methods have the great advantage that they are based on the actual costs of completed projects rather than their predicted or tendered costs but, since the techniques rely entirely on historical data, their main disadvantage is the difficulty of predicting how prices have changed since the earlier projects were completed. This difficulty arises for the following reasons:

- Historical data needs to be related to a specific 'base' date that must be chosen with care. In the case of construction work carried out over a period of time, it can be difficult to choose a suitable date that reflects average costs during the construction period.
- The only practical method for updating costs is to use some form of price index to represent inflation. This can introduce a degree of uncertainty, especially when there has been significant inflation.
- Contract prices are also subject to significant fluctuations in response to market conditions. These affect not only the current project being appraised but will also have affected the projects on which the cost data are to be based. The fluctuations cannot be accurately represented in price indices and will vary with the type of project, with the host country and also with any country providing supplies or resources.
- In general, the more recent the previous projects, the more reliable the cost estimations are likely to be.

Understanding which costs are actually included in the historic data.

To use the historic information properly it is necessary to understand fully what is included in each cost and what is not. This may be difficult unless good documentation is available or the database of information has been managed reliably. The following costs normally need to be included and care is needed to ensure none are missing:

- Engineering fees and expenses of consultants/contractors/client, including design, construction supervision, procurement and commissioning

- Final accounts of all contracts including settlements of claims and any other payments.
- Land acquisition costs
- Transport costs of materials
- Financing costs
- Taxes.

If the costs have been itemized in sufficient detail, as should be the case for the unit rate method, then this problem is much less likely to arise.

Understanding what is included in the unit of measurement.
This is similar to the previous problem of costs; it is also important to understand the unit of measurement and to be confident that all the historic data has been dealt with in the same way. For example:

- Is the cost of a metre/kilometre of road an overall average that includes pro rata costs of bridges or have these been estimated separately?
- Does the cost of a square metre of bridge deck area include pro rata costs of abutments?

Once again, this is less likely to be a problem if the historic costs have been itemized in sufficient detail.

Not comparing like-with-like.
There are many factors that can have a very substantial influence on the costs of a road, so it is important that costs are obtained from projects that are as similar as possible to the project being appraised. Many of these are engineering factors, but not all. For example, large influences include:

- Differing levels of quality e.g. different pavement thicknesses for different levels of traffic
- Different terrain and ground conditions e.g. flat plains compared with mountainous regions, weak swampy ground compared with strong, dry ground
- Different logistics, depending on site location
- Prices of items taken out of total contract prices may be distorted by front end loading by the contractor to improve cash flow.

Statistical reliability (sample size)
The issue of statistical reliability (or sample size) is closely associated with the inevitable problem of comparing like-with-like. Considerable non-specific project-to-project variability exists. To minimize its effect and to ensure that the results are statistically reliable the historical data need to be obtained from a sufficiently large sample of similar work in a similar location and constructed in similar circumstances. It is often difficult to find such projects. Historical data from only one previous project is unlikely to provide a satisfactory cost estimate but is often the only option available.

13.4.3 Accuracy of the methods

The accuracy of the cost estimate relies on the assumption that the unit rates for the project being evaluated will be similar to the historic unit rates obtained from the 'source' projects. For the reasons outlined above, this is not always easy to justify and, even when sufficient information is available to define the source projects in greater detail, it is not easy to compensate for the differences. Thus a scrutiny of all the problems discussed above, especially the effects of inflation, must be made before any reliance can be placed on a collection of cost data. It also follows that the most reliable data are those maintained by a specific organization where there is confidence in the management of that data. The wider the source of the data, the greater is the risk of differences in definition.

However, at certain stages in the development of projects, the unit rate or global methods are the only practical method for estimating the costs. Fortunately, during the screening or evaluation stages, the errors likely to be introduced will be applicable to all the options being screened or evaluated, therefore the choice between options is likely to remain valid despite the possibility of systematic errors in costing. It is also worth noting that as long as care is taken in the choice of source data, the global technique can be more reliable than estimates derived from apparently more detailed unit rates that have been obtained from separate unrelated sources and applied to rough estimates of the quantities involved.

The unit rate method (Box 13.2) is most appropriate for 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.

There is also a real danger that the precision and detail of the individual rates can generate a misplaced level of confidence 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.

Despite the difficulties, 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.

At the engineering design stage it is important that the cost estimate is as accurate as possible, hence it may be necessary to use a different estimating method namely the operational method. This is essentially outside the scope of this Road Note but, for completeness, it is described in Appendix D.

13.4 COST ESTIMATING STAGES AND APPROPRIATE METHODS

The stages of a project have been described in Chapter 2. Table 13.3 summarizes the type of information and the most appropriate method of estimation for each stage of the development of the project. In some projects some of these stages may be omitted or may be indistinguishable from adjacent stages, especially if the project does not lend itself to different options (for example, some straightforward road strengthening projects).

Box 13.2: Summary of the unit rate method

1. Choose source projects that are of a similar type to the proposed project.

2. Obtain priced bills of quantities and information regarding the actual out-turn cost of the projects after allowance for all claims and other cost increases.

3. Choose a particular topic for which a unit rate is required, for example, drainage.

4. Add up all the bill items relating to that topic. For example, in the case of drainage, add up the total bill cost of all items relating to drainage. This total should be adjusted to take account of any increases in the cost of the project resulting from claims or other factors.

5. Decide what single item would be appropriate to represent the relative cost of drainage on the proposed project compared to the source projects. This item will be used to represent the total of all drainage costs. The item chosen must be something that can be measured from the drawings that are currently available. For example, it would not be appropriate to use the total length of drainage pipes if the pipes have not yet been designed or drawn. It may be possible to represent the cost of drainage in terms of the total road surface area of the project.

6. From the source projects, determine a unit rate for drainage in terms of the unit chosen. For example, as a cost of drainage per square metre of the road pavement.

7. Use the same rate to calculate the total cost of all drainage works for the proposed project by multiplying this unit rate by the total area of road pavement on the proposed project.

8. It may be possible to improve the estimate by taking account of any known differences between the source project and the proposed project that might lead to a higher or lower rate.

It is important to strive for the ideal of evolving a cost history for the project from start to finish with an estimated cost total at each stage. This ideal can only be approached if the rising level of definition throughout the stages of the development of the project is balanced by decreasing 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.

A record of the actual costs achieved should be archived in order for a review of the cost performance of the project and for project evaluation to be carried out at a later date. It should include a reconciliation of the actual use of contingencies and of the use of tolerances for dealing with major risks.
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 organizations 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. The availability of a reliable, well managed, global cost data bank together with associated ‘broad brush’ analyses is an essential requirement for any organization involved in the early identification of projects for inclusion in a forward financial programme.

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. 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 are therefore the global and the unit rate methods.

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

- 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 an increased likelihood that the effects of risk, delay and inflation will not 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
- For all ‘one-off’ jobs, there is no credible alternative to operational estimating.

13.5 CONTRACT STRATEGY

The choice of construction contract 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.

The following four types of contract can be used:

- Lump sum payment based on a single price for the total work
- Measurement contract with payment for quantities of completed work, valued at tendered unit 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. In lump sum and measurement contracts

Stage of project development					
	Within the scope of this Road Note			Outside the scope of this Road Note	
	Identification	**Pre-feasibility**	**Feasibility**	**Design**	**Implementation**
Purpose	Inclusion in transport strategy	Inclusion in forward programme. Preliminary report for use in a submission for funding. (Note 2)	Preferred scheme identified (Note 1). Project definition report for detailed submission for Funding	Funding approved for preferred option. Basis for cost control.	Basis for assessment of tenders and ongoing monitoring of costs and progress against approved estimate
Available information for estimate	No design - capacity/size only	Generic design based on similar projects.	Preliminary designs of alternatives.	Engineering design	Tender documents
Methods of estimation	Global	Global	Global or unit rate	Operational or unit rate	Operational

Table 13.3: Project stages and cost estimating techniques

Notes
1 The essential property of these estimates is that they are directly comparable with each other. Therefore base estimates could suffice so long as the same estimating technique and price base data are used. However, in this case, the differences between alternatives will not necessarily be absolute and the danger of their use for forward budgeting must be avoided.
2 If international funding is required, it is essential that preliminary discussions begin as early as possible.

(i.e. price-based), 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 either extremely high prices or in offshore contractors being reluctant to tender at all.

In a cost-reimbursable contract, the client 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 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.
Where there is an active construction industry, tendering mobilizes 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 these conditions are not met, it is likely that negotiation of a cost-plus form of contract is more likely to be practicable. A mixed approach is often adopted with initial tendering followed by negotiation on some aspects of the contract.

There are strong developmental arguments for using local construction capacity where this is available. Not only will this usually be less costly to mobilize but the experience gained will strengthen the industry and help the country to be self-sufficient. There will also be multiplier effects on other sectors of the economy. For these reasons some donors treat local contractors preferentially, however, great care should be taken to make sure that quality is not compromised because, in the long run, the whole life costs of the project will become substantially higher.

13.6 THE FORMAT OF THE ESTIMATE

13.6.1 Information in the estimate

The information required by the estimator includes 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.

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

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

In all cases the estimator should also be required to submit a method of construction and a contract strategy report.

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.

13.7 SOURCES OF DATA

13.7.1 Principal sources

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 organization.
- Published data.

Project specific data

These 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.

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

- Hourly 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.

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 and road administrations
- Contracting organizations (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.

Some of the required information is available in the client organization already and some is actually generated internally and should therefore be particularly reliable. Considerable time and effort could be saved, and potentially serious errors avoided, if this information is well managed so that it is up to date, reliable and easy to retrieve and interpret. This underlines the importance of managing information properly within the client organization.

The translation of the base estimate to a cash estimate usually requires additional information. For example, information on overheads, profit, finance charges, tax, social charges, elements for risk and information on inflation and exchange rates (the latter will be normally available from government sources, financial institutions and publications).

Data banks

Each estimating organization 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 because the management and interpretation of the information is within the control of the organization and therefore consistency in its application should be assured. However, the reliability of any data bank depends on:

- Size of the sample
- Acceptance throughout the organization of standard methods of measurement and definitions of terms
- Recording of any special factors and circumstances which affected the performance of any historic project
- Applicability of data to the specific circumstances, including location and duration, of the project being estimated.

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

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

Cost data

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.

Productivity data

Productivity data are needed if unit rate or global costs are to be developed from scratch (and for the operational method). These data cover outputs and possibly utilization 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
- Utilization figures for the production units.

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 m^3 of clay material’, together with utilization 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 utilization figures for the production unit.

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 utilization must be recognized.

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 utilization.

Such productivity data are unaffected by inflation and therefore can be applied wherever similar circumstances for the works are foreseen.

An example of a data source is ROad Costs Knowledge System (ROCKS), a World Bank initiative to provide an international knowledge system on road work unit cost for road preservation and development activities. It is an institutional memory (database) that collects historical data on road work costs per kilometre or per m^2. The system is not fully functional at the time of going to press, but could prove to be a useful future source of information.

Published data

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 per cent to 30 per cent 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.

DETAILED SOURCES OF INFORMATION

Davis Langdon (editor) (2004). *Spon’s Civil Engineering and Highway Works Price Book* (2005) 19th Edition. Spon Press.

This annual publication contains current UK unit costs for a vast and detailed range of civil engineering activities as well as a range of large scale approximate costs and summary guidance on producing a cost estimate.

John Williams (editor) (2005). *Estimating for Building and Civil Engineering Works.* 9th Edition, Butterworth Heinemann.

This publication contains detailed guidance on preparing a tender estimate for building and civil engineering works.

14. The Benefits of Road Investment

14.1 PURPOSE

In order to analyze the economic worth of a project, estimates need to be made, not only of the costs associated with the project, but also of the benefit streams that are expected to occur as a result of the road investment. 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
- Other benefits not captured in the above (like wider effects on the economic development of the region, and social and environmental benefits).

It is useful to identify the benefits from road investment as either primary or secondary benefits. The primary benefits are the directly measurable 'first round' traffic related effects. Examples of primary benefits include transport or accident cost savings. Secondary benefits arise at a later stage and include changes in land values or the wider economic development generated from the investment. Secondary benefits are very difficult to isolate and measure; in addition it would involve double counting to add primary and secondary benefits together. For example, in theory, reduced transport costs will directly induce a rise in land values; to add changes in land values to transport cost savings would involve double counting.

In general, the more competitive and less distorted an economy, then the more likely it is that the primary traffic benefits will cover the full consequences of a road investment. The arguments for introducing secondary benefits into the analysis are strongest in the following circumstances:

- For remote new rural transport infrastructure investment,
- Where a relatively large change in transport costs are anticipated
- Where there are unemployed resources
- The local economy is perceived to be uncompetitive and weak.

Social benefits (described later) are very much part of secondary benefits. Any analysis that includes social benefits has to be wary of the possibility of double-counting and appropriate action should be taken to resolve the problem.

All types of benefits should be considered for all projects although, depending on the type of project, different benefits will predominate. The main benefits of different types of road investment are listed in Table 14.1.

14.2 VEHICLE OPERATING COST SAVINGS

14.2.1 Factors affecting vehicle operating costs

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.

Vehicle operating costs (VOC) 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 uneveness 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.

The components of vehicle operating cost with their approximate respective contribution to the total are given in Table 14.2.

Vehicle capital costs, driver and conductor labour costs, passenger and freight values of time and overheads are sensitive to trip time. So savings in these items will arise from road improvements that increase speed (e.g. a road widening) or reduce trip distance (e.g. a new road link).

Fuel, tyre and oil consumption and vehicle maintenance costs are all sensitive to trip distance. In addition fuel is sensitive to vehicle speed. At slow speeds fuel consumption (per km) is high, while it is at a minimum at speeds around 40 – 50 km/h and rises gently as speeds increase beyond this. Fuel consumption is also higher with stop-start movements that occur with urban road congestion. Tyre and maintenance costs are sensitive to road roughness, the highest vehicle maintenance costs correlating with the roughest roads.

14.2.2 Non-motorized transport

Non-motorized transport is still important in many locations of the developing world. Headloading, bicycles, rickshaws and animal powered transport are widely used to transport both freight and passengers. Where the analysis calls for information on these types, estimates of the costs of operating these various forms of transport can be made from surveys of the providers (both the 'drivers' and the owners, as appropriate).

Road investment	Main benefits
Inter-urban road rehabilitation, improvement and widening	The main form of economic benefits is the reduction in vehicle operating costs (VOCs) resulting from a reduction in road roughness. An investment in road pavements (e.g. an overlay) will also reduce the rate of road deterioration and hence the need for more routine maintenance expenditure. Road widening will increase the capacity of the road and result in an increase in vehicle speeds that will also change VOCs and generate passenger time-savings. For inter-urban roads traffic forecasts are largely based on long-term trends of existing traffic volumes using growth factors.
Rural access road improvements	Economic justification for the investment rests mainly on the expected impact on rural and agricultural development, and social mobility that greater accessibility yields. In estimating these benefits, it is important to ensure that 'double counting' does not take place in the appraisal. It is also apparent that many of these benefits are unquantifiable in money terms.
Urban road improvements	The main forms of economic benefits identified from improving particular urban road links are the reduction in VOCs, passenger time savings and changes in road maintenance expenditures. These benefits arise from both the reduced road roughness from improved road surfaces and faster vehicle speeds from the road widening or removal of bottlenecks.
Bridge rehabilitation, widening and replacement	The costs to the economy of the total failure of an existing bridge are nearly always extremely high. It is sometimes necessary to quantify the benefits of a proposed investment from the reduced risk of bridge failure or the temporary closure of the bridge. In these cases the benefits will be calculated in terms of the savings of traffic diversion or use of a ferry. However in most instances the need for the bridge is not in question and any investment may be evaluated in terms of minimizing the total long term engineering costs of keeping a bridge in place (i.e. the lowest 'agency cost' solution) together with any traffic disruption involved whilst work is in progress. The benefits of bridge widening are usually identified in terms of passenger time savings and reduced VOCs associated with the reduced traffic delays forecast from the widened bridge.
A new bridge	A new bridge is usually evaluated in terms of the reduction in transport costs to existing and forecast traffic and the possible development benefits that might result. The reduction in transport costs will relate to the savings in route shortening and/or the savings in not having to use a ferry. Ferry costs may be either estimated from the physical costs of maintaining, running and (if necessary) replacing the ferry, or in terms of the commercial charges of running the ferry. For large ferries, particularly if a subsidy is involved, the former approach is preferable. For small ferries run competitively by private enterprise the latter approach will usually be sufficient. There are no reliable standard methodologies for establishing the development benefits that may result from a new bridge. In general the development benefits that are likely to arise will be dependent upon the combined effect of the magnitude of the change in transport costs and the development potential of the area that has improved accessibility.
Major urban road investment and traffic management schemes	The main benefits are the predicted passenger time savings, reduced VOCs and accident savings from less congested traffic conditions. The analysis of any road investment or traffic management scheme that involves a major change in the pattern of traffic flows in an urban area will invariably require the use of an urban transportation model which will provide estimates of trip distances, trip times, link volumes and link speeds. From these outputs the changes in VOCs and the wider economic consequences can be calculated although they will need to be modelled separately. Though much urban transportation modelling assumes a 'fixed trip matrix', (i.e. there is no 'generated traffic' so no new trips are forecast as a result of the investment change), it should be possible to introduce generated traffic into the model. However, both the traffic modelling and its associated economic treatment are uncertain and complex.
New toll road investment	The economic benefits of a toll road are similar in character to an inter-urban road (or a major urban road for an urban toll road). The main difference is in the nature of the traffic forecasts. These will be different because the traffic diversion to the toll road will be dependent upon the level of forecast tolls. The benefits that users receive from using the toll road will be covered by the difference in transport costs identified in the economic analysis. Toll revenues, therefore, should not normally be included separately within the economic analysis. Toll revenues are, of course, an integral part of the financial analysis. The financial analysis will just cover the toll road while the economic analysis will cover both the toll road and traffic flowing on adjacent roads from which traffic has been diverted. The decision to build a toll road will, of course, be dependent upon both types of analysis.
Investment in road junctions	The main predicted benefits of junction investment are passenger time and VOC savings resulting from reduced journey time, as well as reduced accident rates. Although there are computer models to predict changes in journey time from junction improvements, the prediction of VOC savings and the associated economic analysis needs to be estimated separately.

Table 14.1: Key benefits of different types of road investment

Component	Percentage contribution	
	Private cars	Trucks
Fuel consumption	10-35	10-30
Lubricating oil consumption	< 2	< 2
Spare parts consumption	10-40	10-30
Vehicle maintenance labour hours	< 6	< 8
Tyre consumption	5-10	5-15
Vehicle depreciation	15-40	10-40
Crew costs	0	5-50
Other costs and overheads	10-15	5-20

Table 14.2 : Relative contribution of vehicle operating cost components

14.2.3 Road investment models

Computer models are available for assisting in the calculation of vehicle operating and maintenance costs under a range of conditions and hence estimating cost savings as a result of road projects (see Box 14.1). Road planning models such as HDM-4 use VOC relationships that are based on research that has been carried out in a number of countries. HDM-4 is an important source of information on how VOCs change with road condition. However, because wide variations in VOCs have been found in different countries (for the same input assumptions), it is very important to calibrate the models to the local conditions. To use HDM-4 to calculate VOCs the following vehicle input data are required:

- Input prices (without tax and duties) of new vehicles, fuel, new and retreaded or remoulded tyres, oil, crew costs, passenger and freight values of time, maintenance labour costs and overhead costs
- Vehicle and load weights, vehicle and axle configuration, number of wheels, fuel type, engine power
- Vehicle utilization in terms of annual distance travelled and hours worked per day
- Average vehicle age.

For calibration data on typical maintenance costs, tyre wear and fuel consumption are very useful. A mini guide to estimation of appropriate input data is given in Appendix C.

Box 14.1: Highway Cost Models

Highway cost models were initially developed to compute the total transport costs of an individual road project over the 'whole life' of the road and were therefore potentially very useful tools for the economic appraisal of road projects. For example, the first model in the Highway Design and Maintenance Standards Model (HDM) series provided detailed modelling of (a) the engineering behaviour of roads (i.e. how they deteriorate), (b) how maintenance (both minor and major) affects this, (c) how the condition of the road affects the performance of the vehicles operating upon it and (d) the cost of operating those vehicles. The model then calculated the total whole life costs namely the cost of road construction, road maintenance, vehicle operation, and travel time so that an economic evaluation of the engineering alternatives could be made. Subsequent versions of the model provided the facility to evaluate the optimum choice of maintenance, upgrading and construction investments for an entire road network and became an important component of highway network management systems.

The successful use of HDM III over many years subsequently led to the development of a new and greatly expanded version, HDM 4. The HDM 'system' was renamed the 'Highway Development and Management System' to reflect its greater scope and versatility. HDM-4 also considers non-motorized transport, social benefits, road accidents, unpaved roads, flexible and rigid pavements, vehicle emissions and more, thereby providing a powerful system for the analysis and optimization of road maintenance and investment alternatives. It incorporates three main areas of applications namely project level analysis, network level investment programming under constrained budgets, and strategic planning of long term network performance and expenditure needs. HDM 4 effectively superseded HDM-III in 2000 and is the recommended software for evaluating highway investment options.

Simpler models requiring less input data but based on similar principles have also been developed for specific purposes. For example, the World Bank's Road Economics Decision Model (RED) is useful for appraising rural roads carrying low levels of traffic.

14.3 ROAD MAINTENANCE BENEFITS

14.3.1 Introduction

Many developing countries experience difficulties in carrying out adequate maintenance. 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. 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.

14.3.2 Paving gravel roads

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.

The actual traffic level at which paving becomes economic should normally be determined using cost models such as those described in Box 14.1. 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.

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.

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, environmental and agricultural benefits may arise as a result of paving gravel roads, but these are difficult to quantify in an economic analysis.

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.

14.3.3 Strengthening and reconstruction

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 routine 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. Road investment models, such as HDM-4, can be used to assess maintenance benefits in these cases.

The cost of strengthening and reconstructing paved roads is considerably greater than the annual cost of routine 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.

14.3.4 Concrete roads

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 (see Chapter 9).

14.3.5 Diverted traffic

If significant traffic diversion from other roads is expected to take place as a result of a new project, 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.

14.3.6 Traffic delays during maintenance works

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 Chapter 15). 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.

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 projects 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.

14.3.7 Determining maintenance costs

Maintenance costing systems that are implemented in organizations 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 percent 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.

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 organizations 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.

14.4 TIME SAVINGS

14.4.1 General considerations

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.

14.4.2 Vehicle fleet

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 utilization in the 'with' and 'without' project cases, these cost savings will be determined directly.

It is often argued that, in practice, time savings cannot be properly utilized and, as a result, will not lead to pro-rata reductions in fleet size. The reasoning for this is that currently most journeys are 'quantized' 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 visualize 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.

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 percent 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.

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.

The discussions above are less appropriate for privately-owned cars. 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. Taxis should be considered in the same way as other commercial vehicles

14.4.3 Vehicle occupants

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.

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, shadow priced if appropriate (see Chapter 15).

The value of non-working time is usually based on perceived-cost studies (Box 14.2). 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 percent 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 percent 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 maximizes 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.

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

Box 14.2: Methods for estimating the value of time

There are two main methods of estimating the value of time.

Revealed Preference (RP). This is based on observing choices where people can choose between a slow but cheaper form of transport compared with a more expensive but faster form.

Stated Preference (SP). This is based on asking people to choose between different combinations of hypothetical choices.

Although the RP approach may be considered to be more reliable, in practice the approach is constrained by the limited range of choices that are practically available. Because of its inherent flexibility the SP approach is now the principal method of valuing time.

Based on an RP analysis, for many countries non-working time has been valued at about one third the wage rate. New research now tends to suggest that poorer people value their time at a higher rate, in relation to their incomes, than the richer sections of the population. Some studies have found, in consequence, that for inter-urban travel the value of time may even be valued higher than the wage rate. Because the value of time is dependent upon income levels the observed value will vary for different classes of user (e.g. between bus and car users).

Within an economic analysis, values of time are required to forecast how traffic volumes will switch between different modes and routes (e.g. with the introduction of a toll road). In this case different empirical values of time (e.g. between bus and car users or between different income groups) will improve forecasting accuracy. Values of time are also required in final valuation of benefits. In this case most countries have, for equity reasons, chosen not to differentiate values of time between different regions and to use just one value of non-working time for all users.

normally a function of factors other than a trade-off between time and cost, such as comfort and convenience. For example, walking and waiting times may be valued more highly than travelling times.

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

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

14.4.4 Freight

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 immobilized 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.

Studies of modal choice for goods travelling by road and other modes have suggested that, even for non-perishable 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.

14.5 VALUING ACCIDENT SAVINGS

14.5.1 The need to value road accidents

Road improvements are likely to yield a benefit from reduced road accidents, and this benefit should be captured in the road appraisal. There is a cost associated with road accidents which must be quantified. A reduction (or increase) in this cost that results from the road investment is the ‘safety’ benefit (or disbenefit) of undertaking the improvement. A detailed accident cost study will often provide information on the costs of accidents in both urban and rural environments and, possibly, for different regions of a country. Ideally such cost information should be available from the appropriate department of government. How these costs are estimated is discussed below.

14.5.2 Methods available to value road accidents.

The cost of road accidents depends to some extent on the method of valuation that has been used. There are two basic methods namely the ‘gross output’ or ‘human capital’ (HC) method and the ‘willingness to pay’ (WTP) method. The most appropriate of these is the willingness to pay approach, but there are difficulties in obtaining reliable empirical estimates and so the gross output approach is preferred. In order to try to capture some of the ‘humane’ considerations reflected in the willingness to pay approach, gross output values are often augmented by a further allowance for ‘pain, grief and suffering’ of those involved in road crashes.

14.5.3 Classification of accidents

In road safety studies accidents need to be classified for costing purposes. Accidents may involve injury to a person i.e. ‘personal-injury accidents’ or alternatively, may result only in damage to vehicles (and possibly property), in which case they are termed ‘damage-only accidents’. It is standard practice for these accidents to be further classified as being fatal, serious or slight. The typical definitions that define accident severity are:

- A fatal accident is one in which one or more persons are killed as a result of the accident, provided death occurs within 30 days
- A serious accident is one in which there are no deaths but one or more persons are seriously injured i.e. usually detained in hospital as an 'inpatient'
- A slight accident is an accident in which there are no deaths or serious injuries but a person sustains an injury of a minor character such as a cut, sprain or bruise or receives outpatient treatment
- A damage-only accident is one in which no one is injured but damage to vehicles and/or property is sustained.

Accident severity is defined by the most serious casualty class of any of the victims of the incident and road accidents are normally costed by the class of the accident. Thus the 'cost of an accident' is not the same as the 'cost of casualties' resulting from that accident.

14.5.4 Costs of accidents

The costs associated with a road accident include:

- Lost future output
- Property damage
- Medical
- Police and administration
- Pain, grief and suffering.

Value of the loss of output. Road accidents lead to a loss of output in the year in which the accident occurs and, in the case of fatal and very serious accidents, in future years also. In this situation costs in future years are discounted to give present day values. The value of lost output is obtained from the national average wage rate before the removal of taxes multiplied by the working time lost as a result of the accident. Certain assumptions have to be made about the working time lost as follows:

- In the case of a fatal accident, the number of 'person years lost' is determined by obtaining the average age of road accident fatalities and subtracting this from the average age at which a person ceases to work
- In the case of a serious accident, costs are determined from the average number of days that the casualty spends in hospital and then spends recovering at home
- In the case of a slight accident, the costs are determined from the (relatively small) number of days that the casualty is not working due to attending a doctor's surgery, a clinic or hospital (as an outpatient) to receive treatment, or being at home convalescing.

Cost of medical treatment. The medical costs resulting from road accidents arise from treatment in hospital (inpatient and outpatient), treatment by general practitioners, and the use of ambulances. The average costs are worked out from information about the average of the following quantities:

- Length of stay in hospital
- Cost per day of hospital treatment
- Number of outpatients visits
- Cost per outpatient visit
- Costs incurred by general practitioners
- Costs incurred by the ambulance service.

All these factors have to be taken into account in the case of serious injuries. Outpatient and general practitioners treatment can be ignored in the case of fatalities and, by definition, inpatient costs cannot arise in the case of slight injuries.

Information must be obtained on a 'per accident' basis and average costs of treatment for persons killed, seriously or slightly injured must be multiplied by the average number of persons injured in the equivalent categories of accident to provide a cost of medical treatment per accident.

Cost of damage to vehicles and other property. There are three basic sources for information on the cost of damage to vehicles namely, insurance companies, garages, and large fleet operators such as bus companies and freight operators. A comprehensive accident cost study will make use of these sources as appropriate.

In some parts of the world cars carry comprehensive insurance (as opposed to third party cover only) and, if the co-operation of insurance companies can be obtained, then making use of information held by them can be invaluable:

- Background information such as age of persons injured, locality, severity of accident, degree of personal injury (if any), number of casualties and numbers of vehicles, etc
- The payment for damage to the insured vehicle and for damage to vehicles and other property belonging to third parties.

If statistics on cost of vehicular repair are unavailable from insurance companies then an alternative approach is to collect information from garages, repair shops and, additionally from bus companies and freight operators.

In most countries damage-only accidents do not have to be reported to the police and accurate statistics are therefore likely to be unavailable. It may be possible to obtain an estimate from insurance records which can indicate the number of vehicles involved in damage accidents per vehicle involved in personal injury accidents.

Administrative and other costs. Other costs that arise as a result of road accidents include those associated with the administration of insurance, the police and court proceedings. In addition, the cost of the delays caused to other vehicles at the scene of the accident should be considered. None of these costs are particularly easy to determine. Administrative costs are likely to be low and it is probably not worth spending much time and effort in producing detailed estimates.

Subjective or 'human' costs. The previous paragraphs dealt with the costs of accidents that directly or indirectly affect the economy of a country. However, there are other important issues to consider, such as suffering and bereavement, that fall upon individuals. Although these are difficult to express in monetary terms their existence is very real to the persons concerned. Moreover they are costs which the community would usually be prepared to meet in order to avoid the misery involved. If costs derived are to be used in the economic assessments of road improvements, then it is important that they should reflect the value that the community places on the saving of life and the avoidance of suffering.

It is therefore necessary to estimate the value that the community places on the avoidance of loss of human life by adding an allowance for 'pain, grief and suffering' to gross output figures. In the absence of other evidence, the percentage additions to the total resource costs for fatal, serious and slight accidents of 46 percent, 100 percent and 8 percent respectively can be used as a first approximation; these are the values currently used in the UK.

14.6 OTHER BENEFITS

In principle, all impacts of road development can be captured by economic theory, and hence included in a cost-benefit analysis (CBA). In practice, the valuation of many of the impacts is beyond the scope of current economic valuation tools. Thus CBA has tended to focus on so-called 'economic' benefits, which are those that can be valued in money terms. In this context, the non-quantifiable benefits are often referred to as social benefits and/or environmental benefits. The division between these so-called economic, social and environmental impacts is often blurred.

Non-quantifiable impacts are often assessed in a qualified manner, and the CBA may be modified to present option rankings (either in simple form, or in some form of multi-criteria or framework analysis, as discussed in Chapter 15). Many environmental impacts can be assiduously estimated, and in many cases roads will need to be designed to meet stringent environmental standards. In the case of 'social' impacts, there is less clear-cut understanding of impacts, and hence little or no attention is given to this category.

For low-volume rural access roads, economic justification for changes in transport condition rests mainly on the impact on local economic development, manifesting itself in extra, generated traffic. However, there are problems with current appraisal methods for estimating and valuing generated traffic and, as a result, the rates of return on low-volume rural roads are often insufficient, on a quantified economic basis, to justify expenditure compared to other public investments.

Social benefits are a wide range of multi-dimensional, interactive and complex non-economic benefits that arise from changes in transport conditions. These include such things as improved social networks and enhanced social capital that are acquired by maintaining links with family members outside of the immediate rural area; improved health and education through easier access to services, particularly with regard to maternal mortality and girls education; improved service delivery by clinics and schools and associated staff attendance.

Providing access and mobility to a range of activities and opportunities, transport must inevitably have a social impact which is likely to be profound. Social movements cover (amongst others) trips to health

Social benefit	Indicators
Increased access to education services	■ Number of schools (primary and secondary) per 100 children in each settlement ■ Enrolment into primary and secondary school (proportion of children) ■ *Actual* attendance at school (frequency) ■ Distance to primary and secondary school and tertiary college ■ Cost of attending school (transport and school fees) ■ Literacy rates
Increased access and use of health services	■ Distance to health facilities (health post, local clinic, hospital) ■ Number of health facilities (health post, local clinic, hospital) per 100 people in each settlement ■ Attendance at health facility (frequency) ■ Cost of attending health facility (transport and medical fees) ■ Life expectancy
Greater access to income and marketing opportunities	■ Proportion of expenditure on social/transport activities (well-connected compared to remote rural settlements) ■ Economic growth measured by improved living standards and income/expenditure ■ Access to/ownership of transport means by income group ■ Acquisition of credit – proportion of trips and cost of journeys to community associations ■ Unemployment rates
Improved transport and mobility services	■ Transport fare per km ■ Proportion of expenditure on transport ■ Proportion of sample that commute to work and commuting time ■ Improved mobility ■ Distance to transport pickup point ■ Passability during wet/dry season ■ Transport fare per unit of goods ■ Cost of fuel per litre
Enhanced social networks and improved social capital	■ Proportion of expenditure on social activities by income group ■ Distance to social activities ■ Frequency of social trip-making ■ Cost per km of social trips ■ Number of places of worship per 100 people in each settlement ■ Proportion of social visits undertaken by men/women/boys/girls ■ Access to/ownership of communication means, by income group ■ Rate of migration to/from settlement

Table 14.3: Indicators for social benefits

centres, hospitals, schools, government offices and to visit friends and relations. They are important because they strengthen the social capital of the individual and may help in personal or community crisis.

Social benefits from changes in rural transport conditions can be seen as:

- Improved social networks and enhanced social capital from people finding it easier to maintain links with family members outside of the immediate rural area
- Enhanced community development that may arise from the community working together to maintain or improve their own transport conditions
- Increased confidence in an ability to travel to access services and opportunities.
- Improved health and education through easier access to services
- Reduced vulnerability to unexpected events and shocks from crop failure, accidents and poor security
- Greater reliability of clinics and schools in securing staff and easier maintenance of these services because drugs can be supplied and school supplies replenished
- Reduced time burdens from engaging in travel due to the improved environmental impact of roads (e.g. less dust) and increased transport service frequency.

The social benefits of changes in transport conditions are best measured with the use of proxy indicators. These indicators are based on participatory enquiry (part of the social impact analysis) which seeks to estimate a community perspective of how transport influences their lives and livelihoods. Examples are shown in Table 14.3.

In order to identify perceived and actual social benefits for individual cases, and to undertake consultation and sensitization of local communities for defining and assessing road appraisal options, it is advised that a robust methodological approach be adopted for measurement of social impact (see Chapter 7).

DETAILED SOURCES OF INFORMATION

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15. Project Analysis

15.1 PURPOSE

Project analysis is usually on the basis of an economic assessment using the framework of cost-benefit analysis (CBA). Some project analyses may adopt a 'cost-effectiveness' approach that will involve some form of ranking projects. Where private sources of funding are being invested in a road, a financial analysis will also be required.

Through identifying, quantifying in monetary terms, and comparing the costs and benefits of each option the economic evaluation is able to provide guidance on the following:

- Is the investment economically worthwhile? In other words, are the benefits greater than the costs?
- If there is a range of options (e.g. alternative road alignments or pavement designs), which option gives the best economic returns?
- Is the proposed project timing optimal? Or, would it be better to postpone the investment to a later date?
- Should components of the project be phased in over a period of time?
- Would it be better to combine the project with other investments or combine with other traffic management measures?
- How should risk affect the choice of projects?
- If funds are limited and there are many worthwhile investments, which should be built first?

An economic analysis considers the project from a national point of view. In a CBA the total costs and the total benefits that arise from a project are identified and measured, irrespective of who incurs the costs or who benefits from the project. Within CBA it is usual to treat each unit (US$ say) of benefits as being of equal value to each individual in society irrespective of his or her income level. No adjustments are made because of income distribution.

An economic analysis is different from a financial analysis in a number of important respects. A financial analysis is usually carried out from the perspective of a particular individual, company or government department, while an economic analysis takes a wider, national perspective. A financial analysis uses conventional market prices while an economic analysis will use 'economic' prices that only reflect the opportunity cost of using resources to the whole society, hence the taxation component of market prices will be omitted (see below).

Whilst conventional CBA is commonly used to prioritize main, secondary and urban roads, other methods are often employed to prioritize low volume rural access or feeder road investments. These procedures are often referred to as cost-effectiveness or multi-criteria analysis. Although there are many formulations, the different procedures do not fit within a conventional economic framework. The procedures often include indicators or measures of social as well as economic demand, need or benefit. Compared with a conventional economic appraisal, less attention is given to the precision of coverage of benefits (which can result in double counting). Sometimes the procedure will include a method of incorporating consultation (either of local communities or officials) in the selection and prioritization of road investments.

15.2 ECONOMIC ANALYSIS

15.2.1 The impact of different forms of road investment

The expectation is that the immediate economic consequence of road investment is to lower transport costs. As a result, economic activity will be changed throughout the 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 near 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.

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 Chapter 14. In these cases, a 'consumer surplus' approach to assessing benefits should be used as described below.

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.

Providing completely new vehicle access can change transport costs dramatically. For example, the cost of head-loading is typically twelve times the cost of motor truck transport per unit of load carried. 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 standard. 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.

15.2.2 Consumer surplus

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 in:

- Vehicle operating costs
- Time costs
- Road accident costs
- A combination of the three.

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 reductions in transport costs are likely to be distributed.

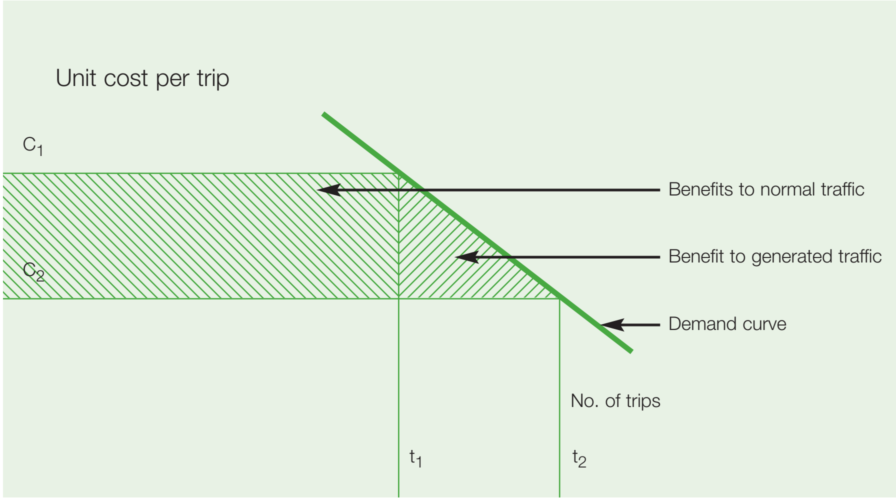

Figure 15.1: Benefits measured as consumer surplus

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. It should be noted, however, that generated traffic and associated benefits are particularly difficult to measure in practice.

Consumer surplus benefits are best estimated using a demand curve as shown in Figure 15.1. 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_8 per day giving:

Benefit to normal traffic =
$(c_1 - c_2)t_1$ per day.

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 Chapter 4. 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 Figure 15.1. 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:

Benefit to generated traffic =
$0.5\ (c_1 - c_2)(t_2 - t_1)$ per day.

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.

15.2.3 Producer surplus

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.

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.

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

- The rise in farm-gate prices brought about by the decline in costs of transporting produce to market
- The decline in transport costs of agricultural inputs.

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. The approach is not recommended unless there is a great deal of knowledge about agriculture and its likely supply response to changes in input and output prices.

15.2.4 Cost-benefit analysis

Principles

This section describes the standard techniques used by economists for CBA. It is included for completeness for the benefit of engineers, transport planners and administrators who may not be familiar with these techniques.

Each project is unique and is likely to have 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 Chapter 13 and benefits should be determined as described in Chapter 14. These costs and benefits can then be compared as described below to determine whether the investment is worthwhile and to identify which is the best of the alternatives being considered.

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 because there is normally an existing road which, in the future, will require some expenditure on 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.

Models are available that compute the necessary CBA outputs based on the input of appropriate engineering and traffic data. The widely recognized software are HDM-4 (see Chapter 13) for major roads and the Roads Economic Decision Model (RED) for rural access roads (see Box 15.1).

> Box 15.1: Economic analysis models
>
> The Roads Economic Decision Model (RED) performs an economic analysis of road investments and maintenance alternatives and is customized to the characteristics of unpaved roads such as: a) high uncertainty in traffic forecasts, road condition, and future maintenance; b) periods during a year with disrupted passability; c) levels of service and corresponding road user costs defined not only through roughness; d) high potential to influence economic development; and e) beneficiaries other than motorized road users. RED is a consumer surplus model designed to help evaluate investments in low volume roads. The model is implemented in a series of Excel workbooks that: a) collect all user inputs; b) present the results in a user-friendly manner; c) estimate vehicle operating costs and speeds; d) perform an economic comparison of investments and maintenance alternatives; and e) perform sensitivity and stochastic risk analyses. The model computes benefits accruing to normal, generated and diverted traffic as a function of a reduction in vehicle operating and time costs. It also computes safety benefits. Model users can also add other benefits (or costs) to the analysis, such as those related to non-motorized traffic, social service delivery and environmental impacts.
> *Source: World Bank*

Prices

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. These adjustments are presented below.

Inflation. A first step is 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 (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. It is also necessary to factor costs and benefits to take account of the different economic values of investments made (or benefit received) 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 sub-sector could, in theory, 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 (back to base year) to convert them to present values of cost (PVC) using the formula:

$$PVC = c_i /(1+(r/100))^i$$

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 and risk also needs separate treatment, the discount rate used on highway projects will differ from market interest rates.

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.

The discount rate normally used is the government accounting rate of interest (ARI). The ARI is the opportunity cost of capital in the public sector, i.e. the rate of return that can be expected on public sector investments. The discount rate to be used in an appraisal will normally be provided to those carrying out the analysis by the planning authority responsible for the project.

Economic prices. As stated earlier, 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 (i.e. of all costs and benefits) should be deducted to give the economic price to be used in the project analysis. This is because these charges do not reflect a demand on real resources but are a transfer of spending power from those benefiting from the project to the government. One obvious example is the removal of fuel tax when accessing the cost of fuel in the analysis. Other transfer charges include such items as vehicle licence fees which should also be excluded.

Shadow Prices. Other distortions 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 will be exaggerated in the appraisal. The converse is also true. To overcome this problem, shadow pricing is used. Thus:

Economic price = market price - transfer charge + effect of other distortions

Some developing countries control the value of foreign exchange to keep it lower in relation to domestic currency than is really justified. The official exchange rate then overvalues domestic currency; imported items appear too cheap and domestic items too expensive. This means 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 carriage insurance and freight, c.i.f.) but excluding import duty. Exports are valued free of any export duty (f.o.b.). This approach will tend to reallocate resources such that 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.

Many developing countries have minimum wage laws or other regulations and inflexibilities which result in wages not correctly measuring 'the opportunity cost of labour'. Where significant unemployment exists, the real cost of labour is much less than actual wage rates being paid. This means that wages of construction workers or truck drivers, for example, may need to be modified to account for overvalued domestic currency.

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.

15.2.5 Alternative ways of comparing costs and benefits

CBA is carried out to determine whether there is an adequate return on a particular project in terms of benefits from the capital investment. This can be done using either the 'net present value' or 'internal rate of return' decision rules (see below). When different project options are available, 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 and the NPV/cost ratio can be used in order to rank schemes in order of priority.

Net present value (NPV)
This is simply the difference between the discounted benefits and costs over the project analysis period.
A positive NPV indicates that the project is economically justified at the given

$$NPV = \sum_{i=0}^{n-1} \frac{bi - ci}{(1+(r/100))^i}$$

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 = planning discount rate expressed as a percentage.

discount rate; the higher the NPV, the greater will be the benefits from the project.

The NPV can only be calculated from a predetermined discount rate must 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 (see earlier). One advantage of the NPV approach is that the result is presented as a sum of money (in whatever currency has been used in the analysis) and is thus 'easy to understand'.

NPV/cost ratio
One problem with the use of NPV is that, other things being equal, a large project will have a larger NPV than a less expensive 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 the NPV/cost ratio, the best choice would be that giving the highest ratio. In this event, several smaller projects which in aggregate had a higher NPV would be chosen over a single larger project.

A large number of possible projects can be ranked by the NPV/cost ratio and those with the highest ratios considered first. The NPV/cost ratio of the project just above the point where money runs out is known as the cut-off rate. The NPV/cost ratio can also be used when assessing alternative mutually exclusive schemes. Thus if these were, for example, two alternative routes on which an improved road could be built or two alternative geometric design options, the incremental NPV/cost ratio can be used i.e.:

$$\frac{\text{NPV option 1 - NPV option 2}}{\text{COST option 1 - COST option 2}}$$

If the incremental NPV/cost ratio is greater than the cut-off rate, then the more expensive scheme can be justified.

A range of NPV's should always be quoted to reflect the range of scenarios and variables 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 (IRR)
This is the discount rate at which the present value of costs and benefits are equal; in other words, the discount rate that makes the NPV = 0. Calculation of IRR is not as straightforward as NPV and is done by solving the following equation for r:

$$\sum_{i=0}^{n-1} \frac{bi - ci}{(1+(r/100))^{i}} = 0$$

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 is the project. If it is larger than the planning discount rate, then the project is economically justified. Note that the IRR does not require the discount rate to be known and is thus considered favourably by international lending agencies.

Project timing and first year rate of return (FYRR)
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 this is to analyze 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 (easier to calculate) first year rate of return criterion can be used.

The FYRR is simply the sum of the benefits in the first year that the project is opened to traffic, divided by the present value of the capital cost, (both discounted back to the same year) and expressed as a percentage. Thus the FYRR is given by:

$$FYRR = 100b_j \Big/ \sum_{i=0}^{j-1} c_i (r/100))^{j-i}$$

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

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
Table 15.1 summarizes the advantages and disadvantages of the different criteria that can be used in a cost benefit analysis. 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.

In general, where the government is using a target or minimum cut-off rate of return on capital, maximizing 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.

Some sponsoring agencies dictate which method they require to be used. Nevertheless, results from the other methods should still be presented to provide a broader picture. The timing of a project should always be tested by evaluating the FYRR and, if this suggests that the project is premature, a range of investment timings should be investigated to determine which produces the highest NPV.

15.3 COST-EFFECTIVENESS ANALYSIS

15.3.1 Principles

For many low-volume roads, the level of traffic is often insufficient to justify any improvements using conventional CBA as the analytical tool. That is to say, the benefits that can be measured in monetary terms are insufficient to outweigh the costs of the project. However, there may well be other benefits that cannot be measured in monetary terms but which need to be considered in the appraisal process. Cost-effectiveness or multi-criteria analysis has been developed in order to try to address this problem of combining both quantified and non-quantifiable benefits. All of these techniques involve some process of ranking of the options on the basis of their performance against a set of pre-determined criteria which may or may not include an economic component.

A critical difference between conventional CBA and ranking criteria is that the former has an established theoretical framework and that practitioners can test their assumptions, through research, against an external reality. In contrast, ranking procedures are much more dependent upon the subjective values of those who initially construct the criteria and by those that are consulted in its implementation. It is for this reason that the CBA which is used in road project appraisal is broadly similar across the world, even though there may be differences in the engineering and economic models employed. In contrast, there is a very wide variation in the formulation and characteristics of ranking criteria.

	NPV	IRR	NPV/C	FYRR
Economic validity of project	Good	Good	Good	Good
Mutually exclusive projects	Very good	Poor	Good #	Poor
Project timing	Fair	Poor	Poor	Good
Robustness to changes in assumptions	Poor	Good	Very good	Poor
Project screening	Poor	Good	Very good	Poor
For use with budget constraint	Fair ##	Poor	Very good	Poor

\# Needs incremental analysis
\## Needs continuous recalculation

Table 15.1: Decision criteria

15.3.2 Ranking procedures

The main advantages of ranking procedures are:

- Speed and simplicity
- Transparency
- The ability to incorporate a measure of social benefits
- The ability to incorporate community choice.

The main disadvantages are:

- The procedures may involve summing and weighting totally different characteristics (i.e. adding up 'apples and pears')
- The weightings adopted are unlikely to be stable in the long run
- It is difficult for the procedure to assist with the range of ancillary planning choices that may be covered by a conventional economic appraisal such as project timing, alternative project designs, combinations with other investment and maintenance options, etc.
- The solution may be very far from optimal, leading to economically wasteful investment in the sense that the same objectives may be achieved with fewer resources.

Conventional CBA does, of course, include benefits for social trip making.
All personal trip making along a road will be treated the same. The lower transport costs associated with a road building investment for a trip to hospital will be valued the same (along the same road) as the benefits for a trip to market.

The argument for separately introducing "social" benefits is strongest when roads become impassable to motorized traffic. When this happens whole communities may be cut off from conventional social services and hence personal trip making will be severely curtailed. The conventional economic analysis of road investment relies heavily on vehicle traffic movements in the estimation of transport benefits. If roads are impassable or suffer from strong trafficability problems, then clearly a measure based on existing traffic volumes alone will underestimate the benefits from road improvement. Even though it is possible, under the conventional analysis, to predict generated traffic and value the associated benefits, it can be argued that when roads are cut off (and people directly denied access to critical services) this procedure is faulty and unlikely to give a reasonable estimate of the benefits of re-establishing access.

Where access is not threatened, and there are no compelling reasons to believe that road improvement will dramatically affect trip making, then the benefits of road improvement can be more clearly identified as the savings in transport costs to existing traffic. In these circumstances the arguments to include a separate measure of social benefits are much weaker. It is for these reasons that social benefits and ranking criteria are used to a much greater extent for rural access and feeder road programmes while conventional transport CBA is used for main and secondary road investment.

The population served by a road is often used in ranking criteria as a direct proxy of social benefits. Population is used either as a total proxy for all benefits, or in combination with other traffic-based benefits (see Box 15.2 for some examples).

15.3.3 Multi-criteria analysis

Ranking procedures may be used in the form of multi-criteria analysis to combine together economic, social, environmental and other considerations in the final choice of alternatives for major road investment. For each characteristic the different projects are assessed and put into rank order (i.e. 1st, 2nd, 3rd etc). This process is then repeated for the other characteristics. Weights are then assigned to each characteristic and an overall score is obtained. (The score for each criteria is the product of the rank and the weight). The process is demonstrated below in Table 15.2. In this table the highest number rank refers to the best. (Thus for the economic evaluation, Alternative 1 is the best, Alternative 2 the worst, and Alternative 3 is intermediate.)

Where, for two choices, there is little difference in the performance then they may take the same rank. In the table it can be seen that for the environment evaluation Alternatives 2 and 3 are equally desirable. The overall score gives a measure of the overall desirability of the project. Here it can be seen that Alternative 1 has the highest overall score while Alternative 2 is the least desirable.

In the example, the high weight given to the economic evaluation (50 percent of the total) is a reflection that the economic analysis is a combined analysis of engineering, traffic, travel times, user

Box 15.2: Examples of cost-effectiveness criteria

1. Population used as a key factor together with the costs of upgrading in the following cost-effectiveness criterion:

$$\text{Cost-effectiveness indicator of link}_{(j)} = \frac{\text{Population served by link}_{(j)}}{\text{Cost of upgrading of link}_{(j)} \text{ to basic access standard}}$$

Links that have the highest ratio are chosen in priority for the investment. The two key drawbacks of this approach are that there is no measure of the change in road condition (in fact the cost in improving access is likely to be highly correlated with the change in access provided) and, secondly, no importance is attached to traffic.

2. Another approach derives two indices: one for impassable roads, the other for passable ones. For impassable roads, ranking is based on the minimum cost per head of establishing access. Once access has been established the second prioritization index is calculated as follows:

$$\text{Prioritization Index} = \frac{\text{Estimate of trips x access change}}{\text{Rehabilitation cost per km}}$$

The estimate of trips is derived from estimates of trips generated by district services, agriculture and fishing. The access change is the 'after' rating subtracted from the 'before' rating on a scale where '0' is very poor and '5' is good. In this approach population is used as the measure of benefit for impassable roads while traffic is used as the measure for passable roads.

3. Another approach is to estimate social benefits as the product of the population multiplied by the prospective change in transport costs. In this procedure two measures of benefits are used based on both traffic (for both motor vehicles and other users) as well as on adjacent population.

benefits and identifiable costs associated with resettlement and environmental mitigation. Sometimes within multi-criteria analysis these components may be introduced separately although, if they are, then there is the danger that 'double counting' of costs and benefits will result if economic decision criteria such as the NPV or IRR are also included in the final choice analysis.

While it is usually possible to rank, for each characteristic, the desirability of different alternatives, it is far more difficult to develop the weighting procedure. This is very subjective and best carried out through a process of wide consultation of different experts. It is important to remember that the weighting procedure should only relate to making a comparison between choices. The absolute value of any characteristic (e.g. the environment) is not being assessed.

An important weakness of the approach is that, sometimes, small differences in one characteristic can often be given undue prominence within the procedure and thus override, in the weighting process, major differences in other characteristics. In the analysis, careful checks should be made to ensure that this does not happen.

15.3.4 The framework approach

This approach also brings together economic, environmental and other factors. In this approach the different effects and characteristics of a road project are summarized within a framework in such a way that the advantages and disadvantages of the different alternatives are easily seen and understood. The components are not explicitly weighted; however, through a process of paired comparisons the reasons behind the recommended choices become transparent. Inevitably, within the procedure, there is a danger of 'double counting' the costs and benefits (or advantages and disadvantages). However, because the process is transparent and the different effects are not weighted and added up (as with the multi-criteria analysis), the user is in a position to take account of these factors and make necessary adjustments in the final choice. The approach relies on the good judgement of those involved in preparing the approach to make sensible decisions.

Analysis criteria	Alternative 1			Alternative 2			Alternative 3		
	Rank	Weight	Score	Rank	Weight	Score	Rank	Weight	Score
Economic evaluation	3	50	150	1	50	50	2	50	100
Environmental evaluation	2	30	60	3	30	90	3	30	90
Development	3	10	30	2	10	20	1	10	10
Public transport	3	5	15	2	5	10	2	5	10
Accessibility/ Severance	1	5	5	2	5	10	3	5	15
Overall score	-	-	260	-	-	180	-	-	225

Table 15.2: Example of multi-criteria analysis

The framework approach may be summarized as follows:

- The key quantifiable and non-quantifiable effects and characteristics of each alternative option are summarized within a table; particular attention is given to the critical differences between the alternatives
- Alternative pairs of 'project cases' are then compared together. Through comparison of the key differences, one alternative of each pair is rejected
- The pair-wise comparison is continued until one 'project case' remains. This is recognized as the most desirable investment option. This alternative is then finally compared with the 'base case' or 'do-minimum case'
- A recommendation is then made whether the project should go ahead or not.

The factors that might be summarized within a framework analysis are likely to include many key components of the economic and environmental evaluations as well as results from participatory exercises and any other ancillary studies. Examples of quantified components that may be included are:

- VOC and time savings
- Accident savings
- Noise levels
- The number of properties within a given distance from the road
- The area of land acquisition covering different land uses
- People affected by resettlement
- Environmental mitigation costs
- Construction costs
- NPVs or IRRs
- The percentage of people that prefer each option.

Examples of non-quantifiable aspects might include statements on the following:
- Visual intrusion and the way that local amenities may be used and affected
- The effects on public transport
- The differential effects on future development
- The nature of the wider effects on the natural environment
- Severance and accessibility effects on different communities.

Tools exist for undertaking multi-criteria analysis and one such is described in Box 15.3.

Box 15.3: Including social benefits in the appraisal process

A social benefits software tool has been developed using the Analytical Hierarchy Process (AHP) Method. This method systematically transforms the analysis of competing objectives to a series of simple comparisons between the constituent elements. In particular, the approach does not require an explicit definition of trade-offs between the possible values of each attribute, and it allows users to understand the way in which outcomes are reached and how the weightings influence the outcomes.

The social benefits software tool requires three major inputs:
- A clear definition of mutually exclusive investment alternatives (for each road section) to be compared
- The main goal, objectives, criteria and attributes under which the alternatives are to be compared
- A statement of preferences on the set of objectives.

A score is calculated for each alternative using the AHP. The scores can be considered as the utility index in terms of social benefits value that each investment alternative could yield, and can therefore be used as an indicator for ranking or prioritization of projects. The ratio of the utility index to the cost of implementing the investment alternative also provides a useful prioritization index.

The social benefits software is designed to be compatible with well established road appraisal tools such as HDM-4. The investment alternatives analyzed in the social benefits software can be exported to HDM-4. These can then be analyzed together with the other investment alternatives defined in HDM-4 within the multi-criteria analysis framework incorporated in HDM-4. The scores (or utility indices) calculated in the social benefits software can be used in HDM-4 to combine social concerns with others (e.g. economic, environmental, energy efficiency, road safety, etc.). For project analysis at community level, the utility indices will be used to rank and select project alternatives. At national, regional or district level, the ratio of the utility index to the cost of implementing each investment alternative can be used through optimization procedures as follows:

- Programme analysis to prepare work programmes under specified budget constraints
- Strategy analysis to allocate budget between road classes, administrative units, and work types
- Research, for example to assess the impact of including/excluding social concerns on funding for low volume road.

Source: Overseas Road Note 22. A guide to pro-poor transport appraisal

Component	Sensitivity Test
Traffic	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 percent of the expected value should be examined for low traffic flows and up to plus or minus 25 percent for high flows. Similarly, the effect of 'optimistic' and 'pessimistic' traffic growths of up to about 25 percent for low growth rates and 50 percent for high growth rates should be examined.
Project costs.	Sensitivity to uncertainties in the project cost of plus or minus 25-100 percent 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	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	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	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 percent should be considered.
Shadow prices	In projects where the shadow prices used differ markedly from the market price minus transfer charges the sensitivity to uncertainties in the shadow price of up to about 25 percent should be considered.
Maintenance	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 for any particular road type. The vehicle operating cost figures obtained may then be used to determine the effect on project benefits.
Special factors	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, and these may need to be partially realigned and rebuilt in the future. Structures may be damaged in areas subject to flooding. 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.

Table 15.3: Sensitivity testing

15.4 ANALYSIS OF UNCERTAINTY

15.4.1 Scenario and risk analysis

The data and parameters used in the analysis of a road project can be prone to substantial errors and it is important to recognize that these exist and to take steps to minimize them. Because of this, the results of an appraisal are subject to uncertainty and there will be a risk associated with pursuing any course of action suggested by the appraisal.

It was recommended earlier 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 options 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 options being considered.

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.

15.4.2 Expected values

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.

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, because 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
- Ways of improving the project by making it less risky, more cost-effective, or both.

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. Both are dealt with below.

15.4.3 Contingency

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

- 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 he used in such cases to cover a variety of items.
- 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.

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

15.4.4 Sensitivity analysis

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, those shown in Table 15.3 should be considered as possible candidates.

Providing that investment models, such as HDM-4, 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. It will assist in the interpretation of the results if the NPV is evaluated separately for:

- Benefits to normal traffic
- Benefits to generated traffic
- Time savings
- Accident savings.

15.4.5 Risk analysis

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.

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. 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 investigation and the expected reduction in the risk. Risk may also sometimes be reduced by a more flexible approach to design and construction such as is possible under cost-reimbursement or target price contracts.

However, for a small amount of effort, even rough-and-ready forms of risk analysis are likely to improve the quality of decision making considerably.

DETAILED SOURCES OF INFORMATION

Lebo, J and D Schelling (2001). *Design and appraisal of rural transport infrastructure: Ensuring basic access for rural communities*. World Bank, Washington, DC.

IT Transport (2001). *Appraisal of investments in improved rural access*. DFID Economists Guide. IT Transport, Ardington, UK.

ITS (2003). *Toolkit for the economic evaluation of World Bank transport projects*. Institute for Transport Studies, University of Leeds, Leeds, UK.

TRL (2004). *The rural transport policy toolkit*. TRL Ltd., Crowthorne, UK.

TRL (2004). *A guide to pro-poor transport appraisal*. Overseas Road Note 22, TRL Ltd, Crowthorne, UK.

16. The Feasibility Study Report

16. THE FEASIBILITY STUDY REPORT

16.1 PREPARATION

Decisions must be made at various stages throughout the project cycle. The early decisions on a project, however apparently innocuous, can 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.

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 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.

Once the need for a project has 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.

Where reports are prepared for aid donors, each will have different requirements. Projects prepared for aid agencies normally dwell heavily on environmental and 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. Most bi-lateral donors likewise impose well-defined and rigorous procedures for approving large aid projects.

The team assigned to prepare the project should normally contain a range of professionals such as engineers, transport planners and economists. Sector specialists need to be added where the size and complexity of the project require, for example, agronomists, engineering geologists, environmental specialists, road safety experts 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. 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.

16.2 PRESENTATION

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

Whatever the nature of the approving body, it should be assumed that the majority of the people who have to take the decision are non-specialists and are 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.

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.

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.

A full checklist of what the feasibility report should contain is given in Table 16.1. 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 and other risk 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. Environmental and social assessments

6. Preliminary engineering design (PED) and costs

- Geotechnical considerations
- Design and costs of:
  - pavement
  - alignment (earthworks)
  - drainage and structures

7. Assessment of benefits

- Vehicle operating cost savings
- Road maintenance benefits
- Time savings
- Reduction in road accidents
- Economic development

8. Economic analysis

- Cost-benefit analysis
- Analysis of uncertainty

9. 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

Item	Components covered	Detail
Existing road	Physical characteristics	■ Description of road location ■ Road length ■ Nature of road (single two-lane; dual two-lane, etc) ■ Construction details (pavement type, layer descriptions, thickness, structural number, etc) plus details of tests carried out ■ Pavement condition (roughness, rutting, cracking, deflection, etc) plus details of tests carried out ■ Conditions of structures and off-road features (description) ■ Other relevant factors
	Traffic characteristics	■ Current estimated AADT, broken down by vehicle class ■ Traffic split between lanes (if appropriate) ■ Details of each vehicle class (description, gross vehicle mass, equivalent standard axle loading, etc)
	Maintenance regime	■ Description of current maintenance activities (works undertaken, extent of works, frequencies, etc.) ■ Cost of works (broken down by major headings) plus costing method, source of cost data and assumptions made
	Road user costs	■ Unit and total vehicle operating costs on existing road (fuel consumption, parts consumption, tyre wear, etc. and unit costs of each) ■ Unit and total travel time costs on existing road (working time, leisure time and unit costs of each) ■ Road traffic accidents (number of fatal and injury-only accidents and unit cost of each) ■ Details of costing method, source of cost data and assumptions made for each of above.
Proposed works	Nature of works	■ General description (new construction, resurfacing, overlay, pavement reconstruction, etc. plus supporting works to structures and other features ■ Design (thickness, materials specification, etc.) plus basis of design, methods used and assumptions made ■ Alternative designs considered (details as above) ■ Cost of works (broken down by major headings) plus costing method, source of data and assumptions made. ■ Range of works options presented with separate data for environment, social factors, traffic, maintenance and road user costs for each of above
	Environmental issues	■ Preliminary environmental impact appraisal, relevant to scope of works proposed, with mitigation measures ■ Cost of additional environmental works, plus costing method, source of cost data and assumptions made in an environmental action plan

Table 16.1: Feasibility report contents checklist

Item	Components covered	Detail
	Social factors	■ Preliminary social impact appraisal, relevant to the scope of work proposed, with mitigation measures ■ Cost of mitigation works, plus costing method, source of data and assumptions made
	Traffic projections	■ Forecast growth rate for different vehicle types, plus estimating method used, data and assumptions ■ Forecast normal traffic over the analysis period, using the above growth rates ■ Forecast diverted traffic over the analysis period, plus estimating method used, origin-destination survey results, other data and assumptions ■ Forecast generated traffic over the analysis period, plus estimating method used, data and assumptions
	Maintenance regime	■ Description of proposed maintenance activities for each year of the analysis period (details as above) ■ Cost of works for each year of the analysis period (details as above) plus costing method, source of cost data and assumptions made
	Road user costs	■ Unit and total vehicle operating costs on existing road for each year of the analysis period (details as above) ■ Unit and total travel time costs on existing road for each year of the analysis period (details as above) ■ Road traffic accidents for each year of the analysis period (details as above) ■ Costing methods, sources of data and assumptions made for each of these
Project analysis	Do-nothing/do-minimum analysis	■ A realistic 'do-nothing' case should be described; if it is necessary to carry out minimum works to prevent the road deteriorating to a point where it is unsafe or impassable, then realistic 'do-minimum' works should be identified ■ Determination of costs for the above for each year of the analysis period, showing separately (in tabular form with a column for each): 'do-minimum' construction cost, current level of road deterioration (e.g. roughness), maintenance cost, vehicle operating cost, time cost, accident cost, other cost (if used, defined with data sources and assumptions)
	Analysis of individual options	■ Determination for each year of the analysis period and for each option (separately analysed), showing in separate columns of a table for each year; construction cost, current level of road deterioration (e.g. roughness), maintenance cost, vehicle operating cost, accident cost, other cost (as above)
	Annual benefits	■ Determination of benefits for each year of the analysis period and for each option (separately analyzed), showing in separate columns of a table for each year difference in cost of proposed option ('do-something') and do-nothing/minimum option (i.e. savings) in: construction cost, maintenance cost, vehicle operating cost, accident cost, other cost (as above) ■ Final column in table to show total savings per year
	Economic analysis	■ Determination of NPV for each option for range of discount rates ■ Similarly calculate NPV/cost, IRR and FYRR for each option considered
	Cost-effectiveness analysis (if used)	■ Set out the ranking procedure used, with assumptions and weightings used ■ Determine, and present in tabular form, the assessment of each option against set of pre-defined performance criteria ■ Prepare the rating of each option, and how the judgement is achieved
	Financial analysis (if used)	■ Set out the pricing strategies that are tested ■ Present the costs of collecting revenues over the period of analysis, with data sources and assumptions made ■ Estimate the level of revenues over the period of analysis, showing data sources, analysis and assumptions made ■ Present the cost (capital, maintenance, revenue collection), revenue and profit (loss) streams for each option ■ Determine the financial return on the investment using discounted cash flow analysis
	Sensitivity analysis	■ Sensitivity of key analytical outputs (whichever is used) to variations in base traffic flow (plus or minus 25 percent) and investment cost (plus or minus 25 percent)

Table 16.1: Feasibility report contents checklist (continued)

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).

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.

Appendices

Appendix A. Environmental Impact Assessment

This Appendix provides supplementary topic-by-topic advice to be read alongside the guidance on Environmental Impact Assessment (Chapter 6 of ORN5). The following environmental topics are covered:

- Water resources
- Soil and geology
- Local air pollution
- Regional air pollution
- Landscape, natural resources and waste
- Biodiversity
- Cultural heritage
- Noise and vibration

This guide is intended to be indicative rather than comprehensive because the actual range of environmental impacts will be specific to the project and its location. For each topic, the following are summarized providing a starting point for more detailed investigations as part of an EIA:

- Environmental baseline data
- Assessment methods
- Types and examples of impacts
- Avoidance and mitigation measures

TOPIC: Water Resources

Baseline environmental data:

- Location of surface waters (rivers, streams, lakes, ponds) and their uses (human consumption, used by livestock, fishery, navigation route)
- Location of groundwater sources including wells
- Identification of drainage basin geographical limits
- Identification of drainage zones
- Geological conditions
- Extent of the seasonal floodplains
- Proximity to other sources of water pollution (e.g. industrial, agricultural)
- Traffic flow and composition predictions

Assement methods (where available):

- Geographic Information Systems
- Groundwater and surface water computer modeling

Types of impact:	Examples:	Avoidance and Mitigation measures:
■ Surface water flow modification	■ Drainage modifications leading to soil erosion (2, 5) ■ Design of new culverts and bridges (2, 5)	■ Naturalized designs and in-stream habitat creation ■ Minimizing the number of water crossings
■ Groundwater flow modification	■ Changes to the water table leading to decreased agricultural productivity or damage to natural flora and fauna (2, 5)	■ Location of works to avoid changing the groundwater network in areas of importance for human or flora and fauna.
■ Water quality degradation (surface and groundwater)	■ Major spillages of polluting material e.g. overturned chemical tanker (4) ■ Temporary contamination of surface waters due to soil disturbance (2, 5)	■ Road safety measures ■ Settling basins, infiltration ditches, wetland treatment systems ■ Use of clean fill material e.g. quarry rock containing no fine soil ■ Silt traps/infiltration ditches

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: Soils & Geology

Baseline environmental data:		
■ Geological conditions ■ Slope		
Assement methods (where available):		
■ Geographic Information Systems ■ Groundwater and surface water computer modeling		
Types of impact:	**Examples:**	**Avoidance and Mitigation measures:**
■ Loss of productive soil	■ Covering productive soil with the road surface and associated land-take e.g. for stopping places and junctions (2) ■ Soil compaction from heavy machinery during construction (2, 5)	■ Align the road to minimize the land-take affecting areas of productive soil
■ Soil erosion	■ Increased slope instability associated with cuttings and embankments (2, 5) ■ Roadside vegetation clearance leading to soil erosion (2, 5) ■ Side-tipping of spoil materials from the construction process (2)	■ Minimize the extent of ground clearance ■ Balance filling and cutting requirements through route choice to avoid the production of spoil material ■ Immediate replanting of disturbed areas
■ Soil contamination	■ Disturbance of contaminated land during construction (2) ■ Major spillages of polluting material e.g. overturned chemical tanker (4)	■ Avoidance or removal and appropriate disposal of existing contaminated land ■ Design of road drainage systems

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: Regional Air Pollution

Baseline environmental data:

- Density and distribution of general population who may be affected
- National/regional emission inventory by source category
- Traffic movement: numbers, speed and vehicle fleet composition
- Fuel type and quality
- Prevailing wind direction, temperature and weather conditions
- Specific geographic issues: coastal, valley etc
- Trans-boundary pollution importation
- Topography
- Extent of unpaved roads

Assement methods (where available):

- Emissions modeling/calculations based on emissions factors
- Dispersion modeling to derive changes in pollution concentrations
- Field measurement of existing air quality
- Geographic Information Systems

Types of impact:	Examples:	Avoidance and Mitigation measures:
■ Energy use, fuel consumption	■ Consumption of fossil fuels (2, 4)	■ Traffic management measures to reduce congestion ■ Avoiding steep grades and sharp curves which would promote deceleration and acceleration and increase emissions ■ Policy measures to improve fuel quality and modernize the vehicle fleet ■ Policy measures to encourage modern public transport, and increase occupancy of all road transport modes
■ Greenhouse gas emissions (primarily CO_2)	■ Contribution to global climate change (2, 4)	
■ Ozone (formed from the reaction of NO_X and hydrocarbons with sunlight)	■ Potential health effects (2, 4) ■ Crop damage (4) ■ Visibility changes and impact on tourism (4) ■ Damage to materials and fabrics (4)	

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: Local Air Pollution

Baseline environmental data:

- Density and distribution of population who may be affected
- Identification of susceptible populations e.g. schools, hospitals etc
- Local/regional emission inventory by source category
- Traffic movement numbers, speed and vehicle fleet composition
- Fuel types and quality
- Prevailing wind direction, temperature and weather conditions
- Topography e.g. street canyon, elevated road, site altitude
- Road and junction configurations
- Extent of unpaved roads

Assement methods (where available):

- Emissions modeling/calculations based on emissions factors
- Dispersion modeling for air pollution
- Field measurement of existing air quality
- Geographic Information Systems

<table>
<tr><th>Types of impact:</th><th>Examples:</th><th>Avoidance and Mitigation measures:</th></tr>
<tr><td>■ Oxides of nitrogen</td><td>■ Potential health effects for NO_2 - respiratory and cardiovascular afflictions such as asthma, bronchitis and emphysema (4)
■ Local dieback of vegetation (4)</td><td rowspan="6">■ Selection of road alignments to avoid proximity to areas of high population density including schools, housing and work places
■ Traffic management measures to avoid congestion
■ Avoiding steep grades and sharp curves which would promote deceleration and acceleration and increase emissions
■ Use of natural landforms and physical/vegetation at the roadside</td></tr>
<tr><td>■ Hydrocarbons</td><td>■ Potential health effects – aromatics and poly-aromatics such as benzene and benzo(a)pyrene, respectively, are known carcinogens. Similarly carbonyls such as acrolien are particularly odourous. Contribution to eye, noise and throat infection (4)</td></tr>
<tr><td>■ Carbon monoxide</td><td>■ Potential health effects - restricts the ability of the blood to carry oxygen – leading to headaches, aggravated cardiovascular disease (4)</td></tr>
<tr><td>■ Sulphur dioxide</td><td>■ Potential heath effects - aggravation of respiratory conditions including asthma, bronchitis and emphysema (4)</td></tr>
<tr><td>■ Particulate matter (exhaust and non-exhaust) and dust from unpaved roads</td><td>■ Potential health effects - Eye and respiratory irritation, asthma (4)</td></tr>
<tr><td>■ Lead</td><td>■ Potential health effects - Nervous disorders, impaired mental function, anaemia.</td></tr>
</table>

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: Landscape, Natural Resources and Waste

Baseline environmental data:		
■ Maps and other information on vegetation, topography, urban/village characteristics, architectural features and recreational areas ■ Aerial/satellite photographs ■ Sources of construction materials ■ Licensed recycling and waste disposal sites		
Assement methods (where available):		
■ Field surveys and photography ■ Landscape characterization ■ Landscape assessment ■ Visual impact assessment ■ Geographic Information Systems		
Types of impact:	**Examples:**	**Avoidance and Mitigation measures:**
■ Changes to the natural relief and morphology of the landscape	■ Loss of vegetation/ deforestation (2, 3) ■ Extensive embankments and cuttings in steep terrain (2)	■ Choice of vertical and horizontal alignment of the road to follow the natural relief ■ Appropriate use of tunnels, bridges and viaducts ■ Earthworks and planting vegetation to soften the transition between the road and the natural landscape
■ Visual intrusion and loss of urban/village character	■ Road infrastructure becomes an eyesore and damage tourist revenues (2)	■ High quality design in sympathy with local design features
■ Consumption of natural resources and generation of waste	■ Maintenance requirements involving materials which are expensive and not readily available locally (2, 5) ■ Generation of waste (2) ■ Road access to mountain areas creates opportunities for tipping (4)	■ Seek to use locally available materials to improve the conditions for appropriate maintenance to be carried out ■ Reuse/recycle materials where possible and seek alternative economic uses for excess construction materials elsewhere in the project or the local community ■ Road design with few stopping places and safety fencing to reduce tipping opportunities

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: Biodiversity

Baseline environmental data:

- Location of important habitats, including designations such as national parks
- Classifications of ecosystem types and sensitivity
- Aerial/satellite photographs

Assement methods (where available):

- Ecological field surveys and characterization
- Identification of indicator species or groups
- Geographic Information Systems
- Ecosystem modeling

Types of impact:	Examples:	Avoidance and Mitigation measures:
■ Habitat loss or degradation	■ Loss of terrestrial habitats such as forests and grasslands (1,2,3,5) ■ Loss of aquatic – wetlands, rivers and lakes (1,2,3,5)	■ Selection of road alignments to avoid sensitive ecosystems ■ Fencing to restrict the extent of area affected by construction and maintenance activities ■ Roadside planting vegetation using indigenous species ■ Use of bridges to minimize physical changes to wetland habitats
■ Habitat fragmentation	■ Loss of connectivity between inter-related ecosystem components jeopardizing wildlife populations (2)	■ Wildlife crossings – overpasses and underpasses ■ Enhancement of wildlife corridors and buffer zones around sensitive habitats
■ Ecosystem contamination	■ Fuel and chemical spillages where a pathway exists to affect nearby habitats (2, 4, 5)	■ Appropriate storage and bunding of fuels and chemicals used during construction ■ Installation and maintenance of water pollution control measures as part of the road design
■ Accessibility into sensitive habitats	■ Increased disturbance of flora and fauna as well as increased illegal logging and hunting (4) ■ Roadside habitat removal for agricultural use or ribbon development of housing/commercial activities (4) ■ Transmission of diseases affecting flora and fauna in wilderness areas (4) ■ Risk of fire	■ Road design with few stopping places, roadside planting and wide drainage ditches to reduce inappropriate access ■ Provision of alternative sites for agricultural use, housing and commercial uses ■ Buffer zones around protected habitats and species ■ Fire breaks and prevention information in roadside stopping places

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: Cultural Heritage

Baseline environmental data:		
■ Location of historic settlements/buildings ■ Results from nearby investigations and excavations ■ Aerial/satellite photographs ■ Secondary sources including site inventories, historic maps and bibliographic sources ■ Details of tourist sites		
Assement methods (where available):		
■ Rapid field surveys ■ Archaeological investigations ■ Local historical and anthropological research ■ Geographic Information Systems		
Types of impact:	**Examples:**	**Avoidance and Mitigation measures:**
■ Loss or damage to historic settlements/ buildings and physical artefacts	Destruction of artefacts through ground clearance and engineering works (1, 2, 4)	■ Selection of road alignment to avoid important sites ■ Physical measures such as soil stabilization and building restoration ■ Survey and removal of artefacts (e.g. to local museums) to preserve the historic record
■ Violation of traditionally exercised land rights	Road access causes increased competition for mineral resources, forestry and agricultural land (1, 2, 4)	■ Measures to protect and preserve the traditional land rights such as long-term tenures ■ Appropriate development actions as compensation such as access to education and health case ■ Road design with few stopping places, roadside planting and wide drainage ditches to reduce inappropriate access

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: Noise and Vibration

Baseline environmental data:		
■ Density and distribution of population who may be affected ■ Road surface type ■ Traffic movement numbers, speed and vehicle fleet composition ■ Prevailing wind direction, temperature and weather conditions ■ Topography and the existence of roadside buildings/barriers		
Assement methods (where available):		
■ Noise measurements ■ Noise modeling/forecasting ■ Noise contour mapping		
Types of impact:	**Examples:**	**Avoidance and Mitigation measures:**
■ Vehicle noise and road/tyre noise	■ Human health effects (2, 5) ■ Annoyance and sleep deprivation (1, 2, 4, 5) ■ Breaching national noise standards where they exist (1, 2, 4, 5) ■ Wildlife disturbance (1, 2, 4, 5)	■ Road design and alignment to increase distance from the road-side to hospitals, housing schools and employment areas ■ Selection of road surface to reduce frictional noise ■ Noise barriers or screens ■ Compensation by double glazing of windows or providing building façade insulation ■ Policy measures to modernize and improve the maintenance of the vehicle fleet
■ Vibration	■ Structural damage to nearby buildings (4)	■ Changes to road alignments, designs and construction methods

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

Appendix B. Social Impact Assessment

This Appendix provides supplementary topic-by-topic advice to be read alongside the guidance on Social Impact Assessment (Chapter 7 of ORN5). The following environmental topics are covered:

- Community severance
- Land acquisition and community displacement
- Labour based works
- Road safety
- HIV/AIDS

This guide is intended to be indicative rather than comprehensive because the actual range of social impacts will be specific to the project and its location. For each topic, the following are summarized providing a starting point for more detailed investigations as part of an SIA:

- Social baseline data
- Assessment methods
- Types and examples of impacts
- Avoidance and mitigation measures

TOPIC: Community Severance

Baseline social data:		
■ Location of transport networks and their uses (movement of agricultural inputs and outputs, service delivery, marketing) ■ Causes of severance (physical, psychological, economic and social factors, and accessibility issues) ■ Effectiveness of mitigation measures to alleviate the impacts of severance on local communities		
Assement methods (where available):		
■ Focus group discussions, key informant interviews, participatory appraisal exercises, household questionnaires ■ Origin and destination surveys		
Types of impact:	**Examples:**	**Avoidance and Mitigation measures:**
■ Physical	■ Infrastructure barriers to pedestrian movement, physical layout/design of road that inhibits accessibility (3, 4)	■ Engineering measures – surface road crossings, subways, footbridges transport services
■ Psychological	■ Unpleasant built environment, fear of crime, personal safety and security (2, 4)	■ Maintenance of mitigation measures and built environment – lighting, cleaning, street furniture (i.e. bus stops) ■ Road safety measures
■ Economic	■ Financial barriers to accessing transport, general economic impact on local households and businesses (4)	■ Subsidy for transport services ■ Institutional support for local road maintenance and employment opportunities for labour based works.
■ Social	■ Division of a community caused by land acquisition and displacement, or by a road infrastructure scheme (2, 4) ■ Impacts on community interaction and communication, social exclusion, social barriers, community isolation, community poverty and deprivation	■ Allow for community consultation and decision-making during problem identification and feasibility to ensure adverse impacts are minimised and the road improvement project facilitates social inclusion.

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: Land acquisition and community displacement

Baseline social data:		
■ Characteristics of population to be displaced – land rights, measures of deprivation, income earning potential, age and gender ■ Characteristics of the land to be acquired – value, ownership, crops, trees and structures to be reimbursed		
Assement methods (where available):		
■ Social impact assessment and cost benefit analysis		
Types of impact:	**Examples:**	**Avoidance and Mitigation measures:**
■ Displacement following land acquisition (1, 2)	■ Loss of agricultural or other type of land by owners ■ Loss of homestead and commercial land ■ Loss of trees, crops and perennials ■ Loss of income and work days ■ Loss of community structure and common property resources ■ Rural-urban migration	■ Avoidance or minimization of impacts where possible; ■ Consultation with affected people in project planning and implementation, including disclosure of resettlement plan ■ Payment of compensation for acquired assets at the market/replacement value ■ Resettlement assistance to affected people, including non-titled persons (e.g. informal dwellers/squatters, and encroachers; special attention to vulnerable people ■ An income restoration and rehabilitation programme ■ Assistance for tenants and squatters ■ Implement an appropriate legal and institutional framework ■ Development of a resettlement plan with inputs from the target communities

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
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4 = operation of the road;
5 = maintenance phase.

TOPIC: Labour-based works

Baseline social data:

- Local employment statistics disaggregated by gender
- Local income statistics disaggregated by gender
- Audit of available labour based equipment e.g. tractors, trailers, towed graders, power tillers, pedestrian rollers and water bowsers etc
- Number of available skilled and unskilled labourers
- Performance data

Assement methods (where available):

- Focus group discussions to establish local demand for labour based works and 'buy-in' from the community
- Questionnaire survey of labourer conditions (pay, conditions, working hours, equal opportunities)
- Post-intervention assessment of impacts on labourers, their income earning capabilities and purchasing power
- Evaluation indicators

Types of impact:	Examples:	Avoidance and Mitigation measures:
Technology choice	Equipment intensive methods; labour intensive methods; labour based methods	Determine appropriate technology - labour and equipment availability, the time available for recruitment and the capacity of local contractors.
Availability of skilled and unskilled labour	Contractors import their own trained labour and remove employment opportunities from local people (1, 2)	Provide training for local labourers and employ community members along the road, providing a competitive salary
Labour protection	Daily task rates, first aid, HIV/AIDS, minimum wage, minimum age, non-discrimination, worker's compensation (2, 5)	Pay labour on time, protect workers rights and provide health and safety protection.

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
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4 = operation of the road;
5 = maintenance phase.

TOPIC: Road safety

Baseline social data:

- Road traffic accident statistics disaggregated by income and hot spots
- Accident data of labour gangs

Assessment methods (where available):

- Accident reports
- Focus group discussions
- Survey of pedestrians and drivers

Types of impact:	Examples:	Avoidance and Mitigation measures:
■ Social	■ Pain, grief and suffering	■ Education of vulnerable groups – pedestrians and drivers through school curriculum and community road safety education ■ Counselling for victims of road accidents
■ Economic	■ Lost future output ■ Property damage ■ Medical ■ Police and administration	■ Enforcement of traffic laws through police and voluntary 'interceptors' ■ Compensation for poor households
■ Physical	■ Permanent injury and disability ■ Damaged or destroyed vehicle	■ Road safety audits to assess the effectiveness of road safety measures incorporated into highway design ■ Engineering safety measures – geometric design, road surfaces, road markings and delineation, road signs, streetlights and road furniture, traffic calming measures, traffic management

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

TOPIC: HIV/AIDS

Baseline social data:		
■ Characteristics of labour used in labour based works ■ Audit of commercial truck drivers and their health status		
Assessment methods (where available):		
■ Impact assessment of new transport routes ■ Attitude survey of commercial sex workers and transport operators/drivers		
Types of impact:	**Examples:**	**Avoidance and Mitigation measures:**
■ Transport activity	■ Transport corridors, stopping places and terminal points that demonstrate increased levels of promiscuous sexual contact especially with commercial sex workers (4)	■ Awareness campaigns and free sexual health advice and condoms at truck stops and cross-border points ■ Educating and counselling truck drivers and sex workers about the cause and effects of HIV/AIDS ■ Alternative sources of income
■ Labour camps	■ Bringing together workers in temporary camps for infrastructure construction and maintenance activities (2, 5) ■ The absence of normal social networks to regulate behaviour encourages sexual activity between non-regular partners	■ Awareness programmes for labourers ■ Training and promotion in contraception use, distribution of condoms ■ Employment of local labour at the site of construction ■ Migrant labourers encouraged to travel with their family, or be encouraged to take regular leave ■ Improved living conditions and contract conditions

Key to timing of the impact:
1 = pre-construction phase (e.g. sources of materials, particularly quarrying);
2 = construction phase;
3 = associated development projects/land use changes;
4 = operation of the road;
5 = maintenance phase.

Appendix C. Highway Investment and Management Tools, HDM-4

1. INTRODUCTION

HDM-4 is the result of the International Study of Highway Development and Management (ISOHDM) that was carried out to extend the scope of the World Bank's HDM-III model. The scope of the HDM-4 tools has been broadened considerably beyond traditional project appraisals, to provide a powerful system for the analysis of road management and investment alternatives and to provide a harmonized systems approach to road management, within adaptable and user friendly software tools. The system has become the de-facto standard for road investment analysis for many road authorities and financing agencies.

The system provides for:

- Project appraisal
- Policy impact studies
- Estimating funding requirements
- Budget allocations
- Predicting road network performance
- Roads management
- Programming road works
- Special applications

2. HDM 4 APPLICATIONS

There are four main areas of application:

- Project Analysis
- Programme Analysis
- Strategy analysis
- Research and Policy Studies

2.1 Project Analysis

The project application is for analysis of one or more road projects or investment options. Road sections with user specified treatments or improvement standards are analyzed over a specified life-cycle. Project analysis, and the other HDM-4 applications, can be used to evaluate the engineering or economic viability of road investment alternatives by performing life cycle analysis of pavement performance, maintenance and improvement effects, and road user costs. The main outputs include:

- Annual predictions of pavement performance
- Pavement maintenance and road improvement effects
- Road user costs and benefits
- Estimates of environmental effects
- Standard economic indicators, such as NPV, EIRR, NPV/C, etc.

Typical projects include new construction, pavement maintenance and rehabilitation, road widening or geometric improvements, etc.

2.2 Programme Analysis

This application can be used to prepare rolling works programmes in which candidate road sections are identified and assigned maintenance or improvement options. HDM-4 calculates the Net Present Value (NPV) and expenditure requirements of each option. The main output from programme analysis is a schedule of optimum pavement maintenance and/or improvement projects which can be carried out within specified budget constraints.

2.3 Strategy Analysis

This application is used for strategic planning to provide medium and long term planning estimates of funding needs for road network development and maintenance. At this stage, the road network is characterized by lengths of road in different categories defined by parameters such as road class, surface type, pavement condition, traffic loading, etc. The main outputs are estimates of medium to long term budget requirements for the entire road system, together with forecasts of pavement performance and road user effects.

2.4 Research and Policy studies

HDM-4 can also be used to perform various road sector policy studies including:

- Funding policies for competing needs, eg. feeder roads versus main roads
- Road user charges for setting up road funds
- Impact of road transport policy changes on energy consumption
- Impact of varying axle load limits
- Pavement maintenance and rehabilitation standards

Example outputs developed from Strategy and Programme Analysis are shown below.

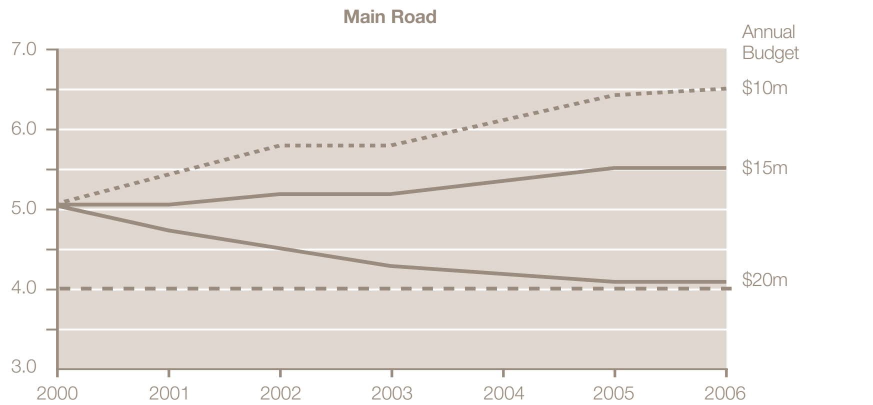
4. THE MANAGEMENT CYCLE

The highway management process as a whole can, therefore, be considered as a cycle of integrated activities that are undertaken within each of the management functions of *planning, programming and preparation* within which HDM-4 can be applied. Each of the management functions are performed in a cyclic manner, with the cycle comprising a series of well-defined steps helping in the *decision support system* activities.

Objective	Example Output

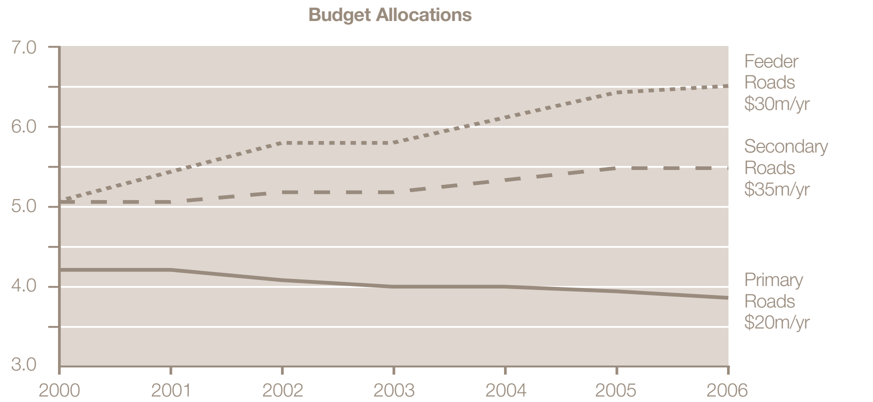
To determine the long term funding needs to meet target riding quality standards for main roads.

Strategy Analysis



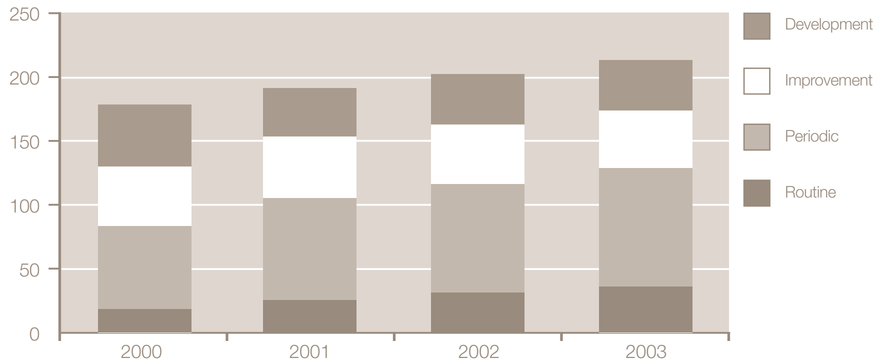
To determine optimal funding allocations to sub networks

Strategy Analysis



To determine optimal budget allocations between budget heads

Strategy Analysis

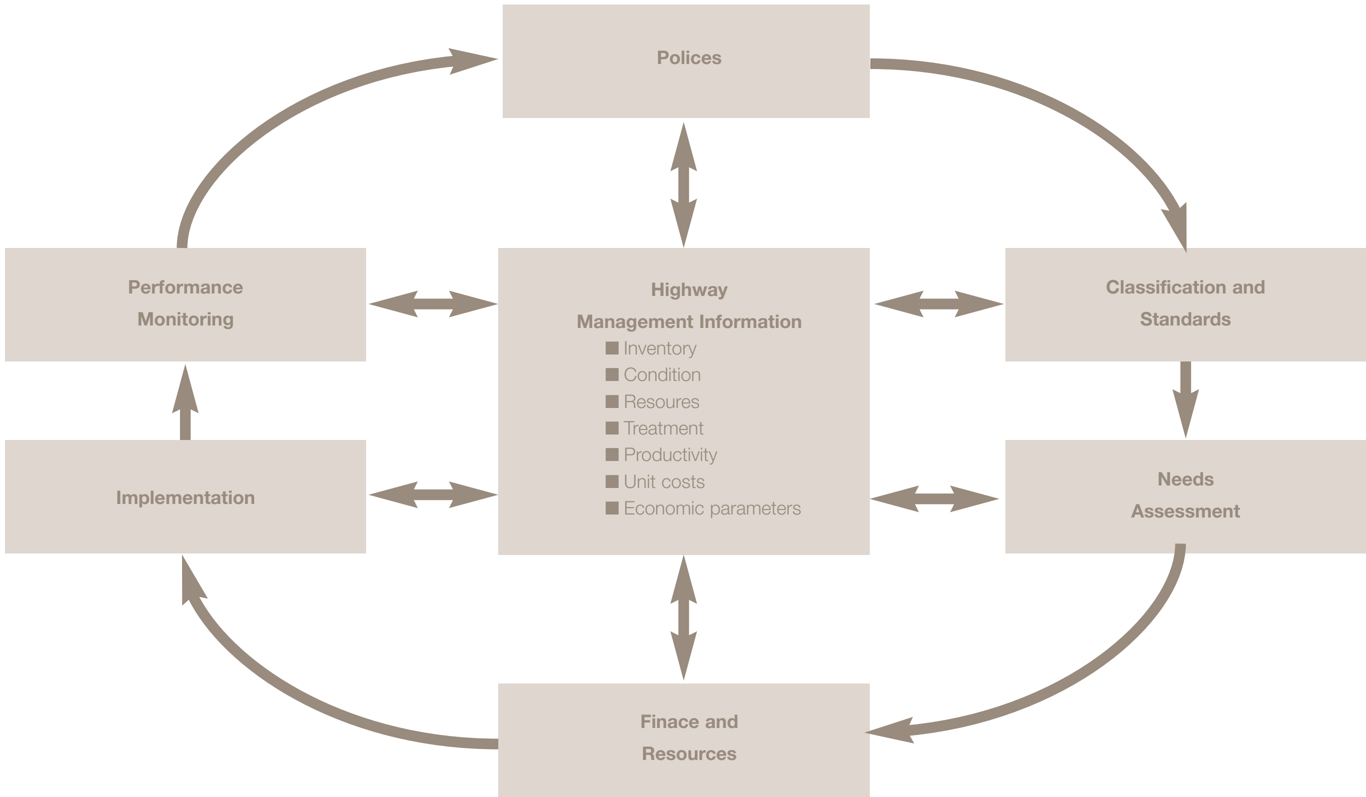


To produce a multi year works programme within specified annual budget limits

Programme Analysis

Priority Rank	Road Section	Length (km)	Type of or District	Schedual Road Work	Cost Year	Cumulative $m	S$m
1	N1-2	20.5	2	Resealing	2000	5.4	5.4
2	N4-7	23.5	7	Overlay 40mm	2000	10.9	16.3
3	N2-5	12.5	5	Reconstruct	2000	8.6	24.9
4	R312-1	30	4	Widen 4 lane	2000	31.4	56.3
5	R458-3	36.2	3	Overlay 60mm	2000	16.3	72.6
1	N4-16	32.1	6	Reconstruct	2001	22.8	22.8
2	R13-23	22.4	4	Overlay 40mm	2001	9.7	32.5
3	N521-5	45.2	2	Widen 4 lne	2001	41.3	73.8
1	N1-6	30.2	4	Reconstruct	2002	8.2	8.2
2	N7-9	17.8	3	Overlay 60mm	2002	9.2	17.4
3	F2140-8	56.1	1	Reconstruct	2002	34.9	52.3

Example presentations of HDM-4 output data



Management cycle

At the core is highway management information, or ‘asset database’, the quality of which is key to decision making. For network level analysis, the cycle is typically completed at annual intervals, whereas project analysis or policy research is undertaken on a needs basis.

The possible uses of HDM-4 are placed in context in Table A1. Terminology varies, and it is the core functionality which is important rather than the specific terms used to describe a system. This helps eliminate confusion when comparing system capabilities.

The synergistic interactions of concepts, knowledge, standards, information systems and management practices promoted by ISOHDM may be thought of as an ‘Investment Decision Support Framework’ to assist road managers at all levels. Such a framework can be broken into its constituent parts and an assessment made of the status of existing or proposed Road Asset Management Systems, including the extent to which they meet the ‘good practice’ standards.

5. DATA PROVISION AND MANAGEMENT

The HDM-4 database provides basic facilities for road network characteristics within HDM-4, these having been assembled in a Highway Information System. Users can define road networks with an unlimited number of road sections. This approach to network referencing is designed to be flexible in order to integrate with a wide range of referencing conventions used in other databases with which HDM-4 may be required to interface.

The HDM-4 database also provides facilities for storing characteristics of vehicle types required for calculating vehicle speeds, operating costs, travel time and other vehicle effects. Several vehicle fleets can be set up for use in different analyses based on the wide range of default data provided. Where specific, local data are available, this can also be employed.

The HDM-4 configuration module can be used to customize all components of the system. Default data and calibration coefficients can be user defined for any country or region, or for other reasons.

The overall quality and usefulness of HDM-4 outputs are dependent on the extent to which the system has been configured to reflect local conditions, and the calibration of the models. Guidance is available on what aspects users should focus on to ensure adequate results. The system incorporates the concept of ‘Information Quality Levels’ for this purpose, and

Management function	Possible uses of HDM-4	Examples of common descriptions	HDM-4 Application
Planning and Policy Research	Investigating policies, standards and resource needs	Strategic analysis system Network planning system Pavement management system	Strategy Analysis
Programming	Determining priority works programmes	Programme analysis system Pavement management system Budgeting system	Programme Analysis
Preparation	Assessing the feasibility of major schemes	Project analysis system Pavement management system Pavement/overlay design system	Project Analysis

Table A1: Role of HDM-4 within the management cycle

recommends different levels of effort depending on the type of study and accuracy required.

The HDM-4 libraries/modules can be interfaced with existing pavement management systems, or road asset databases. Data import and export facilities built into HDM-4 allow data to be exchanged using international conventions.

6. SCOPE OF THE MODEL

6.1 Pavement Deterioration

- For all three pavement classes, unsealed, bituminous/sealed and concrete
- A wide range of structural effects

6.2 Roads Works

- Routine maintenance
- Periodic maintenance, e.g. resealing, resurfacing, overlays and reconstruction
- Development, including road widening, realignment and new sections
- Delays and VOC at road works

6.3 Road User Effects

- 16 representative vehicles have been incorporated based on results of recent research from which users can define an unlimited number
- Vehicle speeds calculated under free-flow and congested-flow conditions
- Improved models for fuel consumption, tyre wear, utilization, spare parts, maintenance labour and vehicle depreciation
- Calculation of generated and diverted traffic benefits
- Calculation of time-savings for passengers and transit goods

6.4 Road Safety, Energy Consumption, Environmental Effects and NMT

- Accident costs can be included within the economic analysis framework using specified rates and costs for different accident severities
- Energy consumption models have been incorporated for estimating the total life cycle energy consumption in terms of national and global energy sources
- Vehicle emissions relationships have been incorporated for estimating quantities of particulates, hydrocarbons and noxious gases
- Non motorized transport (NMT) effects and operating cost models are included

Appendix D. The Operational (resource cost) Method

This is generally considered to be the most accurate method of estimating project costs. It is a 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.

The method requires the process of construction to be broken down into its major components (materials, equipment, labour, etc) and is therefore sensitive to the productivities of plant and/or labour. This may be difficult to estimate in the circumstances of the particular project being evaluated. Also, a detailed programme of work is needed and this will not be available until a relatively late stage in the project. The operational method suffers from the danger that allowance has to be made for every item in the construction; it cannot be assumed that smaller items are included in the rates for major elements. This greatly increases the amount of work and the possibility of omitting a large number of minor items from the estimate creates a danger of underestimating the overall cost.

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 because all plant stands idle at some stage and this down-time needs to be taken into account.

Labour productivities will vary from site to site depending on management, organization, 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. However, it is important to obtain reliable data for labour productivities for two reasons. Firstly, agencies who want to encourage the use of labour-based methods often assist new or inexperienced contractors by specifying realistic labour productivities. Secondly, if productivities are known, it is possible to identify contractors who may be exploiting their labourers. The preferred method is to use 'daily tasks' thereby eliminating the need to consider down-time for labour and considerably simplifying the estimate of time and costs with the result that accuracy and reliability are improved.

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.

The operational technique provides the best chance of identifying risks and 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.

If there is sufficient information available, this method provides a very comprehensive means of comparing options in financial terms. It is especially suitable if the options are similar in environmental and operational terms, so that the cost becomes the most important factor in choosing between options. Sensitivity analysis can be used to assess the effects of changing the various rates and productivities for different options. This may help to determine which option carries the least risk.

The method is also suitable for estimating the cost of the detailed engineering design. At this stage of project development it is important to have the most accurate estimate of the cost. An assessment of risk is also valuable. The operational method provides both of these.

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A guide to road project appraisal