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Manual on the Planning of Labour-Intensive Road
Construction

by: M. Allal, G.A. Edmonds and A.S. Bhalla

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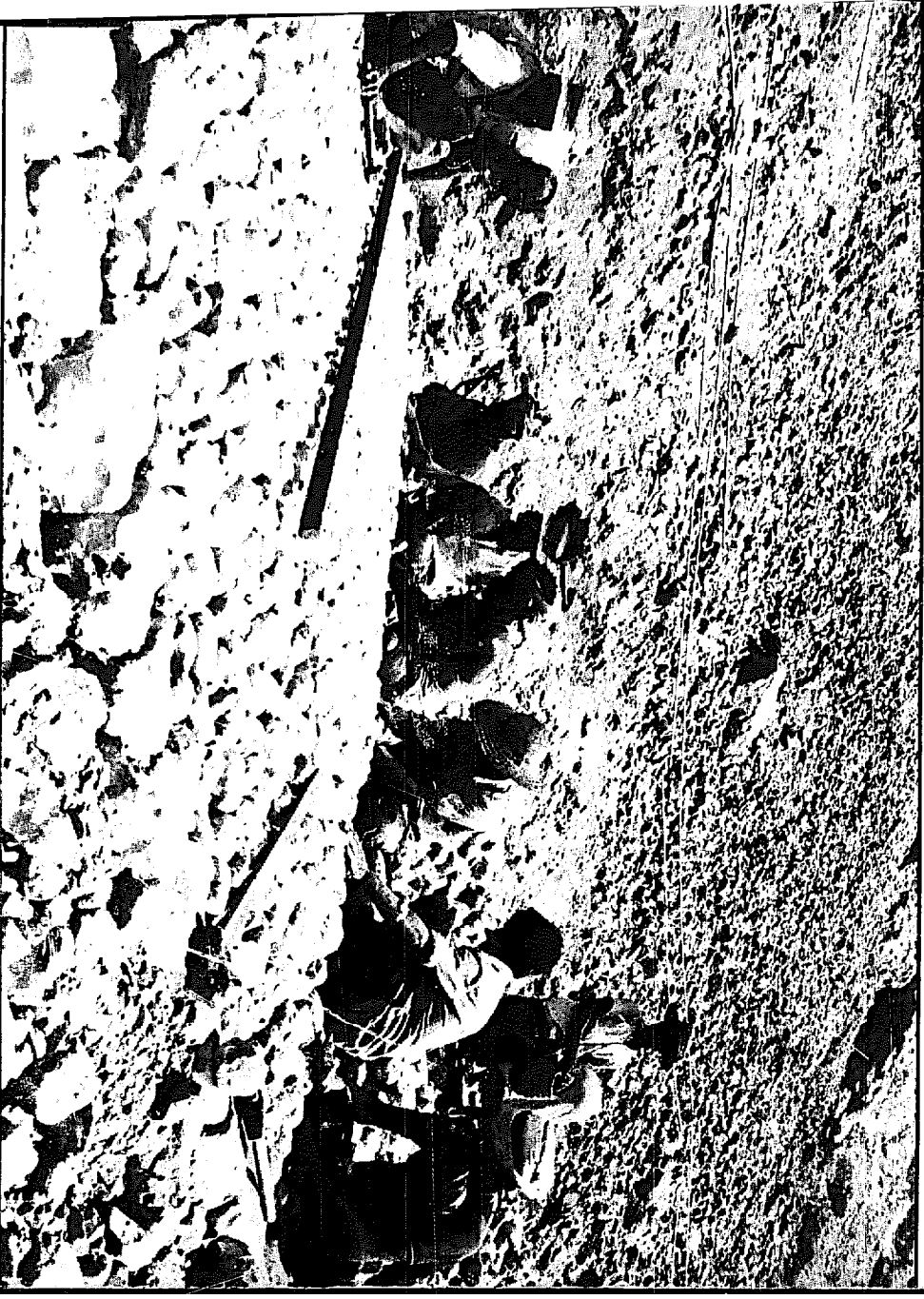Paper copies are $22.80.

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M. Allal and G. A. Edmonds
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The World Employment Programme was launched by the International Labour Organisation in 1969.

It is designed to assist national decision-makers in the reshaping of their policies and plans so as to achieve more effectively the employment and income distribution objectives of economic and social development.

Its main aim is in fact the eradication of mass poverty and unemployment.

The World Employment Programme thus constitutes the ILO's principal contribution to the International Development Strategy for the Second United Nations Development Decade.

There are four major types of WEP action:

1. comprehensive employment strategy missions and exploratory country employment missions;
2. regional employment teams for Africa, for Asia and for Latin America and the Caribbean;
3. country employment teams; and
4. an action-oriented research programme.

This publication is the outcome of a WEP project.

manual on the planning of labour-intensive road construction

Even in countries where labour is abundant and capital is scarce, people concerned with the planning and design of roads generally have no clear idea of the scope for the use of labour-intensive methods in road construction. The scope is in fact considerable. To take the fullest advantage of it, however, road investment programmes and road designs, with their associated technological options, must be methodically reviewed in the light of the essential objectives of the national plan and of the roads themselves. The authors first give systematic descriptions of how the choice of technology can be incorporated into planning and design. They then describe how labour-intensive techniques should be analysed, and the range of technological options available. They also show how to analyse road construction costs proper as well as maintenance costs, road users' costs and indirect benefits, and suggest criteria and methods to be used in evaluating different possible combinations of design and technology, both in orthodox financial terms and in terms of shadow prices using cost-benefit analysis. The concluding chapters review the problems of organisation and management in labour-intensive works, and suggest action that should be taken to eliminate capital-intensive biases in fiscal and financial policy, conditions of tender and contract terms, and the attitudes of engineers.

Other ILO publications

Technology and employment in industry. A case study approach. Edited by A. S. Bhalla. Foreword by Amartya Sen.

ISBN 92-2-101238-7 (limp cover); ISBN 92-2-101241-7 (hard cover)

Up to now it has often been assumed that in industry technological alternatives simply do not exist, particularly in " core " processes. The case studies included in this volume demonstrate that substitution possibilities do exist in both primary and secondary operations and thus that the issue of appropriate technology choice is not a myth. Most of the case studies are based on field surveys. Two of them (that on the minerals industry in the United States, Zambia, Zaire and Chile, and that on the manufacture of tin cans in Kenya, Tanzania and Thailand) are inter-country comparative studies. Others relate to a particular industry in a particular country—jute processing in Kenya, sugar processing in India, cement block manufacturing in Kenya, textile manufacturing in the United Kingdom, engineering in Colombia, and metalworking in Mexico. The concluding chapter by the editor provides a synthesis of the findings of the studies and draws conclusions, one of the more significant being that inappropriate choices are often made not because technical alternatives do not exist but because selection systems are inadequate, and because the people who take the decisions are unaware of the existence of the alternatives. The foreword, by Professor Amartya Sen, who is the author of another major ILO book on technology and employment published by the Clarendon Press—*Employment, technology and development*—puts the informational problem in its proper perspective of macro-planning and explains why detailed technological studies such as the ones included in this book have been neglected for so long.

Roads and redistribution. Social costs and benefits of labour-intensive road construction in Iran. By G. W. Irvin, assisted by B. Nilsson, L. Karlsson and R. Eriksson.

ISBN 92-2-101190-9

Equipment versus employment. A social cost-benefit analysis of alternative techniques of feeder road construction in Thailand. By W. A. McCleary, in collaboration with Moise Allal and Bertil Nilsson.

ISBN 92-2-101501-7

These two books are studies of the real costs and benefits, for society as a whole, of using more labour-intensive methods for the construction of roads in developing countries.

The first book is based on a report prepared at the request of the Government of Iran to elaborate on a suggestion made by a comprehensive employment mission to that country which had been organised by the ILO in 1971-72. It is often argued that when they leave the land, employment on public works could provide the rural poor with a livelihood until they find more attractive jobs elsewhere. On the basis of a field study of a number of road construction projects in Iran by a team of ILO economists and engineers, the book investigates to what extent the substitution of more labour for some of the machinery used to build roads in that country would be justified in social terms. The payment of a subsidy to contractors willing to employ more labour is suggested as the most practical and direct means of altering the capital-labour ratio.

The second book is a study of the economic case for the use of labour-intensive techniques for the construction of a typical feeder road in northern Thailand. Through interviews with private contractors, consulting engineers and the Highways Department, as well as through direct field observations, technically viable and economically promising alternative techniques were identified for most of the 19 operations involved in the construction of the road. This study is particularly interesting in that it was the first ILO study on road construction work to take account of the effects of the energy crisis on technological choice.

Manual on the planning of labour-intensive road construction

M. Allal and G. A. Edmonds
in collaboration with A. S. Bhalla

This manual is being published mainly for the use of people who are engaged in the planning, evaluation and design of road construction projects; such persons will generally be responsible for co-ordinating and implementing road construction programmes throughout their country. This is not to say that policy makers, on the one hand, and site engineers, on the other, will not find anything of value in this guide but merely to specify to whom it will be most valuable.

An attempt has been made to isolate various stages in the planning and implementation of road projects at which procedures can be changed to incorporate the assessment of alternative technologies. The changes required are described in some detail and practical advice is given on how to implement them. Thus, in Chapter 2, various aspects of the design process are selected to show how the design can seriously affect the choice of technology, and practical advice is given to show how the relationship between design and the choice of technique can be evaluated.

The assessment of alternative technologies requires adequate data, and a system of data analysis is described in Chapter 3, whilst Chapter 4 illustrates the range of alternative construction techniques.

Considerable emphasis has been laid on project evaluation, not only in respect of choice of technology but also with regard to the assessment of the real cost to a country of utilising the various resources involved in road construction. Certainly the economic arguments put forward in Chapters 5 to 9 will be unfamiliar to many. What is suggested in these chapters is not only a broadening of perspective to include alternative technologies but also a reassessment of the way in which the costs and benefits of particular projects are estimated for the economy as a whole, through social cost-benefit analysis. Although the rationale behind this evaluation procedure is relatively easy to grasp, it should be said that the actual methodology of evaluation is more complex. An endeav-

our has been made to present the methodology in a straightforward, practical manner so that readers will be able to appreciate its relevance and applicability.

The later part of the manual covers various measures that may be taken in order to ensure that the appropriate technology will in fact be given due consideration. Fiscal and financial policy are analysed in relation to their effects, and the practicality of certain adjustments is considered. The type of organisation and management required for labour-intensive projects is illustrated. Conditions of tender and contract terms are discussed, and suggestions are made for minimising biases towards the use of capital-intensive technologies. Proposals are also made regarding ways of changing the generally negative attitude of engineers and contractors toward labour-intensive technologies, and inducing them to seriously consider their adoption whenever such technologies are proven to be technically and economically feasible.

The manual is principally the work of Moise Allal, an economist, and Geoff Edmonds, an engineer; however, some preparatory work was carried out by Joel Gochenour, André Lumbroso and Runé Ericksson. Geoff Edmonds wrote Chapters 2 to 4 and Chapter 10; Moise Allal was responsible for Chapters 1 and 5 to 9. Ajit Bhalla collaborated with Geoff Edmonds on Chapters 11 and 12.[1]

In the final stages of preparation Jens Müller examined the entire draft and made various valuable suggestions for its improvement.

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[1] Messrs. Allal and Edmonds are both members of the Technology and Employment Branch of the Employment and Development Department of the International Labour Office; Mr. Bhalla is Chief of the Branch.

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INTRODUCTION

It is generally recognised that developing countries have a tendency to use production methods that are inappropriately capital-intensive: since such countries are usually short of capital and foreign exchange, and have high unemployment, the relative prices of labour and equipment should favour the use of technologies that are less capital-intensive than those currently in use. The adoption of appropriate technology could help to alleviate the dependence on foreign exchange, while creating substantial numbers of new jobs and providing the rural and urban poor with the means of meeting their basic needs.

The mere presentation of ideas is not sufficient to make them attractive. However correct the argument outlined above may be in theoretical terms, planners, project evaluators and engineers in the developing countries need something rather more substantial on which to base their day-to-day decisions regarding expenditure of limited funds on a host of competing projects. They may fully agree with the notion of appropriate technology, but they must first be presented with viable alternatives to the technology they are using. They also need to be given the means of evaluating, assessing and taking advantage of these alternatives. The present manual constitutes an attempt to meet that need.

It is often said that the role of a civil engineer is to make the best use of the available resources for the benefit of society. Like many high-sounding statements, this maxim is open to diverse interpretations, generally revolving around the word "best". In recent years road construction has figured prominently in written exchanges about the choice of the most appropriate techniques in developing countries, mainly because of the assumption that many of the tasks involved in road building could be executed by relatively unskilled labour. Advocates of more labour-intensive methods have suggested that the "best" use is not being made of labour: it is argued that in countries with a shortage

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of capital and a surplus of labour, there is an obligation to investigate the possibilities of utilising more labour-intensive methods.

In an effort to provide some facts to justify the use of labour-intensive methods of construction, various case studies have been carried out. They have generally taken the form of theoretical analyses of road construction projects carried out capital-intensively; the feasibility, both economic and physical, of carrying them out by using more labour-intensive methods has then been calculated. A limited number of studies have been done on projects for which these other techniques were actually used. All these studies have been extremely useful for identifying the operations to which a variety of methods could be applied, and to a lesser extent for assessing the efficiency of such methods. However, because the studies were generally not initiated by engineers, the road construction process was considered in isolation. Thus some basic misconceptions were written into the studies: first, the construction process was considered to be independent of the design whereas, in fact, the design is an active constraint upon it. Secondly, and as a logical consequence of the first point, the responsibility for design was considered to coincide with the responsibility for construction. In fact, nothing is further from the truth: most road construction work is carried out by private contractors, who are responsible for the construction but not at all for the design. Thus engineering designers were criticised for not making the best use of resources, but the evidence used in support of the criticism was based on the construction process, for which the designer generally has no direct responsibility. It was also assumed that choice of design had no influence on the choice of construction methods, whereas it is likely that most designs are biased towards equipment-intensive operations because of the designer's training.

It is clear that any dictum about the best use of resources must be viewed within the institutional framework to which it applies. Thus, a design that is based on equipment-intensive technology is unlikely to allow a labour-intensive technology to display its optimum usefulness. To make the best use of the available resources, the engineer or planner must work in the correct framework. The range of designs considered for a road or group of roads must be such as to span the whole range of techniques. If the designs are all geared towards equipment-intensive operations, then no real comparison can be made of the correct use of the two resources, equipment and labour. Moreover, only when the designs provide for different alignments, specifications, and maintenance and road user costs will it be possible to assess accurately the most economic use of the resources.

One of the most prevalent criticisms of road construction methods that do not involve the use of large-scale equipment is that their output is limited. The bulk of such criticism is levelled at the standard of compaction, the effectiveness

of grading and levelling and the inability to achieve he required tolerances. The World Bank, for example, has suggested that this factor severely limits any discussion of the use of more labour-intensive methods.[1] There is indeed some foundation for this criticism when the basis of comparison is a fixed, equipment-orientated design, and it is assumed that a road must necessarily have the pavement thickness, level of compaction and tolerance limits associated with one method even if it can be produced by a variety of methods. However, once it is accepted that a willingness to use different methods of construction implies a change of design philosophy, some of the criticisms are invalidated. Without departing from over-all objectives, it can be accepted that the finished road will have different characteristics if constructed by alternative methods. For example, the road may have varying levels of tolerance as regards the finished surface, and the road user costs will then differ. The compaction of the sub-grade may be limited to 90 per cent of the optimum dry density, and it may have to be sealed to create an impervious layer. Also, the pavement thickness may have to be greater if the level of compaction is limited. The road maintenance costs may vary for each different design.[2] It is necessary, therefore, for engineers to rid themselves of the idea that all methods are to be gauged by the standard of construction produced by equipment-intensive methods. Such methods produce a certain standard which can be associated with particular construction, road user and maintenance costs. Other methods produce roads of different standards which have different costs. It may well be that, all in all, the equipment-intensive methods will be shown to be the most economic. Nevertheless, it should not be automatically assumed that the alternative methods are inferior because they do not produce the same standard.

When discussing the standard achieved by the use of labour-intensive methods, there has been a tendency to consider only cases in which such methods have been used to the exclusion of all others for an entire project. For example, it is admittedly difficult to achieve a high value of compaction with totally labour-intensive methods, and critics therefore assume that highly compacted earthworks cannot be a feature of projects using labour as the major resource. However, the use of equipment for compaction is advisable in such a case.

In this controversy the question of productivity, particularly that of labour, has perhaps received more attention than any other. This is principally because, with the type of studies that have been carried out, any discussion of economic

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[1] International Bank for Reconstruction and Development: *Study of the substitution of labor for equipment in road construction*, [Draft] *Phase I final report*, Oct. 1971, p. 6.

[2] The question of maintenance is dealt with in Chapter 6. It is worth noting here, however, that road maintenance is generally a labour-intensive activity, so that a need for increased maintenance will increase employment.

viability has hinged upon this factor. The productivity of machinery is difficult to assess because factors such as efficiency, rolling resistance, gradient and haul have to be considered. However, the manufacturer can at least indicate the maximum output of the machine, and from that calculation a working figure can be derived. Such a procedure cannot, however, be used in the case of manual labour: attitude, health, environment and physiology all have to be considered (for example, a World Bank study [1] reported a 1,300 per cent variation in the output of workers involved in excavation). It is a little surprising that productivity should be used as a stick with which to beat labour-intensive methods when so little is known about it: our present knowledge of labour productivity in road construction is related to such factors as haul distance and height of lift; very little work has been done on the effect of good organisation and supervision, diet and other conditions. The conclusion drawn by researchers is that when considered in isolation, labour productivity would appear to limit the implementation of labour-intensive methods. A far better approach would be to consider what productivity rates are required to make more labour-intensive methods viable, and whether it is possible to achieve those rates by supplying the right organisational and institutional framework.

When deciding between any two or more designs it will generally be the over-all cost that will be used as the criterion for selection. Of the studies that have been carried out, many come to the conclusion that when evaluated at market prices, labour-intensive techniques currently in use are not economically competitive with modern capital-intensive techniques. However, if accounting or shadow prices were to be used in project evaluation, labour-intensive techniques could appear much more attractive.[2] Moreover, when discussing more labour-intensive methods most analysts have restricted themselves to the construction costs, and the methods have all been assessed in relation to the same design. Thus it is not necessarily the correct alternatives that are being considered: the costs associated with more labour-intensive methods are restricted to the costs of constructing a certain design, whereas a true comparison of cost can be made only if a variety of designs are priced in terms of construction, maintenance and road user costs. The argument of inferiority on a cost basis is based on a consideration of alternative techniques for a limited number of operations such as earthmoving and sub-base laying. While this may provide useful data on the productivity range that can be expected for those operations,

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[1] International Bank for Reconstruction and Development: *Study of the substitution of labor for equipment in road construction*, [Draft] *Phase I final report*, op. cit., p. 28.

[2] W. A. McCleary, in collaboration with Moise Allal and Bertil Nilsson: *Equipment versus employment: A social cost-benefit analysis of alternative techniques of feeder road construction in Thailand* (Geneva, ILO, 1976).

it is not a true assessment of the viability of alternative techniques for entire projects.

Most of the methods used in road construction have been taken over from developed countries. If the methods had been imported in isolation, there would be no great problem in altering them. At the same time, however, the administrative procedures were also imported. Thus in most developing countries the contract terms, specifications and conditions of tender are basically the same as those used in the developed world. In many developing countries the private sector is dominated by European and North American contractors whose expertise is geared towards the use of equipment-intensive methods. How far they would feel capable, or willing, to work to other design specifications and with other construction methods is a matter of conjecture. It may be necessary to unify the responsibility for design and construction in the initial stages, and the public authorities may be called upon to prove the viability of alternative techniques.

It has already been suggested that the attitude of designers and contractors in developing countries is biased towards equipment-intensive methods. While an effort should be made to permit the fair evaluation of alternative techniques, it is necessary to guard against an automatic bias towards more labour-intensive techniques. There is a danger of assuming that more labour-intensive methods are always appropriate instead of regarding them as a possible alternative. It would be a mistake to alter the institutional framework so that it discriminates against equipment-intensive methods: the framework must be altered in such a way that proper consideration will be given to all the technological possibilities. It is possible that although more labour-intensive methods are now appropriate in many cases, in 20 years' time the situation may change. In view of this uncertainty it would be foolish to completely change the institutional framework. The best solution is to widen it so that the methods that are the most advantageous in terms of the public interest can in fact be identified and applied.

PART I

THE OPTIONS

ROAD PLANNING

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In order to facilitate an understanding of the various evaluation procedures described in later chapters of this manual, it is first necessary to describe the framework within which the choice of technology is undertaken. Accordingly the first section of this chapter briefly describes the elements that should be taken into consideration when choosing road projects and construction technologies. The second section describes the steps involved in the elaboration of a road investment programme and the identification of potential road projects. The third section describes how those potential projects must be analysed and their most appropriate versions in terms of routing, design and technology identified. The fourth section describes how the project choice is made for the five types of roads to be considered in the manual.

ELEMENTS OF CHOICE

Evaluating the social profitability of road projects involves the estimation of both direct and indirect costs and direct and indirect benefits. Costs can be divided into capital costs, including the cost of land acquisition and construction costs, and variable costs, including road user costs and road maintenance costs. The social benefits of a road include higher economic activity in the area crossed by the road, and decreases in both road user costs and maintenance costs.

The difficulty in evaluating the profitability of a road project arises from the fact that there are usually several versions of the project. For a given road project, there may be a number of possible routes and various sets of design specifications. Furthermore, a number of different construction technologies may be used in order to build the road. In other words, for a given road project, there usually exists more than one version in terms of routing, design and technology. The project evaluator's task is to evaluate all versions of a road project in order to identify the most socially profitable one. Other, less profitable

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versions may then be disregarded when comparing the profitability of the particular road project with that of other public investment projects.

The routing of a road is mainly determined by socio-economic considerations and by the topography of the area which the road should cross. These are exogenous variables which define the range of potential routes. Within those limits, however, the choice of alignment to be adopted is influenced by the design specifications and the construction technology which are adopted. This aspect of the problem will be examined in some detail in Chapter 2. The main point to be stressed here is that different routes may yield different road-induced benefits since the area of influence of a road is a function of the route it follows. Furthermore, different routes and alignments yield different road lengths, and therefore different construction costs, road maintenance costs, and road user costs.

Road design specifications (governing the solidity of the road and such factors as the maximum permissible gradient and curves) are mainly determined by the current and future traffic volume and composition, by the topography of the area to be crossed by the road, and by the speed at which it is intended or expected that traffic should move. It will be shown later that the design specifications adopted affect construction costs, maintenance costs and road user costs. It will also be shown that the narrower the range of design specifications, the narrower the range of construction technologies that may be adopted. Design specifications therefore affect construction costs by limiting the choice of construction technology. There is generally a trade-off between the initial construction costs, on the one hand, and the future maintenance and road user costs, on the other; and it is therefore very important that road designers should be concerned with both initial and future costs.

The choice of construction technology is mainly determined by the route and design adopted, and by the availability of equipment and labour. Obviously, the use of labour-intensive technologies should not be considered in sparsely populated areas unless workers from other areas are willing to live in workers' camps during the duration of the project. On the other hand, capital-intensive techniques cannot be used if skilled labour and construction equipment are not available. It should be stressed that the construction technology adopted will also affect construction costs. It may be noted that for any particular design specification the technology adopted will not usually affect maintenance costs and road user costs since it may be assumed that all technologies under consideration will yield the required output quality.

To conclude: the profitability of a road project is generally a function of the road's route, its design and the construction technology. It is the version of a road project which maximises social profitability that is to be evaluated for the purpose of comparison with other public investment projects.

THE ROAD INVESTMENT PROGRAMME

The choice of technology follows the identification of actual or potential projects. Road projects are selected either on an ad hoc basis or on the basis of a more or less elaborate road investment programme. In the first case, the selection of road projects is made on the basis of political, social and economic considerations with little or no attempt to link the particular road projects to an over-all national or sectoral plan. In the second case, the selection of road projects follows the elaboration of an over-all transport investment programme which includes a number of potential road projects. If bottlenecks and excess capacity are to be avoided, and if national resources are to be used in the most efficient manner, economic planners must know how projects relate to one another within a given sector, as well as how sectors interact with one another. It is necessary to consider, for example, how the growth of one means of transport (e.g. railways) may affect the growth of other means of transport. Similarly, it is necessary to examine, for example, how the improvement of transport facilities in general will affect other sectors of the economy (e.g. agriculture and industry). Such information is very important in developing countries since the development of transport is usually a prerequisite—although by no means a guarantee—of economic growth. The aim in elaborating a transport programme is therefore to identify promising projects, to relate them properly to one another, and to relate all projects together to the macro-economic plan.

It must be pointed out that the elaboration of a transport sector programme, and consequently of a road investment programme, requires a great deal of work and time. Transport experts may need to spend a year or longer on the elaboration of such a programme for a medium-sized country. Owing to lack of personnel trained in transport problems, lack of traffic data and time constraints, some developing countries may not be able to elaborate comprehensive transport programmes. In such circumstances rudimentary programmes can none the less be prepared on the basis of more subjective assessments to include transport projects which seem to be crucial to the future growth of the country, or for which there is a strong demand.

A transport programme may cover a country's entire transport system, including, in this case, a road investment programme worked out within the framework of the over-all transport programme. The development of an independent programme for a particular means of transport should be undertaken only if it can be shown that no other means of transport can be substituted for the one to which the programme relates. Thus a road network development programme may be elaborated independently of other transport programmes if it is shown that transport by air, rail or inland waterway would not be competitive with road transport. Within the road investment programme

itself, on the other hand, the identification of certain potential projects can be made independently of other transport projects. For example, feeder roads attached to future agricultural projects or roads serving industrial sites are included in the programme as a result of a decision to implement those more general investments projects. In those cases, roads are a joint cost with other investments outside the transport sector, and the realisation of benefits depends not only on the roads but also on these investments. The planning of such roads is thus part of the planning of the sectors from which the above investments originate.

The elaboration of a transport investment programme follows the following sequence:

(a) identification of the basic goals of the programme;

(b) survey of existing means of transport;

(c) traffic forecasts; and

(d) identification of the potential transport projects to be included in the programme.

Means of transport serve to connect production and population centres with one another. Consequently the development of the transport network cannot be dissociated from the country's over-all development goals or strategy. Ideally, a transport investment programme should be elaborated concurrently with the programmes for other sectors, and all programmes should be merged into an over-all national plan. A transport investment programme elaborated with respect to the planned growth in other individual sectors of the economy should take into consideration the need for various means of transport in each of those sectors: if it is planned, for example, to give priority to increasing agricultural production, feeder roads will have to be built; similarly, regional development plans may require that the existing road network be expanded.

The planned growth of individual sectors of the economy can sometimes be achieved through the development of alternative means of transport: for example, the development of mining may require that the existing road network should be developed, or instead, that new railway lines should be built; the problem is then to identify the less costly means of transport in each particular case.

In order to plan future transport, it is essential to have a fairly good assessment of the quantity and quality of existing facilities. Transport data collection is a fairly complex task, and surveys carried out with that object in view call for a great deal of work and time as well as qualified personnel. The total amount of information to be collected depends on the amount and reliability of the information already at hand. On road transport it is usually scarce, and in

most cases unreliable: road condition is not usually known, and little information is available on such factors as vehicle operating costs and traffic flows. A survey should provide a description of the existing facilities in qualitative as well as quantitative terms: for example, a survey of the existing road network should include estimates of the relative extent of various types of roads (e.g. paved, gravel, or earth roads), their current condition (good, fair, poor), and the volume and composition of traffic flows. To be useful, a road transport survey needs to include information about the main commodities and the passengers carried, as well as about the origin, destination, types and capacity of the vehicles using a given road. This type of information needs to be gathered for various times of the day as well as various seasons of the year.

Since transport projects have long lives, of 20 years or more, traffic forecasts are essential for the elaboration of a transport investment programme. Traffic forecasts are needed not only in order to identify specific transport projects, but also in order to schedule project implementation in the cases where construction can be carried out in stages. The way to conduct traffic forecasts will not be described in this manual since many books have already been published on this subject.

Once forecasts of traffic by the various means of transport have been made, potential transport investment projects can be identified. For each means of transport, projects are listed and may be grouped into three distinct classes as follows:

(a) maintenance projects;

(b) improvement and modernisation projects; and

(c) new projects for the purpose of increasing existing capacity.

Once the transport programme has been elaborated, the next step is to rank transport projects and select the higher-ranking ones for implementation, within the limits imposed by budgetary and other constraints. As regards roads this selection process is the subject of the present manual, and will be described in detail.

IDENTIFICATION OF THE MOST APPROPRIATE VERSIONS OF POTENTIAL PROJECTS

In elaborating a transport investment programme, potential road projects are identified but not analysed in great detail. Information about potential roads is usually sketchy: design specifications are not fully elaborated, the route to be followed by individual roads is approximate and little information is available about the way in which the roads should be built. This lack of

information is to be expected, since the purpose of a transport investment programme is to provide not detailed information on specific transport projects but an over-all view of transport investment needs. In order to enable planners to compare and select projects on the bases of their social profitability, a detailed analysis of potential projects must therefore be undertaken before individual projects are selected.

As will be shown in Chapter 2, the choice of road design may affect the choice of construction technology and thus construction costs. Furthermore, road design always affects road maintenance costs and road users' costs. The choice of the route which a road is to follow may affect construction costs, road maintenance costs, road users' costs, and in some cases, the value of benefits derived from the road. Once potential road projects have been ident-ified, project evaluators must identify the most appropriate route and com-bination of design and technology for each potential road project. It is this version of a project that is ranked at the project selection stage.

The identification of the most appropriate route and combination of design and technology generally includes the following steps.[1]

1. *Identification of possible routes for a road*

The route which a road shall follow is determined on the basis of socio-economic considerations as well as a number of technical constraints. Project evaluators may identify possible routes with the help of regional development planners.

2. *Estimation of road benefits for each possible route*

Road benefits may include additional agricultural production or the develop-ment of new industries which would not take place if the road were not built.

3. *Identification of possible road designs for each possible route*

Technical constraints may limit the number of possible road designs for each route.

4. *Identification of possible combinations of design and technology for each route*

The construction technologies considered for a given design must yield the quality of output specified in the design.

5. *Estimation of construction costs for each possible combination of design and technology*

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[1] The identification procedure described in this section is further elaborated in Chapters 2 and 7.

6. *Estimation of road maintenance costs and road users' costs for each combination of route and design*

Road maintenance costs and road users' costs must be those applying to the most appropriate (i.e. least costly) maintenance policy (covering the frequency and extent of maintenance operations over the life of a road).

7. *Identification of the most appropriate route and combination of design and technology*

The most appropriate route and combination of design and technology is that which maximises the difference between road benefits (estimated under step 2) and the sum of road construction costs (estimated under step 5), road maintenance costs, and road users' costs (both estimated under step 6).

The following mathematical formulation summarises the above steps:

Let B_i = road benefits that apply to road route i ($i = 1, 2, \ldots l$);

C_{ijk} = road construction costs that apply to road route i for a given road design j ($j = 1, 2, \ldots m$) and a given construction technology k ($k = 1, 2, \ldots n$);

$(MC + RUC)_{ij}$ = sum of road maintenance costs (MC) and road users' costs (RUC) for a given route i and a given road design j.

The most appropriate route and combination of design and technology is that which maximises the net road benefits $(NB)_{ijk}$ where

$$(NB)_{ijk} = B_i - C_{ijk} - (MC + RUC)_{ij}$$

$(NB)_{ijk}$ must be estimated for each (ijk) combination, the most appropriate combination being the one that yields the highest net benefits. If, for example, there are two possible routes ($l = 2$), two possible road designs for each route ($m = 2$ for all is), and two possible construction technologies for each design (i.e. $n = 2$ for all js), then the total number of (ijk) combinations to be analysed is equal to 8 (i.e. $2 \times 2 \times 2$).

It should be pointed out that the identification of the most appropriate version of a potential road project does not require that all benefits and costs be estimated: those that are common to all possible versions of the same project need not be estimated since they would cancel out when the various versions are compared. In most cases, the benefits of a road need not be estimated since they usually do not differ from one version of a project to another. Moreover if it is felt that there can be only one possible road route and design, the only variable will be construction costs, as a result of the existence of a variety of construction technologies. All costs and benefits must, however, be estimated if projects have to be ranked before the project selection stage.

If benefits are not quantifiable, the identification of the most appropriate version of a potential road project will usually be based on information regard-

ing the cost of different possible combinations of design and technology for each route, and on the economic planner's subjective evaluation of benefits for each route.

The assumption that costs are fully quantifiable implies that different technologies are fairly well known and have already been tested in the process of building existing roads, so that figures on the productivity of labour and equipment are both available and reliable. It also implies that other input prices that will prevail during the implementation of the project can be estimated with an adequate degree of certainty. In practice, however, little may be known about alternative construction technologies. In particular, there may be little information available on the productivity of equipment and labour and on managerial efficiency. This is especially true of labour-intensive construction technologies, in respect of which very few studies have been carried out. Furthermore, the few studies completed to date apply to particular environmental and other conditions such as climate, soil composition, topography and management; and it is difficult, if not impossible, to use their results to arrive at general rules applicable to other countries. A lack of information on the direct cost of a variety of possible technologies precludes the identification of the most appropriate one for a potential road project. Yet cost data are needed if projects are to be ranked for selection purposes, and if the national or sectoral budget is to be properly balanced. One solution to this dilemma is to collect all necessary data prior to undertaking the identification procedure. This solution, however, requires a fairly long time; indeed in some cases data collection could take over two years, which is the period covered by some short-term plans. The selection of road projects—or any public investment projects—generally cannot wait that long: the cost of waiting could be extremely high since scarce funds would be kept idle at the expense of the country's growth. Such a solution is thus not feasible.

An alternative solution, and the one usually adopted, is to estimate direct costs on the basis of past experience, assuming a standard construction technology previously in use in the country, or construction costs per unit of output obtained from completed road projects. In this case, road projects will differ from one another with respect to routing and design only, since different technologies are not considered. Once the most profitable potential project has been identified on this basis and if the project is selected for implementation, a more detailed analysis may be undertaken in order to identify the most appropriate construction technology, providing that enough time is available for such an analysis. Whenever feasible, experiments with different construction technologies should be undertaken before a selected road project is implemented.

Project selection in the absence of quantifiable data has two main shortcomings. First, the modified identification procedure just described may lead

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to the selection of projects that would have been rejected, or, conversely, to the rejection of projects that would have been selected had reliable figures been available. In other words, unreliable information on costs and benefits may lead to an unreliable ranking of projects. This situation cannot at present be avoided, and will continue to prevail until reliable information is available. However, collection of reliable information is not an impossible task: given sufficient time, project evaluators should succeed in improving their data base for project evaluation.

A second shortcoming of the procedure is that actual construction costs may differ from initial estimates based on an assumed technology or on standard unit costs. This situation requires future revisions of the budget in order to balance public revenues with public expenditure. It should be noted, however, that budget revisions would be needed for a number of reasons even if there were full knowledge of construction technologies at the project selection stage. First, input prices used at the selection stage may differ from those that will actually prevail when the project is implemented. This fact is usually recognised by project evaluators, who try to take account of potential price movements in carrying out project evaluation. They may not, however, always succeed in this endeavour. Secondly, unforeseen events may increase construction costs: floods may destroy some of the construction work; delays may be incurred in the import of needed equipment. In general, there is always some degree of uncertainty with respect to the conditions that will exist at the implementation stage, and some discrepancy between estimated costs and actual costs nearly always occurs. Finally, estimated public revenues may differ from actual revenues. This necessitates the continuous adjustment of public expenditure to public revenues through the postponement or earlier implementation of public projects.

PROJECT SELECTION

Depending on the type of road project, selection may precede or follow the identification of the most profitable version of each potential road project. Five types of road projects will be considered in this manual, namely—

(a) road maintenance;

(b) road improvement;

(c) new roads primarily intended to shorten travelling distances;

(d) new roads that are part of wider sectoral investment projects; and

(e) developmental roads.

In general, projects of types *(a)*, *(d)* and *(e)*—concerning road maintenance, new roads that are part of wider sectoral investment projects and developmental roads—are selected before the most appropriate versions of such projects have

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been identified. On the other hand for projects of types *(b)* and *(c)*, concerning road improvement and roads to be built for the main purpose of shortening travelling distances, the identification of the most appropriate version usually prece es the selection of the project. The reasons for these different approaches are explained below.

Projects of types *(a)*, *(d)* and *(e)* are among the many public investment projects for which costs and benefits cannot be fully quantified. Public planners have to choose which non-quantifiable projects should be implemented in the light of the funds available. Their choice may be made by first ranking non-quantifiable projects on the basis of a subjective valuation of their wort! to society. Then, given a ranking of quantifiable projects, each non-quantifiable project may be compared, on the basis of subjective considerations, to successive quantifiable projects in order to determine the rank which should be assigned to it. Once a unique ranking of all projects—quantifiable and non-quantifiable—has been obtained, the higher ranking projects are selected within the limits imposed by budgetary constraints.

Road maintenance

Public works departments are usually responsible for maintaining the existing road network. Road maintenance is carried out either in accordance with rules laid down by those departments or under pressure from road users or local or other authorities. The public works department must know which roads should be maintained, at what time intervals maintenance activities should take place and what will be the extent of each maintenance operation.

There is rarely a decision to take on whether to continue or discontinue maintenance of existing roads. In most cases, existing roads are essential links between population centres, and it is obvious that such roads must be kept open to traffic, and maintained accordingly.

In general, whenever roads are used, there will always be some pressure from road users for continuing maintenance. The only situation in which a government may decide to discontinue the maintenance of roads serving population centres is one in which the government wishes to relocate the population. In other cases roads may have ceased to be useful, and it is obvious that they should therefore cease to be maintained: this is true for roads which no longer perform the role originally assigned to them (e.g. approach roads to closed mines or military camps no longer in use).

Unless it has been decided that a road should not be maintained, the public works department must determine the frequency and extent of each maintenance operation so as to reduce to a minimum the sum of maintenance costs and road user costs properly discounted to the present.

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It will be apparent from the foregoing passage that the maintenance of a given road need not be the outcome of a deliberate decision taken in relation to its merits by comparison with those of other road projects: on the contrary, road maintenance is normally undertaken on the unchallenged assumption of its intrinsic worth. Moreover, if a road is to be kept open to traffic at all, maintenance operations must be carried out as needed since their postponement unnecessarily increases maintenance costs and road users costs, and thus results in the long run in a decrease of the amount of investible funds that may be used for other purposes.

Road improvement

The improvement of an existing road may be required for any number of the following reasons:

(a) traffic so heavy that average travelling times between places along the road are unduly long;

(b) high vehicle operating costs;

(c) a high accident rate resulting from the existence of dangerous sections along the road;

(d) uncommonly high road maintenance costs; and

(e) frequent closing of the road to traffic as a result of floods, landslides or other natural disasters.

When contemplating road improvement, the public works department must compare improvement costs to the sum of the various costs resulting from the use of the non-improved road. These costs include quantifiable items such as—

(a) additional vehicle operating costs;

(b) additional costs attaching to traffic accidents;

(c) additional road maintenance costs; and

(d) loss of income due to frequent closing of the road.

The profitability of a road improvement project may be expressed as the difference between the sum of the above four cost items and the road improvement cost. Unless unlimited funds are available, a road improvement project must be ranked along with other projects in order to determine whether it is sufficiently profitable to be selected for implementation.

The identification of the most appropriate version of a road improvement project precedes project selection.

New roads to shorten travelling distances

The main purpose of a new road is often to lower road users' costs by diverting some of the traffic on existing roads to the new road. Other road benefits may occur, but they are generally of secondary importance.

Benefits derived from such a new road may be expected to include—

(a) lower road users' costs for traffic diverted to the new road;

(b) lower maintenance costs of existing roads since they will bear a lower traffic volume than if the new road were not built; and

(c) increased benefits in the area crossed by the new road (e.g. an increase in agricultural production).

Costs attached to a new road include—

(a) construction costs, and

(b) maintenance costs of the new road itself.

The profitability of this type of road may be expressed as the difference between the benefits and the costs mentioned above. The identification of the most profitable version of such a project must precede project selection.

New roads that are part of wider sectoral investment projects

Some public investment projects require the construction of new roads to serve either as links between the project site (e.g. in the case of a mine or an industrial plant) and existing roads, or as a means of communication on the project site itself, as in the case of feeder roads. Projects that include the construction of roads may or may not be compared to other projects for selection purposes. In any case, the task of selecting such general projects is not a concern of the road project evaluator. Once the over-all investment project has been selected, by whatever method, it is no longer necessary to compare the road project or projects involved to other road projects for the purpose of obtaining the necessary allocation of investment funds.

Road projects falling within wider projects need to be implemented by a construction technology that maximises the social profitability of the over-all project. For example, in the case of an agricultural project, feeder roads must be designed and built in such a way as to ensure that they will not need to be closed to traffic during part of the harvest or planting seasons: the road design must satisfy that minimum quality standard. Subject to this kind of requirement, the identification of the most appropriate version of the road project consists in identifying the one that is least costly in terms of construction costs, maintenance costs and road users' costs.

Developmental roads

The purpose of developmental road projects is to promote economic development in isolated parts of the country in which development has not kept pace with that of other regions. The main motives behind a decision to invest in such road projects may be considerations of social equity. Since the benefits and certain costs attached to these projects are difficult to quantify, it is rarely possible to evaluate alternative versions prior to project selection, and the identification of the most appropriate version is therefore carried out after the project has been selected.

To identify the most profitable version, project evaluators must estimate road construction costs, road maintenance costs and road users' costs for each. In most cases, however, road users' costs are not available since it is extremely difficult to forecast traffic flows for future developmental roads. The identification of the most appropriate version is then based on the first two cost items only.

ROAD DESIGN

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This chapter deals with the effect of choice of design on the choice of technique. It will be shown that the design process can be improved to allow consideration of different construction techniques, and that there are particular aspects of road design that should be analysed to ensure that the optimum use is made of the available resources. In many cases this optimum use is very different from that which would result from designs taking little account of the possibility of using more labour-intensive techniques.

DESIGN SCOPE

There are many roads that do not need engineering design, or at best a very limited amount: rural access roads, roads built under self-help schemes and access roads serving major public works such as dams fall into this category. Their construction has been the subject of extensive study by the United Kingdom Transport and Road Research Laboratory and to a lesser extent the Intermediate Technology Development Group (London).

These roads are generally of a low technological level and lend themselves admirably to the use of more labour-intensive methods. As long as the basic ideas of alignment, drainage and compaction are understood, there is no reason why such roads should not be built without the full-time assistance of an engineer. However, by far the largest amount of money allocated for road works will be spent on roads that require a full-scale design by a civil engineer. The methodology developed in this chapter is concerned with these roads.

The question of over-all road planning was discussed in the previous chapter. In the present chapter an attempt is made to indicate how a design engineer could use a knowledge of alternative methods of construction in designing a particular road, once the road planners have identified an economic priority for it and the engineer has been given the task of preparing a design.

It is quite clear that in many cases the design limits the choice of technique: the road designs are geared towards equipment-intensive techniques and it is therefore difficult for more labour-intensive techniques to compete. It is at the design stage, therefore, that the use of alternative techniques should be considered. What every designer must ask himself is "what purpose does this road serve and what methods could be used to achieve the objective?" An example may help to illustrate this point. It may be necessary for a road to cross a river. The initial solution envisaged may be to provide a sophisticated pre-cast, pre-stressed concrete structure; but the engineer should ask himself why the structure should be of pre-stressed concrete rather than of reinforced concrete or of timber, and also whether it is necessary to provide a bridge at all and whether a ferry crossing would not adequately serve the purpose. Coupled, therefore, with the acceptance of the consideration of alternative techniques goes the need to consider the basic objectives in providing the road and the whole range of designs that might be suitable for their attainment.

Many studies have already been carried out on the possible use of alternative technologies in road construction.[1] The figures that have been assembled in these studies are of value in indicating the efficiency of various methods. However, the studies have concentrated on alternative methods of implementing particular designs, without considering the possibility of altering the designs in order not to impose a constraint on technological choice. Thus, the original design is often biased towards the methods with which the designer is familiar, and it constrains the choice of techniques. It is not surprising, therefore, that when alternative methods are examined they are found to be inefficient. It is as if a motor car designed to be powered by petrol were expected to run equally well on kerosene. It has also been generally assumed that the construction costs can be considered in isolation, and that maintenance costs and road user costs will be the same whatever construction method is used. In fact each individual design will exert different pressures on the choice of technique to be used. For example, one design may call for a pavement construction of high quality which entails a low degree of tolerance in its construction, and has minimal maintenance costs and low road user cost; an alternative design may be less restrictive in the final quality of the running surface and be associated with high maintenance and road user costs; a design may provide for a route which is direct but involves a large amount of rock excavation; another may follow a more leisurely route which merely involves short-haul earth excavation.

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[1] See for example Deepak Lal, assisted by A. Heap, H. Boisen, B. Nilsson and L. Karlsson: *Men or machines: A Philippines case study of labour-capital substitution in road construction* (Geneva, ILO, 1974; mimeographed World Employment Programme research working paper for restricted distribution only).

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In the initial stages the production of alternative designs will not be easy. The engineer will have to reconsider many of his preconceived ideas. There is unfortunately no short cut to the optimum combination of design and construction technique. It is not suggested that no extra work will be involved in the consideration of a wider range of design possibilities: certainly it will be. However, the benefits that will accrue should heavily outweigh any cost in terms of extra time and resources spent at the design stage.

This chapter is therefore intended to show how a more wide-ranging assessment of the optimum design can be arrived at. It is hoped that, with use, the ideas put forward here would eventually be taken for granted. The road designer would then truly assess alternatives in terms of factor proportions and not purely the use of different types of equipment-intensive technology.

COSTING OF DESIGNS

It is possible therefore to think in terms of a road project for which there are a variety of possible designs. Some will be more suited to equipment-intensive techniques, others to labour-intensive techniques. The next step is to make a detailed costing of the designs. For each design a bill of quantities can be prepared. This describes each operation and the quantity of materials required. From the design drawings and the bill of quantities a schedule of material requirements can be made which can then be costed from information on the cost of the materials.

To complete the costing procedure it is necessary to have labour rates for each type of labour used, plant rates for the equipment used and an assessment of the overheads. Some authorities promote the idea of using unit costs for each activity. Thus one item in the bill of quantities may be "excavate in bulk and cart to fill ". The quantity may be 20,000 cubic metres. The estimator would then calculate on past experience and prevailing costs the rate for moving 1 cubic metre of soil. Unfortunately in civil engineering these unit rates vary enormously and past experience is often not a very good guide. A more effective method is the operational approach in which a whole operation of say excavating, loading, hauling, unloading and spreading is costed and the total cost is then distributed among the relevant items of the bill of quantities.

However, whatever method is used it is always necessary to calculate plant and labour rates. The calculation of plant rates involves an analysis of the initial cost of equipment, expected life, maintenance and operating costs and the prevailing interest rates. An hourly rate can then be calculated for each piece of equipment. The calculation of labour rates is equally involved. It is not sufficient merely to know the prevailing wage rate for a specific type of labour; one must know the total net hours paid and add to this any non-productive

time. Deductions must then be made for such factors as inclement weather, strikes and public holidays. A figure is then arrived at for the average effective working hours paid per day. To the basic daily wage for each category of worker must be added allowances for such factors as are appropriate: this may include national insurance, holidays with pay, daily travel, subsistence allowance, medical insurance, tool money, hutting allowance; in Europe these allowances double the basic wage. The cost then to the employer is the total labour cost per day, divided by the effective working hours. These labour rates will vary for different categories of workers and for different times of the year.

The overhead cost consists of a large number of items which are spread over the duration of the contract. Apart from the obvious costs such as the salaries of site management staff and headquarters staff the following would also be included:

(a) attendant labour such as chainmen, laboratory assistants, site vehicle drivers, watchmen and checkers;

(b) site vehicles;

(c) setting up of the offices; this would include any necessary offices for the site management, stores, canteens, sanitation, fencing, access roads;

(d) all surveying and laboratory equipment;

(e) the installation, maintenance and removal of any services that are supplied, such as electricity, water, telephone and sanitation;

(f) administrative charges such as postal charges, stationery, signs and photography;

(g) first aid, canteen supplies and protective clothing;

(h) temporary works, comprising scaffolding, hoists, generators, temporary fencing, etc.; and

(i) other items which would include pumping, land charges, abnormal weather precautions and safety measures.

All these items would be costed as a lump sum and added to the total cost of the project usually in the form of a percentage added to each item of work.

The materials, plant, labour and overhead rates are then brought together to build up a rate for each item in the bill of quantities.

PAVEMENT MATERIALS AND THE CHOICE OF CONSTRUCTION TECHNIQUES

Roads can be broadly classified on the basis of pavement types into three categories—paved roads, gravel roads and earth roads. The distinction be-

tween paved roads and gravel roads usually rests on the distinction between a sealed and an unsealed pavement surface. The distinction is therefore usually clear, except in relation to such surfaces as wet-bound or dry-bound macadam, for which it becomes optional. The transition from gravel roads to earth roads is less clear-cut, particularly in the case of soil-stabilised roads, such as roads built of soil mechanically stabilised with the addition of aggregate.

There are a number of points to be made about the choice of technologies for various categories of pavement materials. First, it is possible to produce a pavement of the same strength and durability using different materials. Because different materials are often best suited to different construction techniques, a choice of materials increases the range of choice of techniques in terms of factor proportions.

Secondly, certain road-building operations provide little scope for the economic use of labour-intensive methods. These operations tend to be those that produce roads of a high standard and that are a necessary part of the construction of paved roads. Thus the use of labour-intensive methods is more likely to be viable for earth than for gravel roads, and for gravel than for paved roads. Research is needed to discover how these operations can be carried out efficiently by labour-intensive methods.

Thirdly, the possibility of using certain materials, which may be either traditional or modern, is generally not taken into consideration when roads are designed. Some of these materials, however, could be used effectively if manual methods were chosen. All these factors are discussed under each category of pavement.

Paved roads

According to O'Flaherty [1] there are at least 25 design methods in use throughout the world for paved roads. These can be divided into empirical, semi-empirical and purely theoretical. The empirical methods, i.e. those that use formulae and specifications based on data accumulation, are the more common. Of these the California bearing ratio (CBR) method is by far the most widely used; it is the method that will be generally referred to in this chapter, and knowledge of that method will be assumed.

A typical cross-section of a paved road is shown in figure 1. With the CBR design method the depth of construction is determined by the CBR value of the subgrade, whereas the quality of the surface and base of the pavement is generally not considered except to state that they should be of a minimum quality. This is because the CBR method consists in determining what depth

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[1] C. A. O'Flaherty: *Highways* (London, Edward Arnold, 1967), p. 561.

Figure 1. Structural elements of flexible and rigid road pavements

Bituminous surfacing
Base
Sub-base (if required)
Subgrade of natural soil

Flexible pavement

Concrete surfacing
Base (if required)
Subgrade of natural soil

Rigid pavement
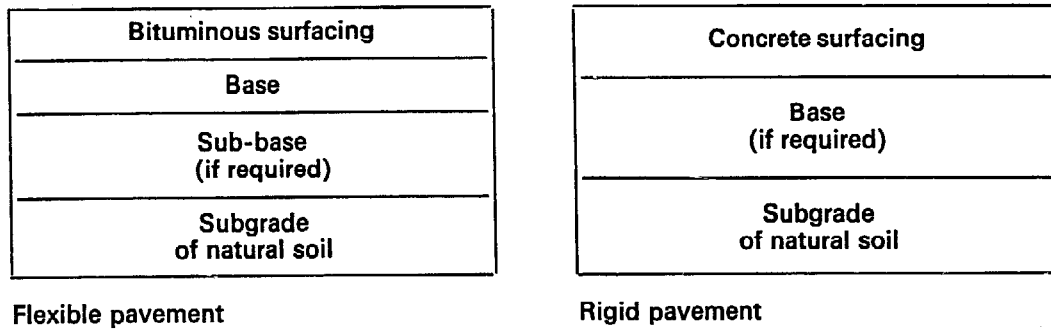
of construction is required with a given material to dissipate the axle loads into the subgrade. The choice of pavement surface and base materials is mainly dependent on the amount of deformation that is allowed, the drainage characteristics of the various materials and—perhaps most important for the surface material — the riding quality of the pavement. For roads carrying a present or expected daily traffic of more than 300 vehicles it is generally assumed that maintenance costs preclude the use of anything but a high-quality surface treatment. The choice of construction techniques for surfacing is somewhat limited in that for a high standard some form of bitumen or tar must be applied, and that cannot be productively and effectively done by manual methods. Hence it may well be that capital-intensive methods are the only possible choice for the surfacing of a paved road. This does not mean, however, that labour-intensive methods cannot be used for the base and subgrade layers of the pavement, and in the choice of methods for those layers the outputs of the labour-intensive and capital-intensive methods should be very carefully compared.

Once the expected traffic volume is known and the necessary quality of the subgrade (i.e. the CBR value) is determined, the quality and depth of materials to be used are decided. It may be that different materials should be used according to whether the construction method is labour-intensive or capital-intensive. For example, modern bitumen madacam is particularly suited to laying by mechanical means and is not easy to place by labour-intensive methods. When consideration is given to the use of labour-intensive methods in the construction of high-standard roads particular attention must be paid to the choice of paving material as some of these materials pre-suppose the use of equipment. Generally the objective is the selection of the most suitable materials for each layer so that the stress distributed to each layer is commensurate with its load-carrying capacity. Furthermore, the materials selected must be those which can be economically placed by a given method.

(1) *Hand-pitched stone.* For roads that do not carry heavy traffic, hand-pitched stone bases (figure 2) are particularly suited to large labour forces. The main problems arise because of the large voids between the stones. If suitable drainage is not provided or if the underlying layer is not sealed, the substratum becomes soft and can work its way up into the base, which may then be heavily deformed. Moreover, layers of stones more than 10 cm in diameter are difficult to compact effectively, which is the reason for which hand-pitched stone bases are not suitable for use on roads with heavy traffic.

Figure 2. Hand pitching

(2) *Dry-bound macadam.* Dry-bound macadam provides a compact and effective pavement layer. A coarse aggregate of a carefully determined size (40 or 60 mm nominal) can be laid by hand, usually in a layer 10 to 12 cm thick. This layer is then rolled with a smooth-wheel roller. A fine aggregate or dust is then spread over the compacted coarse aggregate. This can be done with ordinary farm equipment (figure 3). Afterwards it is usually necessary to broom the surface to spread the material evenly. When compacted with a small plate vibrator (figure 4), the dust fills the interstices between the coarse agregate, thus filling the voids.

(3) *Wet-bound macadam.* A road of wet-bound macadam is similar in construction to one of dry-bound macadam, the difference being that in the wet-bound method water is sprayed onto the surface and the resulting surface

Figure 3.   Spreading fine aggregate for dry-bound macadam

Figure 4.   Compaction of dry-bound macadam

is then compacted and rolled. The water acts as a lubricant allowing the aggregate to move and thus lock more easily. Further, a certain cementing action is produced with the interaction of the water and the fine aggregate. A potential drawback to the use of wet-bound macadam is that each layer must be allowed to dry thoroughly before the next layer is laid. In the case of labour-intensive methods this drawback may become an advantage in that the slower speed of working with those methods may match the need for a drying period.

(4) *Stabilised soil.* There are numerous ways in which the properties of a soil can be modified to give a dense homogeneous mass. These include mechanical stabilisation with the addition of aggregate, chlorides, lignin and molasses, cement stabilisation and stabilisation with bitumen and lime. Many of these operations can be carried out by manual methods. Some stabilised soils can be used as base material for roads, but usually not as a running surface because of their poor resistance to abrasion. Equipment such as levelling machines, rotary mix-in-place equipment and stationary mixing plants can carry out the mixing and placing operation. However, it is perfectly feasible to use modified agricultural equipment and labour to produce the required result (figures 5 and 6).

(5) *Bituminous paving.* Grouting or penetration of road metal with a binding material in a liquid state stabilises a road, i.e. it reinforces its structure to

Figure 5. Lime stabilisation: bags of lime are dumped along the road

Figure 6. Lime stabilisation: a rotary plough raises a cloud of lime dust

withstand traffic loading. There are various types of bituminous paving which are useful for different intensities of traffic. The simple method of bituminous paving requires no special tools or plant or skilled labour. The method consists of spreading the aggregate on the subgrade, to a thickness of at least 125 mm, and rolling with a smooth-wheeled roller. Then either a cold (emulsion) or a hot (bitumen or tar) binder can be allowed to penetrate into the consolidated stone layer either to the full depth or to half the depth. The binder is poured by workers using pouring pots. After the binder has been applied, and while it is still hot in the case of hot binder or before it "breaks" in the case of emulsion, small hard stone chips should be spread evenly over the surface and lightly rolled to force the chippings into the binder. A variant is the pre-mixed method, under which the aggregate is first mixed with the binder (hot or cold) and then spread on the road. In the hot process the bitumen is heated in a boiler and mixed with aggregate either in a power rotary mixer or hand drum mixer. The pre-mixed aggregate can be hauled in wheelbarrows and unloaded onto the prepared sub-base; it is then spread by workers with rakes, and finally rolled by smooth-wheeled rollers. The hot bitumen can be handled in pouring pots or cans. For pre-mixing with emulsion the aggregate can be placed in perforated buckets and then coated by dipping into tanks containing emulsion; the coated aggregate is spread on the road and then left for 24 hours before rolling to let

the water content of the emulsion evaporate. There are cases in which the binder is first applied on the road bed and the coarse ingredient is added immediately afterwards. "Surface dressing" is a kind of bituminous surface treatment under which a film of bitumen, tar or emulsion is first applied on top of road foundations; a thin layer of stone chippings or other fine mineral aggregate is then spread on this film and the surface is rolled.

(6) *Concrete paving.* For concrete paving the natural subgrade or the top of the sub-base is first given the required shape. Wooden or steel forms are placed and the laying of concrete is planned in sections. The mixing of concrete is carried out by mechanical or hand-operated mixers; if such mixers are not available the mixing can be carried out by workers with shovels. If a mixer is used its size naturally determines the rate of production and therefore a balance must be struck between the size of mixer and the number of workers employed to haul and lay the concrete. The concrete can be taken from the mixer either in wheelbarrows or in head baskets and laid between the forms, where the concrete can be consolidated either with a hand tamper or with a mechanical vibrator. The hand tamper or a wooden tamping beam (see figure 7) consists of a beam 75 mm wide by 225 mm deep and of a length equal to the width of the section, plus 300 mm. The underside of the beam has a metal plate equal to the width of the beam. The concrete can be compacted with the tamper by using a backwards and forwards sawing motion across the section in combination with a series of lifts and drops with an advance of about 1 cm each time. Tamping is continued until the mortar in the mix begins to work up to the surface. The surface finish is produced with wooden floats. Whenever desired the surface can be roughened by brooming with a stiff fibre brush. After two to four hours the finished surface is covered with a layer of hessian bags or other suitable material, which is kept wet about 24 hours. Then the bags are removed and a layer of sand about 50 mm thick can be laid on top of the concrete and kept moist; as an alternative the surface is divided into a number of sections by forming small 50 mm earthen ridges and the sections are then filled with 25 mm

Figure 7. Wooden tamping beam

Handle of mild steel flat plate

Beam

Side view   Metal plate on bottom   End view
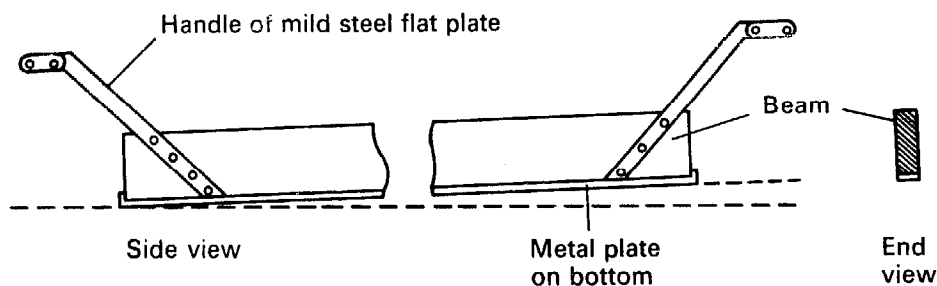
of water and the concrete surface is kept moist for the curing period. After the curing period the top 75 mm of the expansion joints between the sections are filled with bitumen.

Gravel roads

Gravel is generally used for roads on which the traffic flow is not expected to be more than 200-300 vehicles a day. The simplest form of gravel road is that in which gravel or coarse aggregate of a less carefully determined size than in the case of macadam construction is laid onto the subgrade. Each layer is then rolled and compacted. The final surface may be produced by spreading a thin layer of a finer aggregate.

Gravel roads by their very nature are more adaptable to construction by labour-intensive methods than paved roads. With capital-intensive methods one can use gravel from any suitable quarry or borrow pit within several kilometres of the construction site. However, it is difficult to find efficient methods of transport by labour-intensive methods for haul distances greater than 1 kilometre. In order to attain a given standard, therefore, consideration may have to be given to using greater thicknesses of inferior material that can be obtained in the close vicinity.

Earth roads

The term " earth roads " covers roads from mere penetration tracks to high-quality earth roads with some form of stabilised surface. The expected maximum traffic for earth roads would be of the order of 50 vehicles per day, depending on the type of vehicle. Earth roads are the most suitable for labour-intensive construction. Earth-moving provides the best opportunities for labour-equipment substitution. Also, earth roads are generally used to transport farm produce to market or to provide access to remote villages. Accordingly they are of direct and obvious benefit to the local population. This fact not only makes it easier to enlist local support for the building of these roads but also facilitates routine maintenance because the local people think of it as their own road.[1]

Most earth roads are of very simple design, as shown in figure 8. One of the major problems of earth roads is deformation under wheeled traffic, which generally produces longitudinal grooves. This tendency can be reduced by placing circular timbers of small diameter in the tyre tracks.

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[1] J. Müller: "Labour-intensive methods in low-cost road construction: A case study", in *International Labour Review* (Geneva, ILO), Apr. 1970, pp. 359-375.

Perhaps the most important requirements for earth roads from the engineer's point of view are adequate maintenance and proper drainage: although these roads are not usually designed as all-weather roads, the proper crowning of the surface and careful placing and shaping of drainage channels can make all the difference between high and low maintenance costs.

Figure 8.   How to make a simple earth road

① Clear trees, bushes and roots. Clear trees far enough to keep road in sunshine.

② Strip off topsoil for at least 8 metres from centre of road

③ Dig wide ditches and dump sub-soil towards centre line to raise road level.

④ Complete the ditches and roll, compact the formation using minimum slopes and widths shown.

⑤ Check the slopes and levels on formation and along ditch to make sure that water can run away.

⑥ Lay the topsoil on the ditch slopes to encourage grass to grow again.

1 in 20

3m (10 feet)   9 metres (30 feet)   3m (10 feet)

Roads made of other materials

As has been emphasised, the use of labour-intensive methods requires that the design and the construction materials should be orientated towards their use. Certain materials, which may not normally be considered for use with capital-intensive methods, are worthy of mention here.

In some parts of the world there is a traditional local expertise in the construction of cobblestone roads. These are similar to the hand-pitched bases referred to above, except that the cobblestones are used as the final running surface. The subgrade is first levelled and then the stones are placed with great precision so that the final surface is smooth. Sand or fine aggregate is then spread over the surface and this fills the interstices between the stones. Speeds of 100 k.p.h. are perfectly feasible on this type of road. It should be added that they are usually built in areas of very low rainfall because of the damaging effect of rain on this type of road. A typical cobblestone road construction is shown in figure 9.

This is one example of materials that could be considered. There are many others, such as wood or stone setts, pozzolan bricks and asphalt blocks which have been abandoned for pavements by engineers in developed countries because their use involves dependence on labour. It is this very dependence,

Figure 9.   Cobblestone road construction

however, which makes the use of these materials of interest to developing countries with abundant labour supplies.

THE DETAILS OF DESIGN CHOICE

One of the earlier road studies undertaken by the ILO emphasised the limiting role that the design played in the choice of technique. It was suggested that "the adopted design standard . . . will . . . determine the range of choice of appropriate construction technologies" and that "in the selection of design standards . . . a bias . . . will generally operate in favour of known (or Western) standards".[1] In the present section the relationship between the design and the choice of technique is examined more closely in order to show how the choice of technique can be considered at the design stage, when the design itself is a variable. The design of a road mainly consists of structural elements (i.e. the composition and structure of the pavement surface, base and sub-base), the routing of the road and its vertical and horizontal alignment, or slope and curvature. All of these elements can be treated as variables.

The interaction between a design and a construction technique can be taken into account in two main ways. The first is to start by choosing the design, and then to make a choice among the methods by which it would be possible to produce a road of that design; i.e. the design standards of the road are fixed. The alternative approach, where the design standards of the road are variable, is not to start by determining the design, but to allow for the fact that there is a trade-off between the initial construction cost and the future maintenance and road users' costs, and to recognise that the trade-off may justify the choice of a design giving a road of a lower standard, which is likely to be more suited to construction by labour-intensive methods. In this section both approaches are discussed, but more attention is devoted to the second, which has hitherto tended to be ignored.

In road design where the standards are fixed, the possibility of a trade-off between subgrade strength and pavement thickness should be examined in order to extend the range of construction methods, in terms of different factor proportions, that might then be considered by the designer.

Trade-off between pavement thickness and subgrade strength

For paved roads the depth of construction depends upon the quality of the subgrade as measured by the CBR value. As a consequence of this there

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[1] G. W. Irvin, assisted by B. Nilsson, L. Karlsson and L. Eriksson: *Roads and redistribution: Social costs and benefits of labour-intensive road construction in Iran* (Geneva, ILO, 1975), p. 25.

Figure 10.   Relationship between pavement thickness and subgrade strength

Pavement thickness (cm)

Subgrade strength (percentage CBR values)
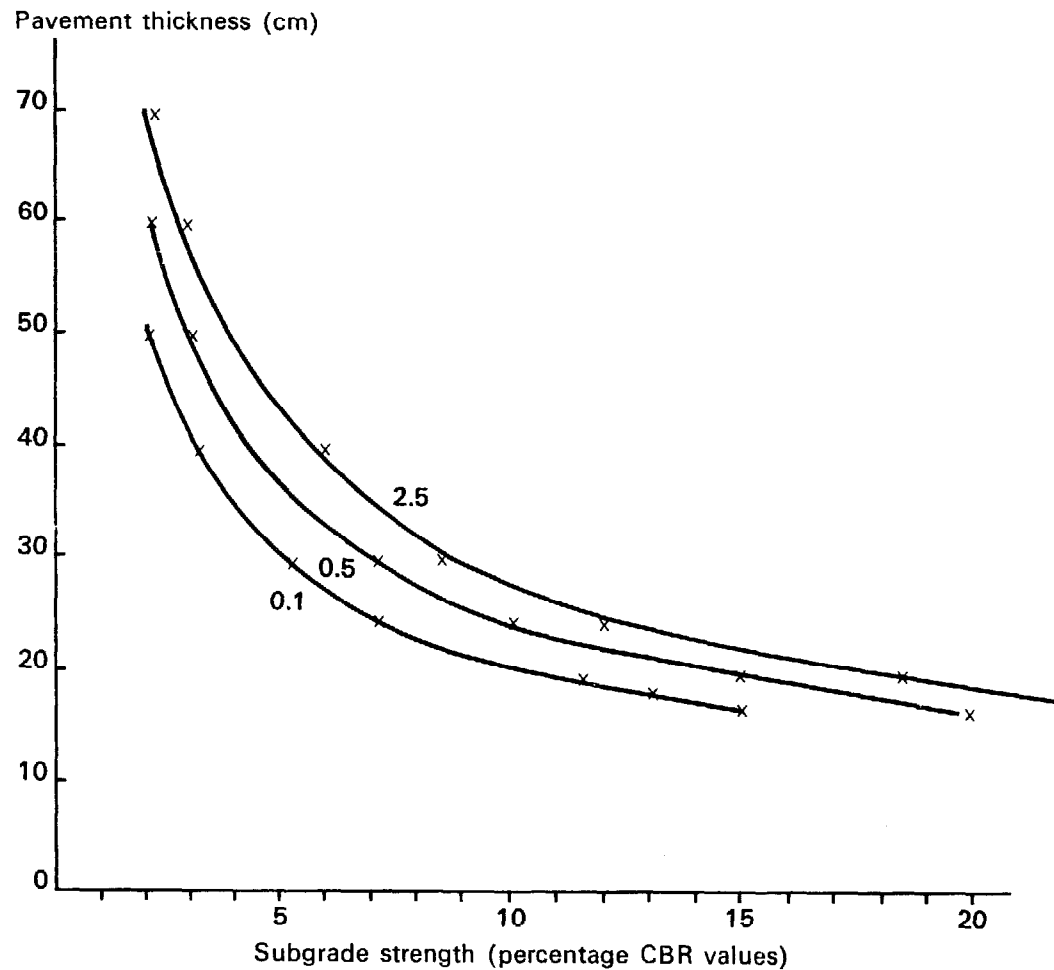
The figure beside each curve (in millions) is the traffic (in terms of the cumulative number of axles of a specified weight passing in one direction) that can be carried in the course of its design life by a road of the specifications indicated by the co-ordinates.

Source: L. Odier, R. S. Millard, Pimentel dos Santos and S. R. Mehra: *Low cost roads: Design, construction and maintenance* (London, Butterworth, n.d.), p. 79.

is a certain amount of trade-off between pavement thickness and subgrade improvement. It is unlikely that the trade-off rate will be the same for roads built by labour-intensive and capital-intensive methods respectively. Particularly in the case of gravel roads for which long-distance hauls of gravel may be unavoidable, it may be better to improve the subgrade to a very high quality and to reduce the depth of gravel.

In practice the extent to which the subgrade can be improved will be the limiting factor. An experienced engineer may be able to assess the trade-off almost by looking at the quality of the subgrade material. It is useful, however, to try and quantify the relationship between subgrade strength and pavement

Figures 11 and 12. Pavement thickness and subgrade strength cost functions

Figure 13. Road cost isoquants

curves of increasing cost
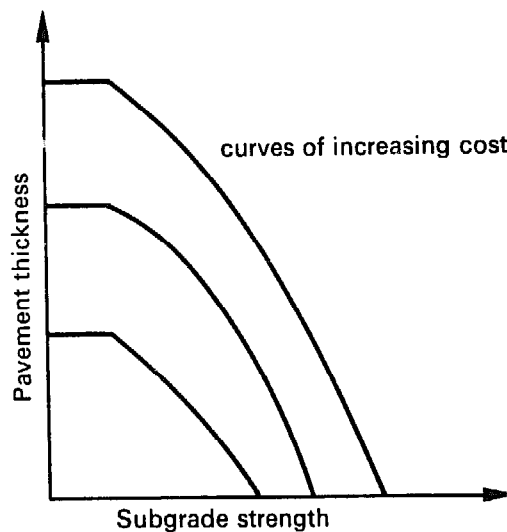
thickness, for it may be that, as shown by Soberman [1], a change of factor costs may move the point of optimum balance between the two. Moreover, there is a clear relationship between pavement thickness, subgrade strength and the design axle load.[2] This is shown in figure 10.

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[1] Richard M. Soberman: *Transport technology for developing regions: A study of road transportation in Venezuela,* a publication of the Joint Center for Urban Studies of the Massachusetts Institute of Technology and Harvard University (Cambridge, Massachusetts, and London, M.I.T. Press, n.d.), pp. 13-14.

[2] See L. Odier, R. S. Millard, Pimentel dos Santos and S. R. Mehra: *Low cost roads: Design, construction and maintenance* (London, Butterworth, n.d.), pp. 76-80.

The cost of increasing the pavement thickness can be easily calculated or obtained from experience of pavement costs. A typical relationship could be similar to the one shown in figure 11. The cost of improving subgrade strength is more complex and depends a great deal on the type of material of which the subgrade is composed. However, there seems to be no reason why this relationship could not be easily calculated on the basis of data usually available in the costing unit of the public works department. The relationship is unlikely to be linear, and could be as shown in figure 12. Of course, the subgrade can be improved in a variety of ways, the simplest being compaction, although more expensive methods suchs as soil stabilisation could be used. The actual costs will depend on local factor costs.

From the cost functions shown in figures 11 and 12 and from the amount available for the road project, it is possible to construct isocost curves like those in figure 13, in which each curve describes different ways of spending a specified amount. At one extreme all the money can be spent on the pavement, at the other it can all be spent in improving the subgrade. Naturally isoquants will vary in shape if the relative costs of the two possibilities change.

If quality isoquants (of which the curves in figure 10 are an example) are superimposed on isocost curves as shown in figure 14, the cheapest combinations of pavement thickness and subgrade quality are then given by the points at which the isocost curves are just tangential to the quality curves.

It must be emphasised that the shape of the cost curves, and hence the points of tangency of the two sets of curves, would vary with factor costs: the cost curves for labour-intensive and capital-intensive methods would not be the same, and thus the most economical trade-off between subgrade strength and pavement thickness would be different. A mistaken belief that the factor proportions do not have a direct effect on the choice of designs is one of the main reasons for the choice of inappropriate designs in developing countries.

Routing and geometric alignment

The possibility of a trade-off in terms of pavement thickness and subgrade strength having been considered, attention will now be devoted to the other major elements in the design of roads, i.e. routing and geometric alignment; and the possibility of relating these to the choice of construction technique will be investigated.

The route which a road is to follow is often dictated by the need to maximise the benefits of the project. It may be proposed that a road should be built from *A* to *B*. In between these points, it could approach various areas of industrial and agricultural production and population centres, and the benefits that would accrue from it, and consequently its economic justification, will

Figure 14. Tangency points of quality and cost curves
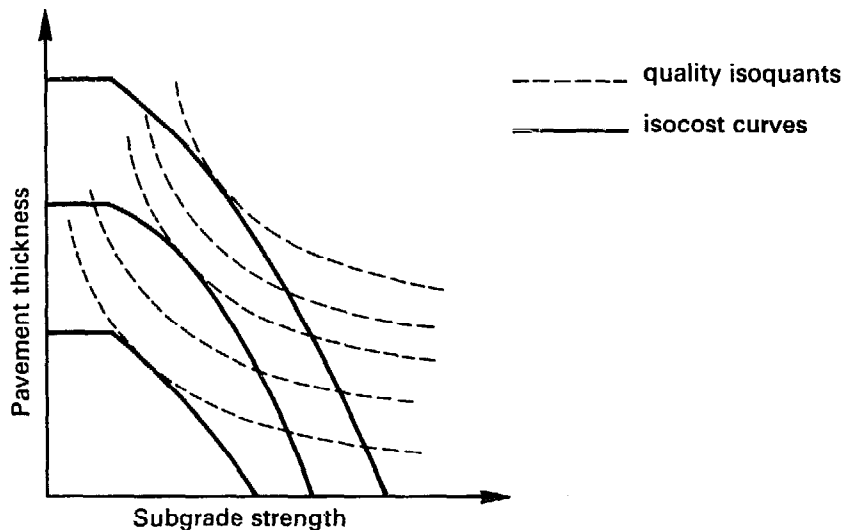
Source: Soberman, op. cit., p. 16.

often depend on how well it would serve those areas. There will be other cases, however, in which the building of a road between points A and B may have been already decided once and for all, but the more detailed aspects of its location and therefore the route to be followed may not be unalterable. It is possible in such cases that the route can be changed so as to facilitate the adoption of more labour-intensive construction techniques.

There are various operations that are less amenable to the substitution of labour-intensive for equipment-intensive methods: these are principally the haulage of earth over long distances, rock excavation, the clearance of dense vegetation on the site, and the building of very high embankments and large structures. A judicious choice of route could limit these operations to a minimum, although the result may well be that the road is less direct.

Of these operations, earth hauling is extremely important in limiting the choice of technique. A re-routing of a road so that it runs closer to borrow pits or quarries, so as to reduce haul distance to a minimum, may increase the length of the road and thus some of its direct construction cost. These increases, however, must be weighed against the benefits of using labour-intensive methods. With regard to the other operations, the road may have to be routed away from areas where hard rock would have to be excavated. It is even possible to follow the ground contours, building simple embankments instead of taking a more direct route and building complex bridges or high embankments. Naturally the extra cost of extending the length of the road would have to be considered in any comparison. However, it is important to bear in mi .d the

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Figure 15. Example of the relationship between design speed and construction cost in different terrains
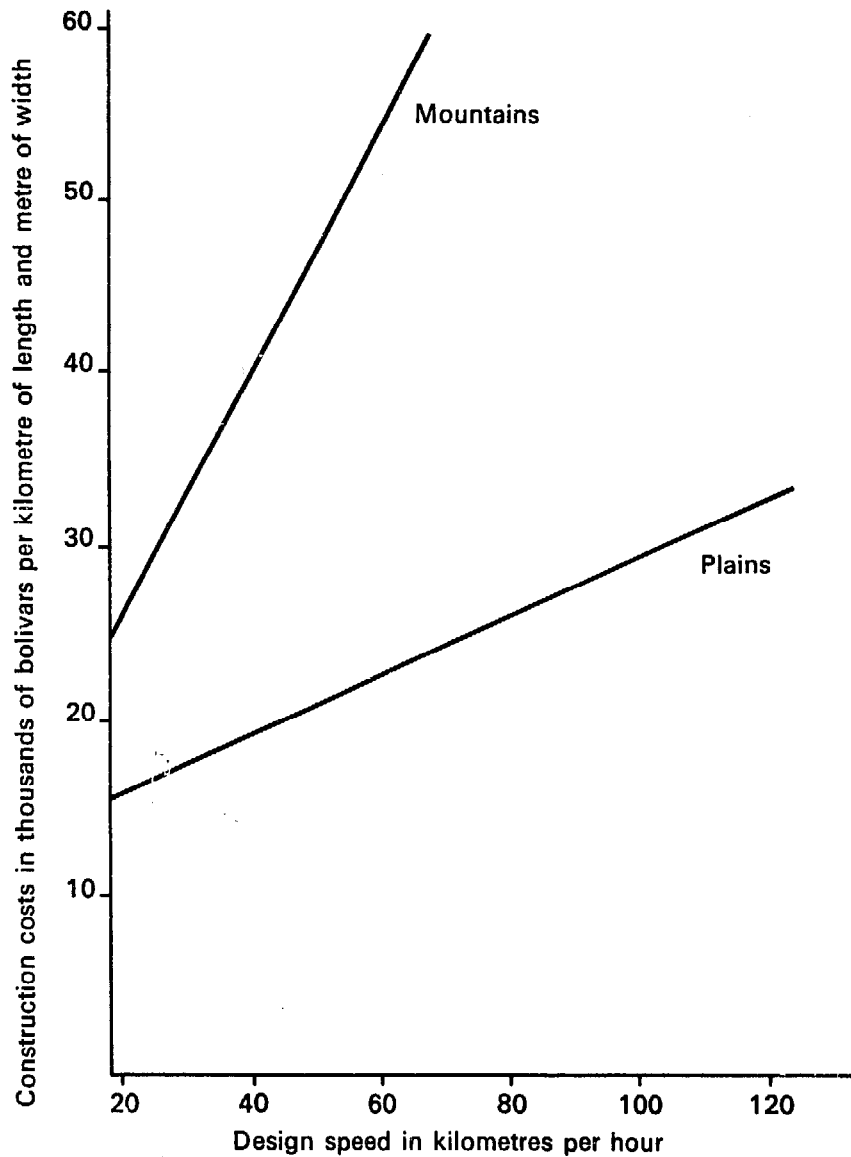
Source: Soberman, op. cit., p. 44.

possibility of altering the route of a road in order to achieve the optimum social cost-benefit ratio.

The geometric alignment is dependent to a great extent on the design speed: it is in relation to the design speed that maximum vertical and horizontal curvatures and maximum gradients are specified, mainly according to the sight distance of vehicles travelling at a particular speed and the centrifugal force exerted on vehicles at certain speeds on a particular curvature. It is not totally unreasonable to think in terms of lowering the design speed of certain roads

so that the limitations on curvature and gradient are reduced. This would allow a road to follow a less direct route and could reduce the earth works required, since the road could more easily follow the land contours. However, the reduction in design speed would have serious repercussions on the road users' costs: the depreciation cost of vehicles may be increased, the time of travel would be longer and consequently the cost of transporting passengers, goods, and material would also increase. This might result in a net loss in benefit. Moreover, it might also preclude the upgrading of a particular road to a higher standard when the traffic flow on the existing road reached capacity. Again, the possible reduction in design speed in relation to labour-intensive methods would have to be evaluated in terms of the total cost of the facility provided. As a first step it would be necessary to attempt to quantify the relationship between design speed and construction costs. This was done by Soberman for Venezuela, as shown in figure 15.

VARIABLE ROAD DESIGN STANDARDS

The various possibilities that present themselves in relation to the choice of design have been discussed. In practice four cases are likely to arise:

(1) The techniques are fixed although the design is variable. It may be that the choice of the technique to be used is dictated by political reasons, so that there is in fact no choice even if it were possible to produce a road of the same standard by different techniques. In this case the design must be tailored directly to the methods: thus if there is no alternative to using certain equipment, the most effective design will be the one that allows the machinery in question to work most effectively.

(2) The design is fixed, but there is no objection in principle to making a choice among a number of different techniques. This is likely to be the familiar situation in which the practical possibility of using more labour-intensive techniques has to be viewed in the context of a framework which favours capital-intensive methods. Although this situation often puts the manual methods at a disadvantage, in the case of earth roads and low-quality gravel roads labour-intensive methods are probably still competitive.

(3) The routing and geometric alignment of the road remain fixed, but the design of the pavement may be varied to suit the techniques that are employed. It would be assumed in this case that, because the product would in any event be of a specified strength and durability, the maintenance and road users' costs would be the same irrespective of the design. For example, it has been suggested above that a stabilised soil road can be adequately and efficiently laid by

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manual methods. If such a road has the same structural strength and durability as a sealed surface road that is more easily constructed by equipment, then the over-riding criterion will be the comparison of construction costs, whether at market or shadow prices.

(4) There are no limitations in principle on the choice of geometric alignment, pavement design or method of construction. This also implies complete freedom of choice with regard to routing. In practice, however, the possibility of altering the general route followed by the road is somewhat remote and has not in fact been considered in the subsequent analysis; roads are usually conceived as providing certain definite benefits, and it will be regarded as inappropriate to re-route a road to such an extent that it does not fulfil the function for which it was originally planned. Total operating costs (i.e. maintenance costs and road users' costs) can be directly affected in two ways by variations in road alignment: if the length of the road is increased, however slightly, this will clearly increase the operating costs; and if the geometric alignment standard is lowered the design speed will also be reduced, again with important repercussions on the operating costs.

In this fourth case, as in the third case already discussed, the composition and structure of the pavement are also regarded as variables; unlike the situation in the third case, however, the standard of the pavement in terms of strength and durability is treated as a variable also, and it is recognised that the different standards of pavement design will certainly imply changes not only in the construction costs but also in the maintenance and road users' costs. It is this possibility of trade-off that is discussed further in the present section. The three basic cost elements in road construction will first be briefly described.[1] An example will then be given of a trade-off in which accounting (shadow) prices are used in addition to market prices.

Construction costs

There are two important facets of road construction costs, namely the standard of design in terms of quality [2] and expected life and the distribution of the costs among the various roadbuilding operations.

It needs no detailed figures to show that in many cases the cost of earthworks as a proportion of the total is much higher for minor roads (which are not necessarily earth roads) then for major roads. The extent of the difference

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[1] The calculation of maintenance and road users' costs is described in more detail in Chapter 6.

[2] The question of design standard has been dealt with above and is also expanded in the discussion of maintenance costs and road users' costs in this section and in Chapter 6.

Table 1. Percentage distribution of road construction costs among various operations in certain parts of Asia and the Far East

Operation	Type of road		
	Feeder	Secondary	Primary
1. Clearing	3	2	2
2. Excavation of earth with haul less than 100 metres	20	16	14
3. Excavation of earth with haul more than 100 metres	12	10	9
4. Compacting and grading	12	11	10
5. Production and hauling of road materials other than earth	30	23	16
6. Laying of base course and surfacing	9	18	25
7. Drainage and structures	14	20	24
	100	100	100

is illustrated by the case referred to in table 1. The first point to appreciate is that in this case even for minor (feeder) roads the production and haulage of road materials other than earth constitutes no less than 30 per cent of the total cost; this aspect of the matter must therefore be considered if the adoption of more labour-intensive methods is under consideration. The second point is that because labour-intensive methods are more applicable to items 1, 2, 3 and 5 it is clearly much easier to substitute labour for equipment in the construction of minor roads than in that of major roads.

Maintenance costs

Maintenance accounts for only a small part of the total cost of a road project. However, if maintenance is not carried out to the originally designed standard, a road that is intended to last ten years may have to be reconstructed after seven, and this shortening of the road's life will make nonsense of any project evaluation: there is no point in contemplating the construction of a road on the strength of a project evaluation assuming a standard of maintenance that is never achieved in practice. To enable realistic maintenance costs to be applied to the appraisal of projects, two steps should be taken. First, accurate records should be kept of the amount of expenditure on maintenance for each category of road. Secondly, total expenditure on the maintenance of the road system should be planned, as well as the allocation of that total among the various classes of road.

National standards of maintenance vary: in some cases the authorities aim to retain as nearly as possible the original standard of the roads, whereas

in others they merely wish to ensure that the roads will remain passable. Road maintenance to a given standard is in any case generally regarded as consisting of two elements. First, vegetation must be cleared and the drainage system kept clear; this involves a fixed cost independent of the amount of traffic that travels on the road. Secondly there is the variable amount of work required to repair the damage caused by traffic. Maintenance costs in the first year can therefore be represented as follows:

$$MC = X + (Y . ADT)$$

where X = cost of clearing,
         Y = cost of repair per unit of traffic, and
   ADT = average daily traffic.

The average daily traffic is usually assumed to grow at a constant rate per year. Thus one obtains

$$MC_n = X + Y . ADT (1 + g)^n \qquad (1)$$

where MC_n = maintenance cost in year n,
    ADT = present traffic flow, and
        g = expected absolute annual increase in
           traffic flow.

Road users' costs

The total road users' costs for a road project are calculated over the design life of the project in relation to the traffic flow. For a major road these costs are therefore usually far in excess of those for a minor road, first because the traffic volumes are usually greater on a major road and secondly because the design life of a major road is usually longer than that of a minor road. In the case of a major road the road users' costs generally account for much the greater proportion of total costs, whereas in the case of a minor road the road users' costs and the construction costs are much more nearly equal.

The great relative importance of users' costs in the case of a major road can be a source of difficulty. Total road users' costs are very dependent on the traffic flow projections and these are often very tentative at best, so that the amount of the major cost to be considered in the project evaluation is the one most open to error. One difficulty is the estimation of traffic flow: the higher the speed at which traffic moves, the lower the number of vehicles which can safely travel along any given length of road at the same time. If the estimated speed-flow relationship used in an evaluation is in error by as little as 5 per cent, the error can mean the difference between a positive and negative net

present value for the whole project. To make the point another way, Jan de Weille finds that a 5 per cent change in traffic growth is reflected in a change of roughly 5 per cent in the rate of return on a project irrespective of the specific assumptions concerning the project's life.[1]

A further difficulty arises in the assessment of the lifetime of the road. If a high rate of traffic growth is assumed, benefits in the more distant future become more significant. Thus, if the lifetime of the road is assumed to be 30 years, it requires, with the same traffic growth, a much lower initial average daily traffic to produce a given rate of return than if the lifetime is assumed to be 20 years.

It should be clear that the choice of realistic values for the lifetime of the road and the traffic growth rate is supremely important: in fact, cynics suggest that to produce the required rate of return on a project one need only choose a suitable lifetime and traffic growth rate. The estimation of road users' costs should therefore be seen in its correct context: it is possible to estimate them quite accurately, but the estimates will be useless unless the assumptions made concerning traffic growth rate and road lifetime are realistic.

EXAMPLE OF THE DESIGN TRADE-OFF IN TERMS OF INITIAL AND FUTURE COSTS

In Chapters 5 and 6 the detailed evaluation of construction, maintenance and road users' costs is described. In Chapter 7 the evaluation of the most economic combination of design and construction technique in terms of present and future costs is discussed in detail. In this section, however, a simple illustration of the trade-off between initial construction costs and future maintenance and road users' costs is given. (The comparison will be made in terms of the trade-off not only at market prices but also at shadow prices. Shadow pricing and social cost-benefit analysis were mentioned in the Introduction and are discussed in detail in later chapters. In brief, it is a matter of valuing resources in terms of the true cost of their utilisation to the country. For reasons described in Chapter 8, this valuation is often different from the market cost that is given to them.)

Let it be supposed that the road under consideration is to be a gravel road 6 metres wide in rolling terrain.[2] It will be assumed that there are two possible designs. The first would be suitable for construction by equipment-intensive

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[1] Jan de Weille: *Quantification of road user savings*, World Bank Staff Occasional Paper No. 2 (International Bank for Reconstruction and Development, 1966), p. 81.

[2] The example is based on an actual road project in the Philippines.

Table 2. Market and shadow prices of alternative gravel road designs
(in US dollars)

Design	Market prices	Shadow prices
Capital-intensive [1]	38 200	42 250
Labour-intensive [2]	32 200	27 380

[1] Distribution of costs: plant, 67 per cent; labour, 6 per cent; materials, 12 per cent; profit and overheads, 15 per cent. [2] Distribution of costs: plant, 26 per cent; labour, 45 per cent; materials, 14 per cent; profit and overheads, 15 per cent.

methods. It would have a high design speed and therefore a high geometric design standard. The alternative design would be more suited to construction by labour-intensive methods; it would have a lower design speed and possibly also a reduced width. It is assumed that the external benefits in terms of, for example, an increase in the marketability of produce, would be the same for each design.

Let it be assumed that the cost of construction to the two designs at market prices and shadow prices is as shown in table 2.

Let it be further assumed that the maintenance costs would be higher for the labour-intensive design than for the equipment-intensive one. Using the summation of equation (1) the net present value [1] of the stream of maintenance

Table 3. Annual equivalent maintenance costs at market and shadow prices for various combinations of design and type of maintenance
(in US dollars)

Maintenance method	Design	Nature of prices	Costs			
			Labour	Local capital	Foreign exchange	Total
Capital-intensive	Capital-intensive	Market	686	611	229	1 526
		Shadow	343	671	275	1 289
Capital-intensive	Labour-intensive	Market	915	814	305	2 034
		Shadow	457	895	366	1 718
Labour-intensive	Capital-intensive	Market	1 160	244	122	1 526
		Shadow	580	269	147	996
Labour-intensive	Labour-intensive	Market	1 546	326	164	2 034
		Shadow	773	358	195	1 326

[1] Readers not familiar with the concept of net present value should refer to Chapter 5.

Table 4. Annual equivalent road users' costs[1] at market and shadow prices for labour-intensive and capital-intensive designs (in US dollars)

Design	Nature of prices	Costs			
		Labour	Local capital	Foreign exchange	Total
Labour-intensive	Market	7 423	4 455	2 969	14 847
	Shadow	3 712	4 900	3 563	12 175
Capital-intensive	Market	5 104	3 062	2 042	10 208
	Shadow	2 552	3 369	2 450	8 371

[1] In this example the road users' costs represent the vehicle operating cost component only, because it was not possible to obtain realistic data for the other component.

costs can be obtained. For ease of comparison these are then converted into a series of annual equivalent costs over the life of the road, assumed in this case to be ten years. This group of maintenance costs is shown in table 3. Table 4 gives annual equivalent road user's costs.

To be able to assess the substitutability of construction costs on the one hand and maintenance and road users' costs on the other, the construction costs are also converted to annual equivalent costs.[1] Figure 16 then shows graphically the potential trade-off. For a capital-intensive maintenance programme the basic costs to be compared are as shown in table 5.

In order to make the best use of the money available for the project, the aim is to ascertain whether the reduction in initial costs is more than offset by the increase in future costs.

Table 5. Annual equivalent initial and future costs at market and shadow prices for labour-intensive and capital-intensive designs (in US dollars)

Design and costing	Initial [1]	Future[2]
Labour-intensive design at market prices	5 240	16 881
Labour-intensive design at shadow prices	4 456	13 893
Capital-intensive design at market prices	6 217	11 734
Capital-intensive design at shadow prices	6 876	9 660

[1] Construction costs.   [2] Maintenance and road users' costs.

[1] These are the initial costs in table 5.

Figure 16.   Example of possible trade-offs between initial and future costs, at market
              and shadow prices
              (in thousands of dollars)
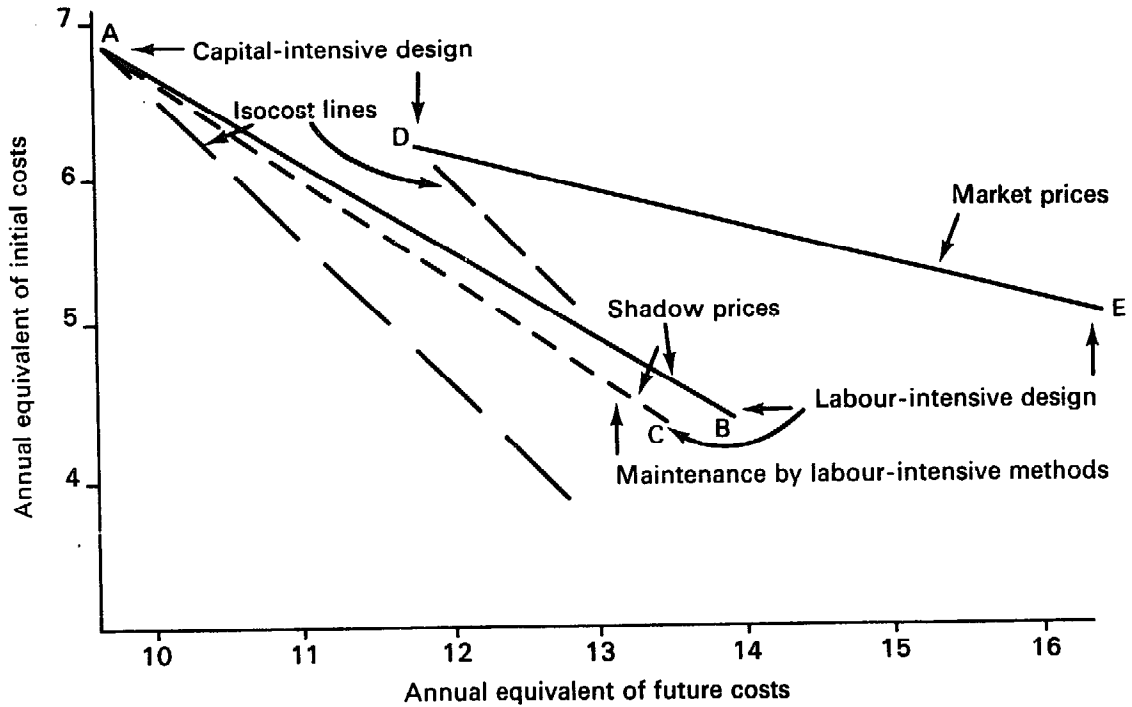
A simple comparison of the angles of lines AB, AC and DE with those of the isocost lines immediately reveals that in this case substitution of future costs for initial costs is never advantageous.

Where IC_1 =   initial cost of the equipment-intensive design,
      IC_2 =   initial cost of the labour-intensive design,
      FC_1 =   future cost of the equipment-intensive design, and
      FC_2 =   future cost of the labour-intensive design,

the reduction in construction costs is justified if

$$\frac{IC_1 - IC_2}{FC_2 - FC_1} > 1$$

In this particular example it is clear that neither at market nor at shadow prices is such a trade-off advantageous. It will be noted, however, that the use of shadow prices markedly affects the possibility of a trade-off: the labour-intensive design is seen to be much more economic at shadow prices. It should also be noted that being small in relation to the total cost, the maintenance costs have little influence on the trade-off relationship. In figure 16 line AC represents the use of labour-intensive maintenance methods. Although it does lower the cost curve for the labour-intensive design, the reduction in cost is very limited and is unlikely to affect the total trade-off.

PRODUCTIVITY

3

Until recently there has been little collection of data on labour-intensive methods of production or construction, which are generally traditional and have been assumed to be highly inefficient by comparison with the corresponding capital-intensive methods. Wherever labour-intensive methods are deemed only to be a poor substitute for capital-intensive ones, there has hitherto been no reason for a rigorous assessment of the advantages and drawbacks of methods in those two respective groups. Recently, however, the increasing demographic pressures in the developing world have forced engineers and economists to attach more value to labour-intensive methods than they did in the past. Unfortunately, the theoretical arguments in favour of these methods, though very powerful, have generally been undermined by the fact that there is little or no information available on their productivity (and hence their cost) in practice, and the effectiveness of the theoretical arguments has accordingly been somewhat reduced.

In 1963 the ILO undertook the first serious study of labour-intensive construction activities. The results of this study, which are well documented [1], showed that by careful innovation the productivity of labour-intensive methods could be vastly improved. The study was perhaps ahead of its time, for no similar studies were carried out until the end of the 1960s. Since then both the ILO and the World Bank, among other institutions, have been carrying out detailed studies of the viability of labour-intensive methods. However, while useful in themselves, the studies that have been carried out have lacked uniformity. For any useful comparisons to be made some sort of common framework must be followed. This does not necessarily mean that the information itself must be collected in a uniform way: each individual study is undertaken in

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[1] ILO Management Development and Productivity Mission to India: *Men who move mountains*, an account of a research project concerned with manual methods of earthmoving (Bombay, R. Leslie Mitchell, 1963).

different circumstances, and the most advantageous way of obtaining the information has to be found in each case. However, it does imply that the comparisons made are of like with like. It is not sufficient merely to present the over-all productivity of a particular technique in a particular construction operation. In a recent work [1] the World Bank showed that for excavation alone the reported productivity varied by as much as 1,300 per cent. The parameters that affect construction operations have a very pronounced effect on the productivity, and must be measured so that the output can be related to them.

Data on road construction operations, whether labour-intensive or equipment-intensive, can be collected in a very detailed fashion. The productivity of each different technique can be observed over a length of time, and from statistics prepared on that basis the most likely productivity under particular conditions can be established. By using a detailed rating system the effect of each parameter on productivity can be estimated. If enough detailed data are collected in this systematic, rigorous way it will be possible to give an accurate assessment of the productivity of each operation under a given set of site parameters. Moreover, it will be possible to predict what the productivity of a particular technique, observed in one region or country, will be under different conditions in another region or country. For example the use of animal-drawn scrapers was tested in the Philippines.[2] One can say what the productivity of that technique is, in the Philippines, under particular conditions (e.g. site supervision, method of payment, soil type). If one wants to use that technique in Thailand, for example, it should be possible to predict what its productivity will be under the different environmental, physical and economic conditions obtaining in the latter country. Nevertheless the amount of data required to be able to predict productivities of particular techniques or to make a detailed inventory of techniques is very large. A team of two or three trained people, working full time, may be needed to produce the necessary information. The World Bank and the ILO have produced a joint manual on data collection [3], which shows what is involved. The recommendations in that manual represent an ideal. It is hoped that it will be possible to collect data in this organised, systematic way; cer-

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[1] International Bank for Reconstruction and Development: *Study of the substitution of labour and equipment in civil construction: Phase II final report, January 1974*, by C. G. Harral, L. H. Miller, I. K. Sud, R. A. Williams, A. A. Churchill, D. Jordan, A. Truneh and C. Gochenour (IBRD), and K. C. W. James, J. J. Gandy and G. Little (Scott Wilson Kirkpatrick and Partners), Staff Working Paper No. 266 (mimeographed).

[2] See Chapter 4.

[3] International Bank for Reconstruction and Development (Transportation and Urban Projects Department, Transport Research Division) and International Labour Office: *A field manual for the collection of productivity data from civil construction projects*, World Bank Study of the Substitution of Labor and Equipment in Civil Construction and ILO Technology and Employment Project Study on Labour-Intensive Road Construction, Technical Memorandum No. 8 (1975, mimeographed).

tainly future ILO and World Bank studies will incorporate data collected along the lines recommended in that manual, and the information already obtained is now being used to produce a detailed inventory of labour-intensive techniques to enable the effect of particular parameters on productivity to be analysed in detail.

It is unlikely that the developing countries themselves will be able to afford to use the data collection techniques recommended in the joint manual in the near future. However, it is possible to collect data in a simplified fashion. The productivity figures that will emerge in such a case will not be as accurate as those developed from the ideal method mentioned above, nor will they usually be capable of being transferred to other regions or countries. However, they will be suitable for national planning purposes, and the collection of the data should be within the capability of the public works departments of developing countries.

It should be recognised that detailed information on the productivity of capital-intensive road construction techniques is not readily available in spite of their wide application, and that an extremely detailed and rigorous analysis of the productivity of labour-intensive techniques is therefore not absolutely essential as yet. In the circumstances the methods of calculation described in this chapter are useful means of assessing the productivity of both kinds of techniques with a reasonable degree of accuracy.

A SIMPLER EVALUATION METHODOLOGY

The simplicity of this alternative method lies in the fact that it relies on two coefficients which can be used to assess the total time needed to complete a particular operation by a given method. One of these coefficients tends to be project-specific, the other is more related to the region. The basic concepts of the methodology were evolved in a recent study [1] and have already been used in an ILO project in Kenya.

Subdivision of the time spent on construction operations

In any particular area or region of a country one can make the assumption that many of the general parameters are similar from one site to another. This assumption facilitates evaluation of the productivity of a particular operation.

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[1] Jens Müller: *Choice of technology in underdeveloped countries, exemplified by road construction in East Africa*, report of a study of choice of technology in underdeveloped countries undertaken at the Department of Construction Engineering and Management at the Technical University of Denmark in collaboration with the Institute for Development Research, Copenhagen (Technical University of Denmark, 1973).

The productivity is evaluated by subdividing time spent on the operation, as described below and illustrated in figure 17.

Figure 17. Subdivision of the time spent on a construction operation

Total time for the operation			
Operational time			Breakdown time
Method time		Site time	
Purely productive time	Method time allowance		

The total time spent on a construction operation is first divided into "operational time" and "breakdown time".

As any experienced engineer knows, "normal" conditions are the exception rather than the rule. There is usually some "external" factor that prevents the construction process from flowing smoothly: machines break down, torrential rain washes away part of an embankment, a new culvert is suddenly required, the local villagers discover that the road is going through a tribal graveyard and stop the work. When such delays last longer than one working day, they are regarded as falling within breakdown time.

Operational time is itself divided into "method time" and "site time", which covers interruptions to the work cycle that can be directly attributed to the conditions that are peculiar to a particular site. In practice it is difficult to differentiate between delays caused by site conditions and those caused by "external" factors such as a shortage of spare parts, and accordingly only delays of less than a working day are attributed to site conditions. The site time can be broadly regarded as allowing for —

(a) general management conditions (delays due to bad organisation or lack of instructions);

(b) lack of personnel management (largely a matter of the quality of supervision, which is reflected in the motivation of the workforce); and

(c) equipment servicing (this takes account of the degree of skill of the maintenance crew).

Site time is affected by changes in such other site-specific parameters as the method of payment, physical condition and aptitude of the workers. On the

other hand breakdown time tends to be influenced by a number of "general" parameters applying to entire regions. As far as equipment is concerned they include the availability of spare parts and the age of the equipment. Other factors that would also have to be put under this heading include labour relations and social factors, and the quality of communications with the site in terms of physical access and the telephone network.

"Method time" is defined as the irreducible time required to accomplish an operation under the given general and site-specific parameters. This is not an ideal method time; i.e. it is not the time the operation would take in perfect conditions, since on the contrary the parameters in question correspond to imperfect conditions.

Method time itself consists of two elements, viz. "purely productive time" and time corresponding to the " method time allowance".

Purely productive time is the time actually spent in the production of a physical quantity of output.

The method time allowance takes account of the fact that in any activity there are certain delays that are absolutely unavoidable in any conditions, e.g.—

(a) some moving of equipment, materials or labour between working cycles;

(b) necessary waiting time (because of interaction of resource inputs);

(c) normal preventive maintenance; and

(d) reasonable rest intervals for workers for immediate recuperation after a particularly heavy effort (but not meal or tea breaks that are excluded from working hours).

The method coefficient

The foregoing subdivisions of the total time spent on a construction operation provide a basis for the calculation of a "method coefficient", q, which will be generally applicable throughout a particular region. This method coefficient is defined as the ratio of the total time (OVT) to the method time (MET).

Thus $q = \dfrac{OVT}{MET}$ and $q . MET = OVT$. It should be clear that if it is possible to establish MET by detailed observation and q is known, then the total time, which is one of the important elements as far as work scheduling and cost estimating are concerned, can be assessed immediately. It has already been assumed that in absolute terms the method time will not change substantially from one site to another in a given area. The method coefficient, q, however, is less stable. The site conditions, affecting site time, as well as the more general conditions affecting the breakdown time, are unlikely to be the same on different

sites. It is useful, therefore, to bring into play the notion of operational time (*OPT*), and to disaggregate the method coefficient into two further coefficients —the site coefficient, *s*, and the breakdown coefficient, *b*. These are defined as follows:

$$s = \frac{\text{Site time}}{\text{Operational time}} = \frac{OPT\text{-}MET}{OPT}$$

$$b = \frac{\text{Breakdown time}}{\text{Operational time}} = \frac{OVT\text{-}OPT}{OPT}$$

If *b* and *s* are known it is a simple matter to calculate *q* from the formula

$$q = \frac{1 + b}{1 - s} \text{ for each site.}$$

Careful studies at various sites in the given region will be needed before *b* and *s* can be established. Implicit in the evaluation of these two coefficients would be an assessment of the general and site-specific parameters. Once this has been done it will be possible to estimate the coefficients for a new site by an assessment of the parameters that apply to it.

As already stated, the method time is unlikely to change substantially from one site to another. For both capital-intensive and labour-intensive methods, it should be the easiest element to assess. What is required is a work study analysis [1] of the irreducible time required to carry out a given operation or group of operations, due allowance being made for normal rest intervals, for necessary waiting inherent in the interaction of the resources used and for manoeuvring.

When comparing different projects or project versions, however, it is necessary to ensure that the construction operation is similar, mainly in terms of the type of equipment being used: thus whereas the method time in an operation with bulldozers is likely to be of the same order as that for an operation with a traxcavator, it is likely to be substantially lower than for an operation carried out with ordinary shovels. If the operation is to excavate, load and haul soil with wheelbarrows it would be important for the type of soil, haul distance and condition of the haul road be similar; if they are not, some adjustment will have to be made to the method time. Unless conditions are very different, it is unlikely that the effect of the site-specific parameters will produce any great over-all increase or reduction in the total time, *OVT*.

With regard to site time and breakdown time allowance it is useful to differentiate between single operations and operations combining, for example,

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[1] See Rowland Geary: *Work study applied to buildings* (London, The Builder Ltd., 1962); R. M. Currie: *Work study* (London, Pitman, 2nd edn., 1963); and ILO: *Introduction to work study* (Geneva, revised edn., 1969).

Table 6. Method coefficients corresponding to different values of the site and breakdown coefficients

Site coefficient (s)	Breakdown coefficient (b)					
	0.0	0.1	0.2	0.3	0.4	0.5
0.0	1.00	1.10	1.20	1.30	1.40	1.50
0.1	1.11	1.22	1.33	1.45	1.56	1.67
0.2	1.25	1.38	1.50	1.63	1.75	1.87
0.3	1.43	1.57	1.72	1.86	2.00	2.14
0.4	1.67	1.83	2.00	2.17	2.34	2.50
0.5	2.00	2.20	2.40	2.60	2.80	3.00

excavation, loading, hauling, unloading and spreading (abbreviated in the following discussion as "ELHUS"). For a single operation the delays can be directly observed and attributed. The b, s and consequently q coefficients can then be calculated for a particular operation carried out by a particular method. For more complex operations the analysis is more complex also. In the case of the ELHUS operation, for example, the over-all delays may be due either to long delays in one element of the operation, such as loading, or many short delays in each element. In the latter case the governing element must be identified: for example it will be found that if the hauling is carried out by lorries and one breaks down, or if the site management has mismatched the lorries and the excavator, productivity will merely be reduced, but that if the excavator breaks down the whole operation will come ⟶ a standstill. The element that governs the operation as a whole therefore has to be identified, and the q coefficient must be equated to that element. Where there are two or more elements that are totally limiting the highest q coefficient should be evaluated. It is of course possible merely to observe the whole operation, record the delays and evaluate the q coefficient. However, this does not indicate the limiting task. It may be that by using different equipment in one task, such as excavating, the q coefficient could be greatly reduced.

The foregoing examples relate to equipment; the kind of analysis required is the same for labour-intensive methods, but observation is more involved because it relates not to a small number of machines but to large groups of workers. For labour-intensive methods health and nutrition, for example, may retard the work but it appears likely that the site and breakdown time will depend more on the type of operation than on the characteristics of the labour force: for instance, the recent ILO study in the Philippines shows that for all earthmoving operations q had a relatively constant value of 1.25 for the more labour-intensive methods.

The way in which q varies with b and s is shown in table 6.

To assess q for each and every road construction operation would be a very long process. It is not necessary, however, because in most projects about 10 per cent of the operations account for between 80 and 90 per cent of the total amount of work. Thus it should be necessary to calculate the coefficients for these major operations only. These are —

(a) site clearance, which may be light, medium or heavy;

(b) excavation in small quantities;

(c) excavation in bulk;

(d) loading;

(e) hauling;

(f) unloading;

(g) spreading;

(h) compacting and finishing; and

(i) production of local materials.

Operations *(c)* to *(g)* inclusive are often regarded as constituting a single complex operation connected with earthworks (i.e. the ELHUS operation already referred to).

Capacity and productivity

It is possible to define productivity in terms of the method coefficient. Let it be assumed that the quantity produced in a given method time, MET, is Q. Then, method capacity $(MEC) = \dfrac{Q}{MET}$, and over-all capacity $(OVC) = \dfrac{Q}{OVT}$.

Thus, $OVC = \dfrac{MEC}{q}$. The value of q, of course, gives an indication of the suitability of the particular method for the operation being considered: a high value of q would indicate poor suitability and low value that the method is particularly suitable.

The following is an example of the application of the concepts of method capacity and over-all capacity to the use of equipment. In the case of equipment a general idea of the ratio of method time to total time can be obtained from the equipment utilisation rate. To say that a machine has a 70 per cent utilisation rate [1] implies that it is actually working for 70 per cent of the time, the remain-

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[1] The "utilisation rate" referred to here is defined in terms of the over-all time and the various kinds of non-productive time described in this chapter. To estimate equipment costs (see Chapter 5), one must use the concept of a "yearly utilisation rate" which allows for additional non-productive time.

ing time being covered by the method time allowance, site time and breakdown time. Over-all utilisation rates should be treated with reserve because they generally tend to overestimate the utilisation of equipment, the method time allowance, in particular, being left out of account. Thus, one may be considering the activity of excavating and loading into trucks using a power shovel. If it is known, for example, that the utilisation rate of this type of equipment under the prevailing parameters is 50 per cent and that the unhampered method capacity is 100 cubic metres per hour, q is 2.0 and the over-all capacity is 50 cubic metres per hour. However, the method time cannot be assumed to be constant as a matter of course. It is unlikely that a power shovel that is excavating and loading from a borrow pit into a fleet of lorries will have the same method capacity as one that is excavating in a road cutting. Allowance would have to be made, therefore, in the method time for type and quantity of work. This can be done either by observation or from experience. For the methodology to be fully applicable, therefore, one needs to know not only the utilisation rate of each type of equipment but the method capacity for the various types of machine on each operation. This may seem difficult to achieve, but many of these method capacities are already known and those that are not generally relate to very minor operations that account for only a small proportion of the total work. It is clear from the example above that when the method time is calculated the parameters must be explicitly stated. If the observations were made on an old piece of equipment with an inexperienced operator it would be wrong to assume that the resulting method time would also be applicable to a new machine with an experienced operator. Thus great care must be taken when assessing the method time.

It is clear that this methodology provides a simple productivity evaluation system. If one has a reasonable estimate of the method time for particular techniques and therefore of the method capacity, and an evaluation of s and b for the particular project site, the over-all capacity, OVC, can be simply obtained by using the method coefficient, q, as shown in figure 18 overleaf.

Tentative standard rating of productivity factors

Pending the accumulation of data on equipment and labour productivity in the developing countries it would be useful to establish tentative and approximate ratings of the productivity in relation to the main parameters.[1] In the developed countries such ratings already exist for equipment, and are often embodied in a matrix similar to those in tables 7 to 10. The figures in those

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[1] This refers to productive time only, and has no relation to the method time allowance.

Figure 18. Evaluation of the productivity of an operation

A. Productive and unproductive hours

Quantity of output (e.g. in cubic metres)
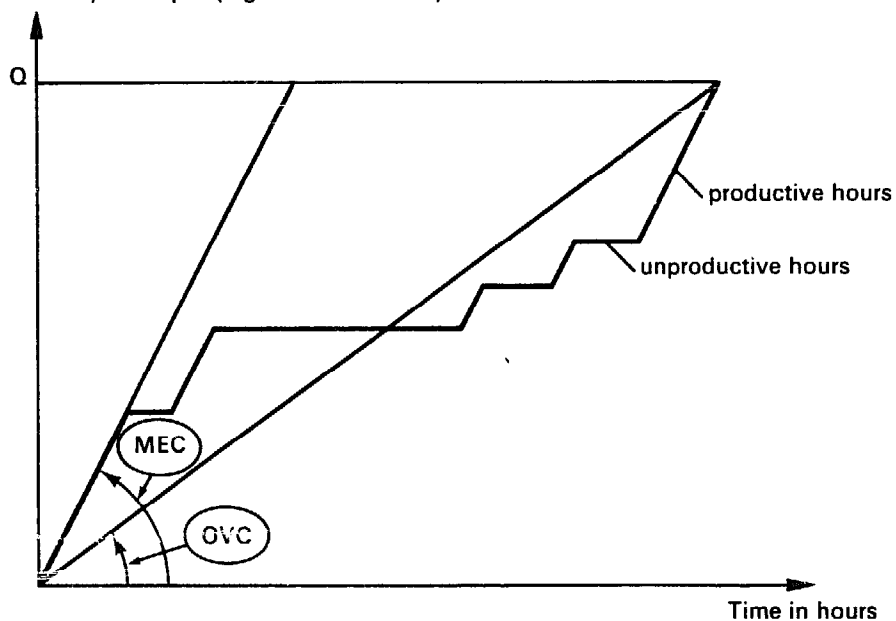
B. Theoretical subdivision of total time

Quantity of output (e.g. in cubic metres)
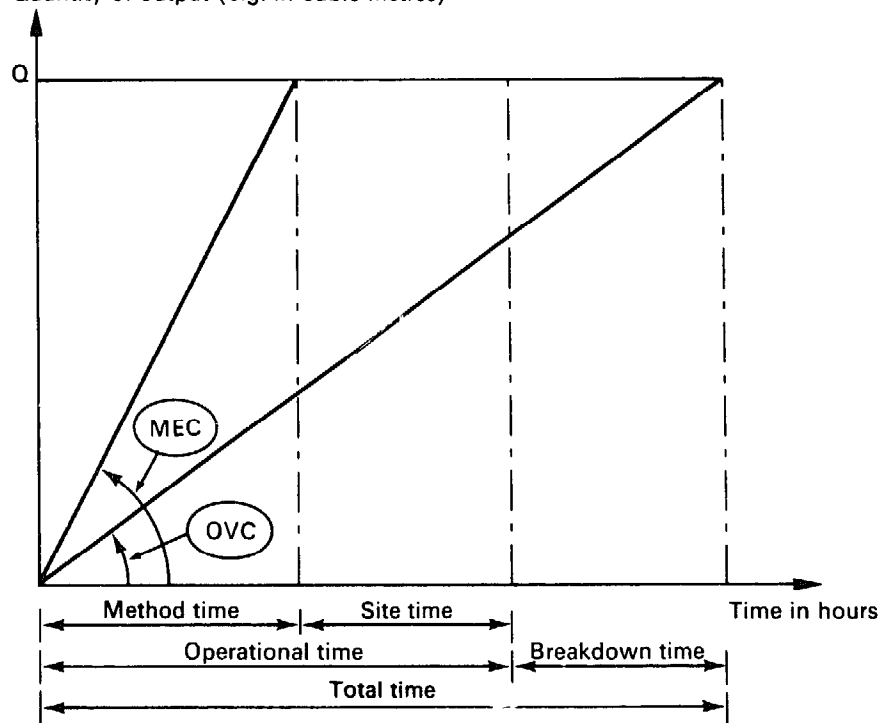
Key: MEC = method capacity;
     OVC = over-all capacity.

The staggered line in diagram A indicates the various phases of the operation. A horizontal line indicates delays due either to site conditions or to breakdown (i.e. external conditions). A slope indicates method time.

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Table 7. Specification of condition of machinery as determined by its age and the quality of its maintenance

Age of machinery (hours)	Quality of maintenance			
	High	Average	Low	Negligible
0-2 000	Excellent	Excellent	Excellent	Good
2 000-4 000	Excellent	Excellent	Good	Fair
4 000-6 000	Excellent	Good	Fair	Poor
6 000-8 000	Good	Fair	Poor	Poor
8 000-10 000	Fair	Poor	Poor	Poor

tables, however, reflect the fact that in the developing countries the over-all productivity of machines is much lower owing to lack of maintenance and skilled operators and general unfamiliarity with the machines. Trials on known data with these ratings appear to suggest that they may have some value. Further tests are being made with a view to arriving at closer approximations, although in the final analysis there is no substitute for detailed studies of operations carried out under controlled conditions.

The two main general parameters affecting equipment productivity could be assumed to be the condition of the equipment and the operators' skill. The conditions of equipment could be specified as shown in table 7. It could be assumed that whatever the circumstances the maximum productivity of a machine is 83 per cent of the manufacturer's maximum estimate (i.e. operating for 50 minutes out of every hour of working time) and the minimum productivity is 15 per cent. The operators' skill could then be related to the condition of the equipment as shown in table 8. The following is an example of an assessment along the lines just described. A specified type of scraper is to be used to

Table 8. Tentative scale of equipment productivity as determined by the condition of the machinery and operators' skill (percentages)

Condition of machinery	Operators' skill			
	Outstanding	Great	Adequate	Inadequate
Excellent	83	65	47	30
Good	68	53	39	25
Fair	54	42	31	20
Poor	40	31	23	15

Table 9. Values tentatively attributed to physical condition, aptitude and climate in calculating the probable productivity of labour

Factor	Excellent	Good	Fair	Poor
Physical condition	1.0	0.80	0.60	0.4
Aptitude	1.0	0.76	0.53	0.3
Climate[1]	1.0	0.83	0.67	0.5

[1] The range from "excellent" to "poor" for climate corresponds to a corrected effective temperature ranging from 25° C or less to 33° C or more.

haul dry earth over an average distance of 750 metres on a road project in Central Africa. The operators can be rated as highly skilled. However, the machine has been in service for 5,000 hours and there is a shortage of spare parts and skilled mechanics. What would be the expected output of this machine? From a reading of the first table, the condition of the machinery would be described as fair, and from the second table the productivity of the equipment would then be assessed at 42 per cent of the manufacturer's maximum estimate, which is 472 cubic metres per hour. Thus the expected output is 200 cubic metres per hour.

The assessment of labour productivity is more complex, mainly because there is no upper limit. It is suggested that figures such as are given in this section should be applied either to the maximum observed output in an operation or to the engineer's estimate of what that maximum would be. To simplify matters it could be assumed that apart from labour management, the three general parameters that have the greatest influence on the productivity of labour are the physical condition of the workers, their aptitude and the climate. (The effect of the method of payment would have been allowed for in the engineer's assessment of the maximum possible productivity.) A tentative range of values for the three parameters in question is given in table 9. Where P is the physical condition of workers, A is their aptitude and C is the climate, the joint effect of three parameters, L_f, could be calculated according to the following formula:

$$L_f = 0.60P + 0.25A + 0.15C.$$

The resulting values of L_f could be classified as "excellent" (1.0-0.85), "good" (0.84-0.70), "fair" (0.69-0.55) or "poor" (0.54-0.39). The effect of the quality of labour management could then be amalgamated with the effect of the other three parameters as shown in table 10.

Table 10. Tentative scale of labour productivity as determined by the quality of labour management and other factors

Labour management	Factors other than labour management, combined (Lf)			
	Excellent	Good	Fair	Poor
Excellent	0.83	0.60	0.40	0.25
Good	0.68	0.49	0.32	0.20
Fair	0.54	0.38	0.25	0.16
Poor	0.40	0.28	0.18	0.12

Examples of the use of the methodology

To exemplify the use of the methodology in the planning of projects three brief examples will be given, relating respectively to site clearance by manual methods, earthmoving by manual methods and earthmoving by equipment.

Example 1

The first example relates to site clearance by manual methods: the task is to clear 20,000 square metres of vegetation of medium density using a gang of 48 unskilled workers with hand tools. The method productivity has been observed to be 12 square metres per man-hour. The site coefficient, s, is 0.3; the breakdown coefficient, b, is 0.1; the method coefficient, q, is therefore 1.57.

The hours of unskilled labour are calculated as follows:

Method capacity for 48 workers = 48 × 12 square metres per hour
= 576 square metres per hour

∴ over-all capacity = 576 ÷ 1.57 = 367 square metres per hour

Over-all time for 1,000 square metres = 1,000 ÷ 367 = 2.73 hours

∴ time for total operation [1] = 20 × 2.73 = 55 hours

The time required for the equipment used in the operation can also be calculated in a similar way:

Equipment input for 20,000 square metres = $O\dot{V}T$ × number of machines or tools
= 55 × 48
= 2,640 hours.

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[1] The method coefficient q is an over-all figure. If there is a degree of breakdown time represented by b then it is possible to envisage that the workers would not be idle during this time but could be moved on to other projects. Thus q could be reduced by a factor of say 10 per cent to account for this.

Example 2

The second example relates to excavating, loading, hauling, unloading, spreading and compacting of 900 cubic metres of soil by workers with hand tools, wheelbarrows, a towing roller and a water bowser. The method capacity for a gang of 200 labourers is 40 cubic metres per hour. The site coefficient, s, is 0.4; the breakdown coefficient, b, is 0.1; the method coefficient, q, is therefore 1.83. The total time can then be calculated.

The hours of unskilled labour required are calculated as follows:

Method capacity for 200 workers = 200 × 0.2 cubic metres per hour
                                 = 40 cubic metres per hour

Over-all capacity   = 40 ÷ 1.83 = 21.8 cubic metres per hour

Over-all time for 1,000
    cubic metres   = 1,000 ÷ 21.8 = 45.8 hours

∴ Time for total operation   = $\dfrac{900}{1,000}$ × 45.8 = 41 hours.

The time required for the equipment used in the operation is as follows:

Equipment input for 900 cubic metres (OVT × number of machines):

For agricultural tractors	=	41 hours,
For attachments	=	82 hours,
For tools	=	8,200 hours.

Example 3

The third example relates to the same complex operations as example 2 but carried out by capital-intensive methods and involving a total of 1,500 cubic metres of earth. The machines used are two motor scrapers, one grader, one self-propelled roller and a water bowser. There are 24 unskilled workers employed. The method productivity for the equipment is 120 cubic metres per hour. The site coefficient is 0.5; the breakdown coefficient is 0.4; the method coefficient is therefore 2.8. The over-all capacity of the machines is 2 × 120 ÷ 2.8 = 86 cubic metres per hour.

The hours of unskilled labour required are calculated as before:

Over-all time for 1,000 cubic metres = $\dfrac{1,000}{86}$ = 11.6 hours.

Time for total operation = $\dfrac{1,500}{1,000}$ × 11.6 = 17.4 hours.

The time required for the equipment used in the operation and its skilled operators is as follows:

Equipment input for 1,500 cubic
metres ($OVT \times$ number of machines):

For scraper	$= 34.8$ hours,
For the grader	$= 17.4$ hours,
For roller and bowser	$= 34.8$ hours.

RANGE OF LABOUR-INTENSIVE TECHNIQUES

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There would be little point in showing the economic desirability of using labour-intensive methods if they existed only in the minds of protagonists of appropriate technology in developing countries. Moreover the traditional labour-intensive methods are admittedly often inefficient. They are capable of improvement, even to the stage of being competitive; the most promising future may lie in the adoption of so-called "intermediate techniques" that are designed to be labour-intensive but do incorporate some capital outlay on tools and light equipment. Unfortunately, because of the radical switch that commonly occurs from one extreme of the technological range to the other, these methods are not readily identifiable, but by imaginative and creative thinking, engineers and planners should be able to modify existing labour-intensive methods in ways that increase productivity enormously while barely reducing the amount of labour required. To quote solutions described later in this chapter, the use of steel scrapers and bottom unloading carts are excellent examples of practical modifications of existing methods, and the use of small trucks on rails in excavation and hauling also shows how the provision of inexpensive machinery can effectively increase the productivity of labour-intensive methods.

Various labour-intensive methods evolved in different parts of the world will now be described in relation to different stages of road construction. They are presented as a spur to the imagination, so as to show engineers and planners that by small modifications and innovations, methods that were previously inefficient can be made highly productive.

SITE CLEARANCE

The principal operation involved in site clearance is the clearing of vegetation from the strip of land reserved for the roadway. This vegetation can range from grass and scrub to dense forest, and the methods used will vary accordingly.

The capital-intensive method is to use a bulldozer with a blade or various other attachments, and in the case of heavy vegetation to use tree-cutting equipment in addition to a crawler or wheeled dozer with a ripper attachment. The more dense the vegetation the more difficult it is to rely on manual methods. For dense vegetation the best intermediate technique relies on the use of small power saws and other small mechanical tools; for light and medium vegetation, on the other hand, agricultural implements such as long-bladed knives, hoes and picks are suitable, and productivity depends mainly on the organisation of labour. One effective way of increasing productivity is to organise a team of six or seven workers to clear a particular area, which is staked out into units for each man to clear. These units, constituting a target for each man, should be carefully estimated; a unit should not be so large that the worker feels he will not complete it within a reasonable time, nor should it be so small that the workers get in each other's way or find it easy to stop work and talk. A piece-rate system could be based on a standard productivity per day and the number of units the workers actually complete.

Once the vegetation is cleared the next step is to strip the overlying topsoil or other unsuitable material. This operation can be regarded as falling under the heading of earthworks, most of which are dealt with in the next section. However, the preparatory operations of loosening and clearing the top layer of material is often regarded as part of site clearance. The surface layer can be effectively loosened by agricultural ploughs drawn by animals or by small tractors. Although high productivity can be achieved with animal-drawn ploughs, the use of draught animals is not universal, and in many parts of Africa small tractors may have to be used instead.

EXCAVATING AND LOADING

Earthworks constitute the major part of road construction. The excavating and loading of material constitutes a major part of the earthworks and therefore has a limiting effect on the productivity of the construction as a whole. Excavating and loading by manual methods are interlinked but separate operations: it is perfectly feasible, and in many cases more productive, to have one group of workers excavating and another group loading; naturally the productivity of each group will be different and it is necessary to match their size accordingly. On the other hand if mechanical equipment is used the two operations are not normally separate: machines (front-end loaders, both crawler and wheeled bulldozers with buckets, motor scrapers, bucket wheel excavators) are designed to carry out the two operations as one, and it is usually inefficient to use them to carry out the two operations separately.

Figure 19.   Use of head baskets to carry excavated material (India)

Figure 20. Carrying excavated material on stretchers (Philippines)
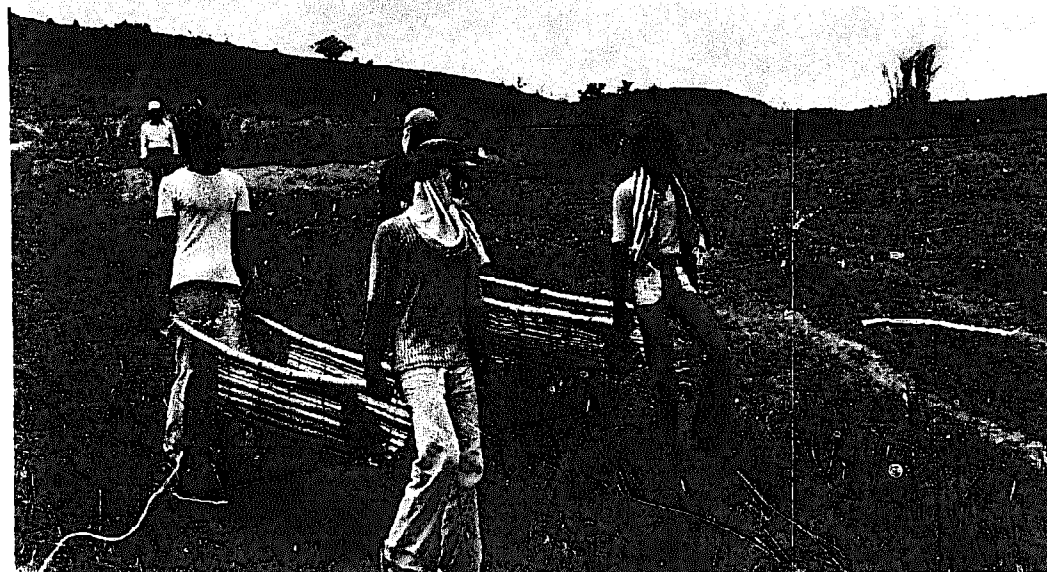
The labour-intensive methods used for these two operations are generally very traditional. No small manually operated machines appear to have been developed for excavating and loading; the tools used are basic farm implements such as picks, hoes, shovels and spades. Excavating and loading by traditional methods are reasonably competitive as long as the loading height is quite small (e.g. 1.5 metres). As already mentioned, the productivity of these operations depends more on the organisation and matching of the two, and on the means of hauling that are used. Thus high productivity can be achieved in the loading operation with a loading height of virtually zero, when the material is loaded into head baskets (figure 19) or stretchers (figure 20). However, this high productivity in loading is usually offset by the fact that head baskets and stretchers are an inefficient means of hauling because it is difficult for human beings to travel quickly when carrying heavy weights. In the case of wheel-barrows, trucks or carts, however, the greater possible length of haul usually offsets any reduction in productivity caused by increased loading height. The small trucks on rails mentioned in one ILO study [1] were excellent hauling vehicles; however, some of the efficiency is lost because the sides of tipping trucks are about 1.5 metres off the ground and therefore difficult to load

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[1] *Men who move mountains*, op. cit., Ch. 7.

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Figure 21. Loading tipping trucks from head baskets (India)
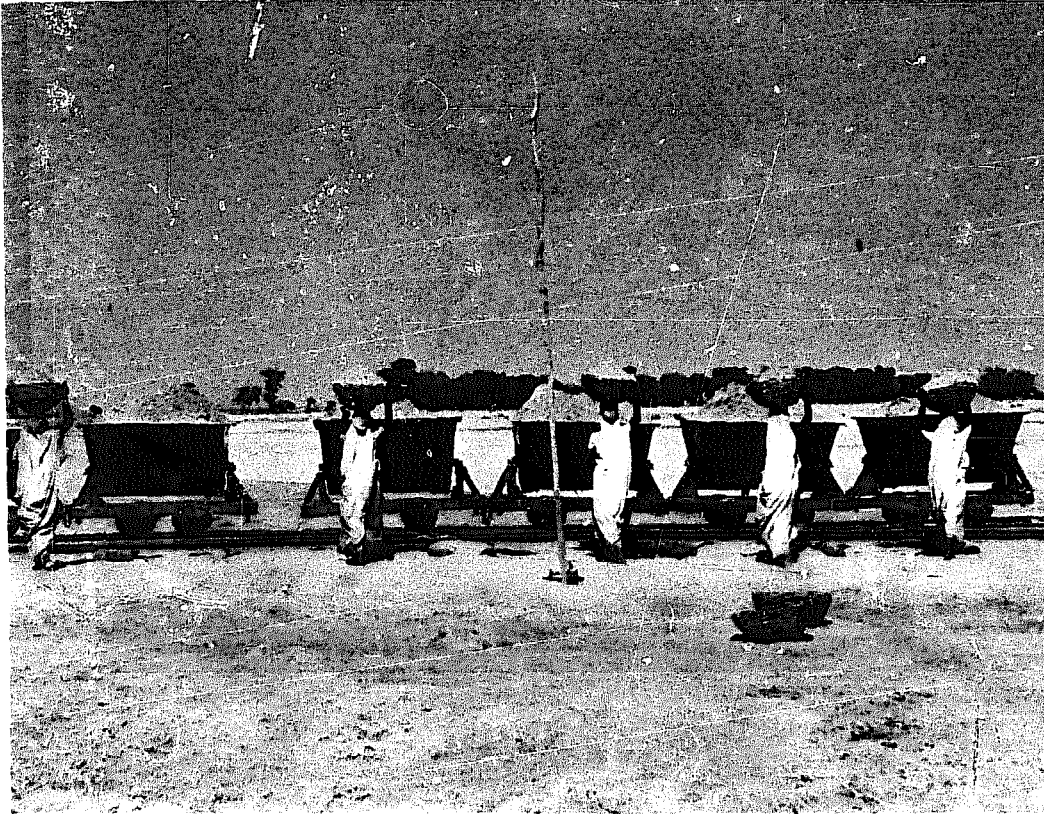
(figure 21). A loading height of 1.5 metres seems to be the limit for efficient loading by hand, and care should therefore be taken to select equipment with a loading height below that limit.

The development of the tools used in excavating and loading has received little attention so far. In many parts of the world the principal tool used for light excavation and loading into small containers is what is known as a mattock in Europe and a mumty in India. It is wielded like a pick-axe and generally the material is then pulled through the legs of the operator, who stands astride. This tool comes in various shapes and sizes, often according to its agricultural uses; it is usually not specifically designed for earthworks.

The use of spades and shovels is common in Europe and North America, but they are not found throughout the developing world. Where they are not indigenous it should be recognised that their use will require a certain amount of learning. Moreover there is no point in issuing shovels or spades with sharp top edges to workers who have no shoes, but some models (see figure 22) have a footplate which is at right angles to the blade and on which a worker can push with his foot. Even in areas where the spade is in common use care should be taken to ensure that the model used is suited to the job to be done. The cutting

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Figure 22. Spade for barefoot workers
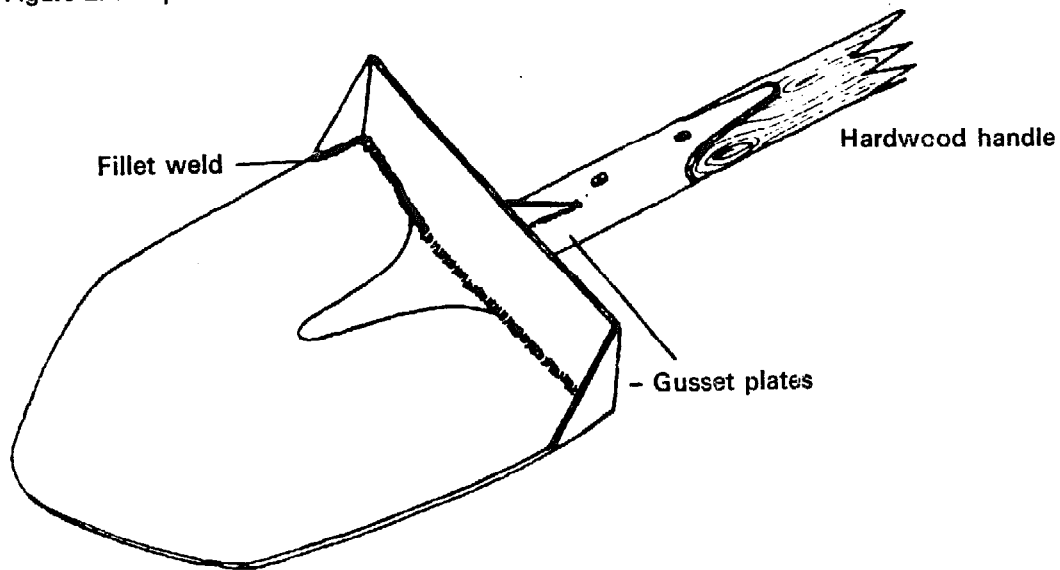
end may be straight or pointed, the sides may be built up for lifting material, and the size of the blade may be adjusted to the worker's lifting capacity. The planner of any labour-intensive scheme must bear in mind that the choice of the right sort of tool is as important as the choice of the right type of machinery on a capital-intensive project: given the right tools a worker's productivity can be enormously increased. A small research unit to consider the appropriate designs of small tools and equipment would be very useful.

HAULING AND UNLOADING

Traditional labour-intensive methods are generally not competitive for the hauling and unloading of material. Transport (as distinct from loading) by shoulder yoke, head baskets or human chains is generally very inefficient, very arduous and possible only for short hauls (20-25 metres in the case of head baskets). Only intermediate techniques involving the use of small machines or trucks or animal-drawn vehicles can compete with equipment-intensive methods involving the use of scrapers or dozers and trucks. Draught animals can generally be used in one of two ways, viz. either to transport material on their backs as pack animals or to pull various kinds of transporting equipment. A factor affecting the productivity of draught animals is the need for rest and watering: in the Philippines the water buffaloes, for example, need to be watered for an hour a day.

Pack animals

Donkeys (figure 23) and camels are used as pack animals in various parts of the world. Although both animals tend to be slow, they can be useful in moun-

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Figure 23. Donkeys carrying soil (Pakistan)

tainous areas where the passage of small wheeled vehicles is difficult. In the World Bank study in India a typical work unit for embankment construction using donkeys over a haul distance of between 75 and 200 metres consisted of four or five labourers with ten or twelve donkeys they owned.

The donkeys carried woven rope panniers and were loaded with about 150 kg of soil. Their productivity, of some 1 or 2 cubic metres per man-hour, was reasonable for this haul distance.[1]

Animal-drawn carts

For haul distances up to 500 metres animal-drawn carts constitute an efficient means of transport. The comments already made about loading height are applicable in this case. Various ways of improving such carts were tried out in the Philippines.[2] The wooden wheels were exchanged where possible for pneumatic tyres, and the sides were slightly built up to contain the material

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[1] International Bank for Reconstruction and Development, Transportation and Urban Projects Department, Transport Research Division: *Comparison of different modes of haulage in earthworks*, World Bank Study of the substitution of labor and equipment in civil construction, Technical Memorandum No. 3 (1975, mimeographed), pp. 4, 9.

[2] See Deepak Lal *et al.*, *Men or machines*, op. cit., p. 31.

Figure 24. Animal-drawn carts (Philippines): this one has rubber tyres but has to be unloaded by hand

(figure 24). The most important feature of these carts was that the bottom had been modified to allow the material to be discharged through it. A bamboo mat was placed over the modified bottom of the cart before soil was loaded into it, and discharge was effected by pulling out the bamboo mat (figures 25 and 26). A possible further modification of this system would be the provision of opening hinged flaps underneath the cart so as to do away with the effort required to pull out the bamboo mat. Pneumatic tyres not only reduce the tractive effort required but also provide better compaction. The cost of the conversion of the carts in the Philippines was about US $3. The pneumatic tyres cost a further US $37.

Other animal-drawn equipment

For the transport of material that is loose or has already been loosened scrapers can be used. They are limited to hauls over distances of less than 100 metres, but they have the advantage of being self-loading and self-unloading. Such implements were used in the latter half of the nineteenth century in North
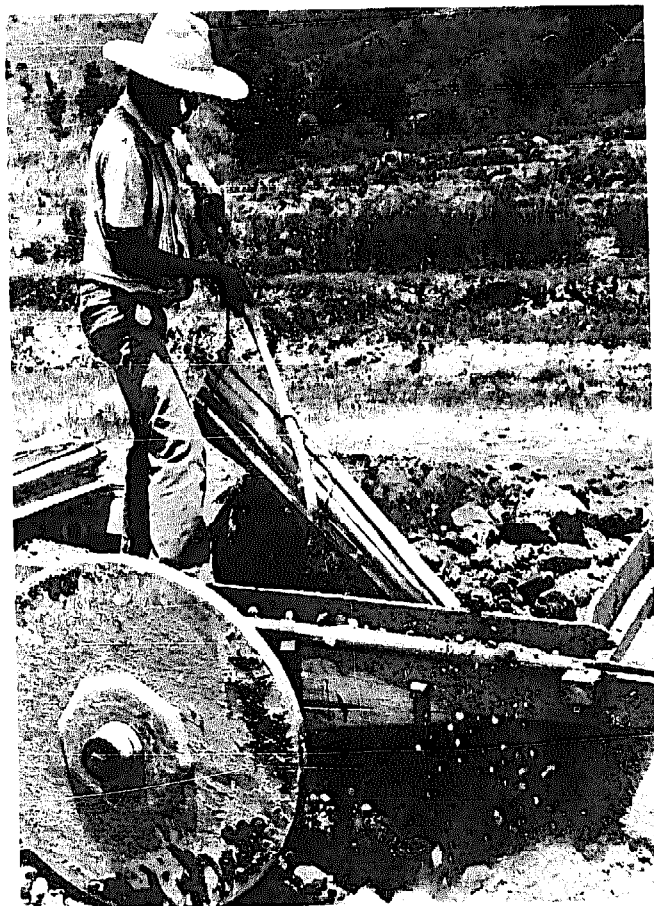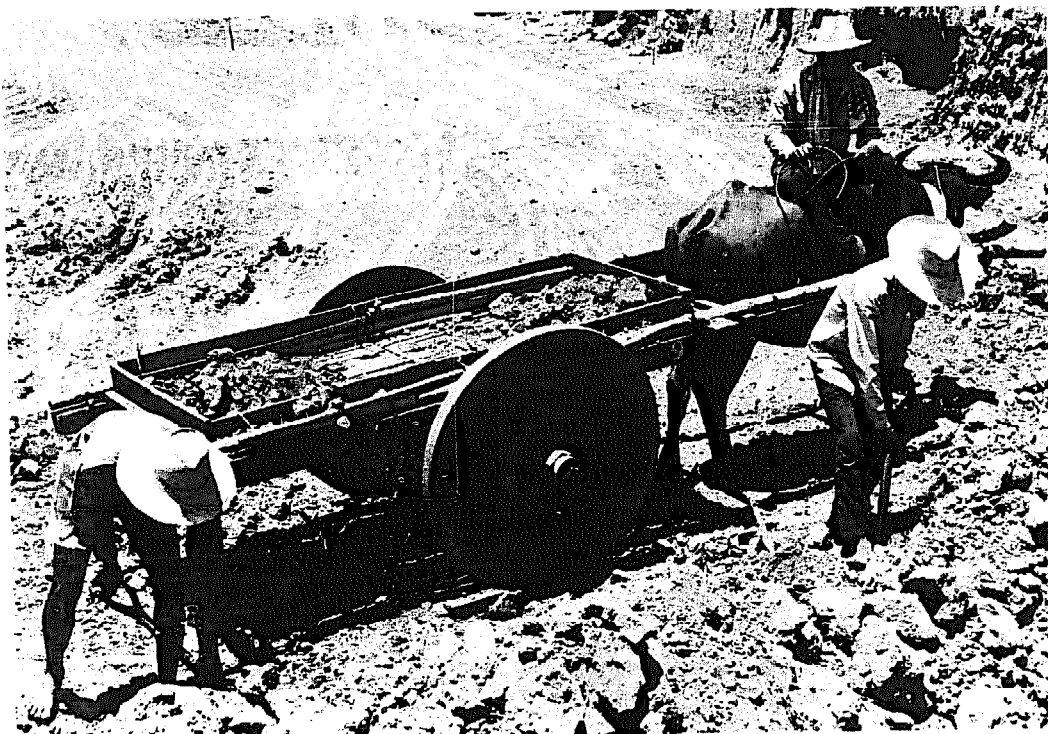
Figures 25 and 26.

Animal-drawn carts (Philippines): these do not have rubber tyres, but their bottoms consist of bamboo mats which are simply lifted to unload

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Figure 27. Steel scoop scraper used in North America in the nineteenth century
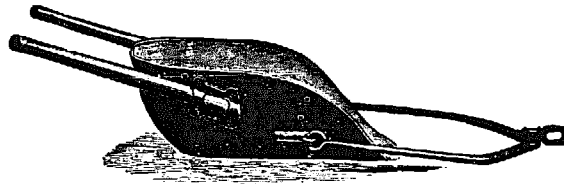
Figure 28. Steel buck scraper used in North America in the nineteenth century
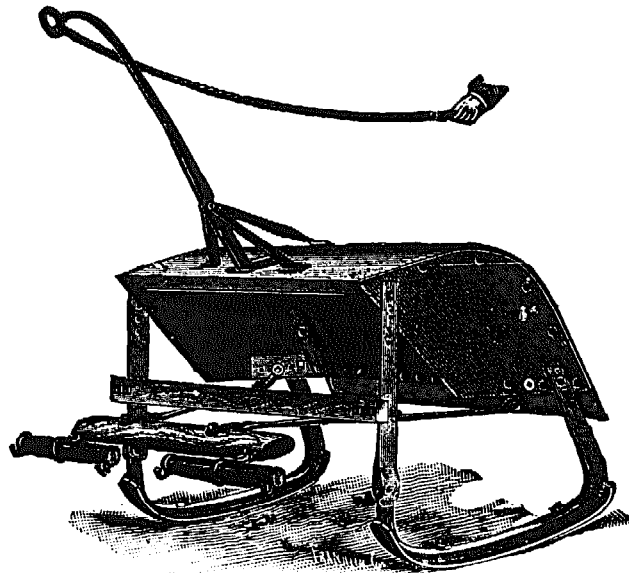
America (figures 27 and 28). The models illustrated are drag scrapers. There were also wheel scrapers; in those models the scraper itself is mounted on wheels and furnished with levers for raising, lowering and dumping.

These sophisticated models are mentioned to provide food for thought rather than as models of equipment that should be directly copied. Engineers would have to assess whether materials that are locally available could be used to provide comparable pieces of equipment. Scrapers made out of bamboo (figure 29) or oil drums cost virtually nothing, but of course are not as robust as the steel ones (figure 30), which cost about US $100. However, large-scale production would further reduce the cost of the steel models, and the provision of replaceable runners and cutting edges would prolong their life.

Figure 29. Bamboo scraper (Philippines)

Small trucks on rails

The use of small tipping trucks on rails has been reported on in two studies relating to India. These trucks are of a standard type, shown in figure 31. The loading height, 1.2 metres, is close to the upper limit for effective manual loading. The capacity of these trucks is usually 0.76 cubic metre. Certainly these trucks, which workers can easily push, are efficient hauling vehicles. An ILO study team assessed the cost for a 100-metre lead as US $0.20 per cubic metre [1], while an IBRD team for the equivalent operation involving the transport of boulders observed the cost as US $0.50 per cubic metre. [2] The main disadvantage of these vehicles is that the track has to be laid, moved periodically and finally taken up again. In the ILO study it was found that inexperienced labour required 10 man-minutes to lay a metre length of track onto a pre-

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[1] ILO: *Men who move mountains*, op. cit., p. 218.

[2] International Bank for Reconstruction and Development, Transportation Department, Transport Research Division: *The use of rail systems in civil construction*, World Bank study of the substitution of labor and equipment in civil construction, Technical Memorandum No. 23 (1976, mimeographed), p. 26.

Labour-intensive road construction

Figure 30. Animal-drawn steel scraper (Philippines)

Figure 31. Tipping truck on rails (India)
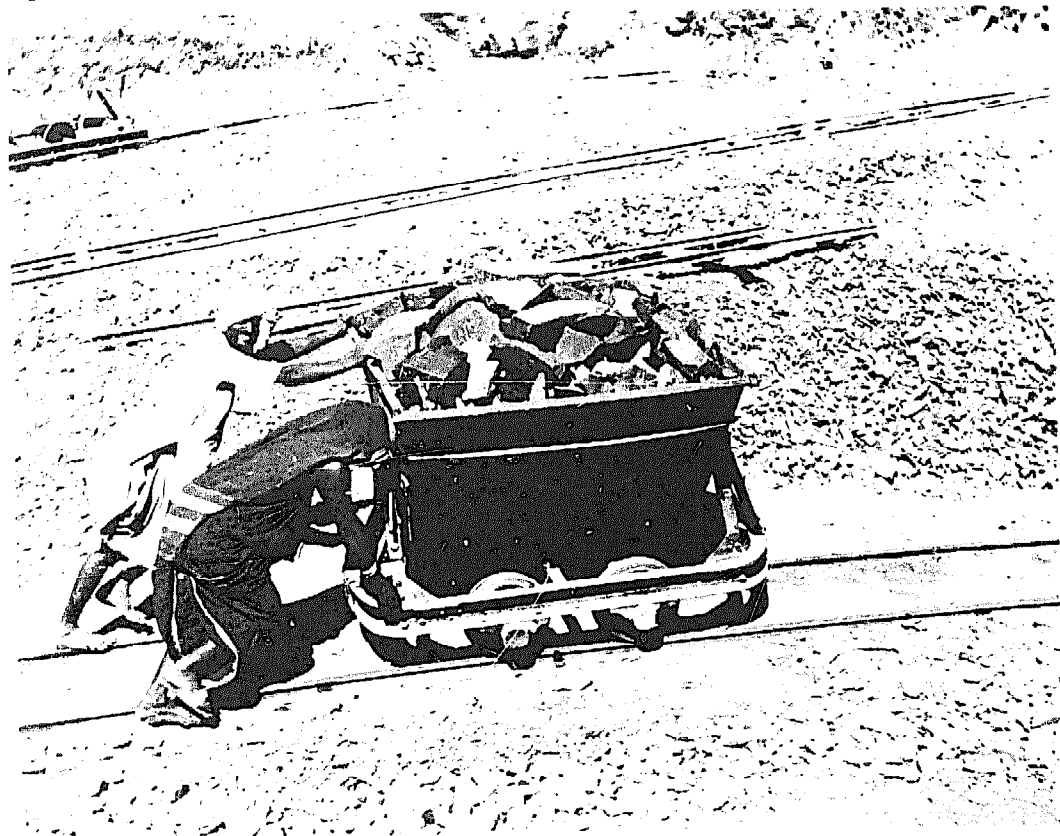
viously prepared foundation. A further problem is that the trucks are too heavy to be pushed up steep gradients. However, this problem can be overcome by the use of a winch. Various suggestions can be made concerning the improvement of the trucks, which were originally designed to be pulled by locomotives and are unnecessarily robust for manual operations:

(a) the loading edge should be lowered;

(b) the included angle between the sides should be increased;

(c) some form of pushing bar should be provided to assist the workers; and

(d) a more effective tipping mechanism should be evolved to ensure stability and to prevent the sides from becoming embedded in the discharged material.

Wheelbarrows

For hauls of less than 75 metres the wheelbarrow is another efficient means of hauling. There appear to be as many types of wheelbarrow as there are countries in the world: some have two wheels, some have one; some are lightweight with pneumatic tyres, others are heavyweight with solid tyres; some have wheels in front of the container and others underneath it. In identifying the best design for wheelbarrows the following factors are critical:

(a) the distance between the handles;

(b) the relative position of the grips, the centre of gravity of the loaded barrow, the axle, and the point of contact of the wheel on the ground; and

(c) the rolling resistance of the wheel.

The distance between the handles affects the ease with which the pusher can correct any tendency to tip sideways and apply the maximum effort to pushing the barrow.

The longitudinal position of the centre of gravity determines the proportion of the total load that will be borne by the worker at the grips. The closer it is to the handles the more load he carries. The heavier the load on the handles, the easier it is to control the barrow, but also the more fatiguing is the operation; conversely, the closer the centre of gravity to the wheel the lighter is the load on the handles and the more difficult it is to control the barrow. Naturally, a compromise has to be reached.

The vertical location of the centre of gravity is the main factor affecting stability. If the barrow is to be stable the centre of gravity when the barrow is being pushed should be on or below a line drawn between the level of the handles and the point at which the wheel touches the ground.

The bigger the wheel the better for pushing the barrow. However, as the wheel size increases the centre of gravity is pushed back and more weight rests on the handles. Again a compromise has to be reached.

Pneumatic tyres are clearly superior to solid tyres. On the other hand wheel-barrows with two wheels are more difficult to push and not as manoeuvrable and cannot be used on narrow tracks, in addition to which the extra wheel doubles the chance of hitting an obstacle.

Trailers

For longer hauls (up to 2 km) farm tractors and trailers have been used. The trailers are generally cheap, while the tractors are expensive. It therefore is important to keep the tractors permanently working, by ensuring that there is always a surplus of trailers either loaded or ready to be returned empty for a tractor to tow.

A recent innovation observed in Southern Africa is shown in figure 32; it is a complete unit of small tractor, towed chassis and hauling container. The container (figure 33) can be hydraulically off-loaded at the excavation point, and is then filled by hand as shown in figure 34. Again, it is advisable to have a surplus of containers so that the standing time of the tractor is limited. To use this piece of equipment is, of course, to adopt a more capital-intensive method. However, the towed chassis and container could be of wood, thus reducing capital costs. Some form of hydraulic or mechanical arrangement to off-load the container could be attached to the wooden frame.

Figure 32. Small dump truck combination consisting of small tractor, towed chassis and hauling container (Southern Africa)

Figure 33. Hauling container on its towed chassis (see figure 32)

Figure 34. Hauling container being loaded by hand (see figures 32 and 33)
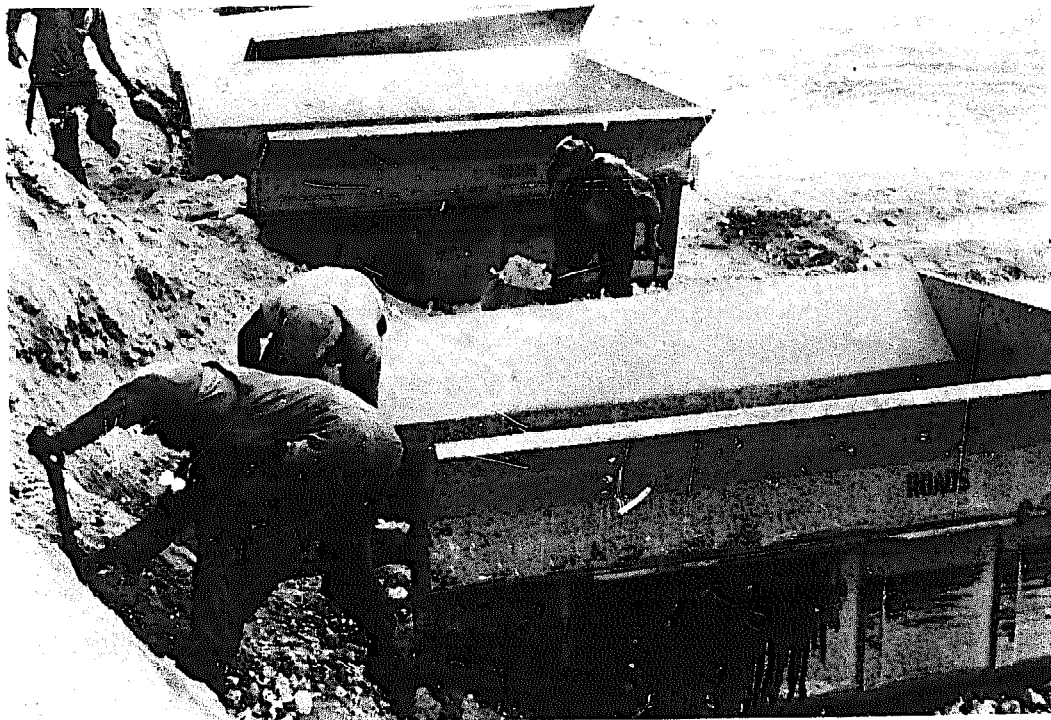
Figure 35. Small ropeway for hauling material (Indonesia)

Upper timber frame

Pulleys with
self-aligning bearings

Wheels
with sealed
ball bearings

Hauling rope
(manilla)

Anchor ropes
(steel wire)

Hauling ramp

Unloading platform

Carriage for
sand bags

WEATHERED
ROCK

Concrete footings

Anchors

Travelling rope
(steel wire)

Lower timber frame

Concrete blocks
retain sand and stabilise
frame pivot point

Counterweight of concrete blocks
applies tension to travelling rope

Pivots on timber
footing

SAND BANK

Figure 36.   Lever and transfer basket (China)
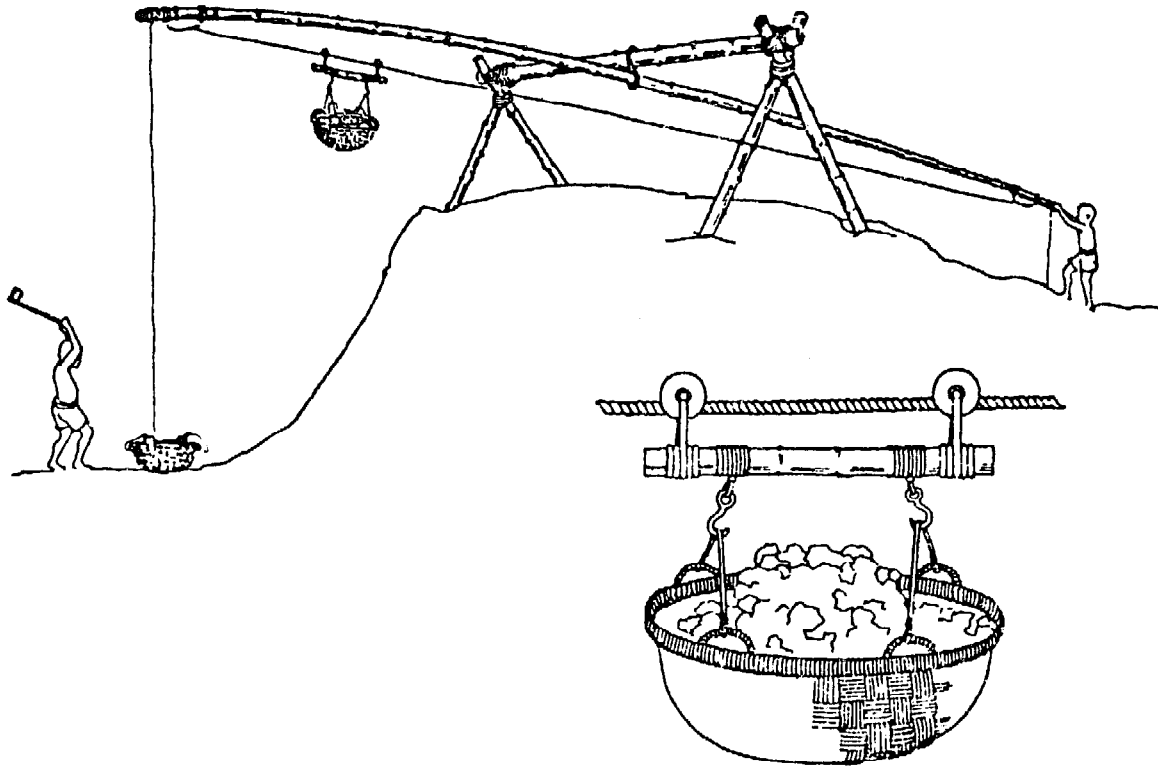
Quick-release, self-emptying basket

Notes: 1. Designed for two-man operation, lead approximately 10 metres.   2. Steel content approximately 2 kg for pulleys and hooks (see detail).   3. Other materials: bamboo, rope.   4. Operation: *(a)* excavator attaches full basket to pulley-rig; *(b)* spreader pulls boom down by means of suspended rope; *(c)* excavator begins loading second basket; *(d)* spreader unloads first basket by releasing one hook; *(e)* spreader rehooks empty basket and signals to excavator; *(f)* excavator pulls his rope and empty basket slides back to borrow-pit; *(g)* excavator detaches empty basket and attaches full basket to pulley-rig; *(h)* operation is repeated.   5. Excavator and spreader exchange positions regularly.

Other hauling devices

The hauling devices dealt with in this section have not yet been used on a large scale. However, they appear to offer particular benefits and are therefore worth investigating.

(1) Small cable ropeways to haul materials (figure 35) have been used in Asia on a limited scale.[1] The ropeways were manually operated and the material was carried in small bags. According to the circumstances, the hauling mechanism could be manual, animal-powered, pedal-powered or mechanical. Pedal power has the advantage that the driving unit can also be used as part

[1] International Bank for Reconstruction and Development, Transportation and Urban Projects Department, Transport Research Division: *Haulage using aerial ropeways*, World Bank study of the substitution of labor and equipment in civil construction, Technical Memorandum No. 22 (1976, mimeographed).

of a bicycle, i.e. a means of transport to and from the worksite. The hauling containers could be simple bags or large metal skips. Instead of a simple hoist over short distances it would be possible to have a system of ropeways carried over long distances on pylons.

(2) The lever and transfer basket used in China is also a useful means of transporting material vertically. Figure 36 shows a simple version, more sophisticated equipment with steel or aluminium parts could be considered.

(3) The use of conveyor belts in conjunction with labour-intensive methods of excavation and loading is also worth investigating. Because of their continuous hauling there would be less of a problem of trying to match the output of loading with that of the hauling equipment. The conveyor belts could be driven by pedal power. Deployment of a group of interconnecting conveyor belts driven by hand, pedal or machine certainly seems a feasible method of effectively transporting material in large open areas.

SPREADING AND LAYING

The capital-intensive methods of spreading and laying material involve the use of scrapers, graders or angledozers. The operation can also be carried out entirely by hand, although this is not generally very productive and it is often difficult to produce a reasonable finish. The animal-drawn scrapers described in the previous section can also be used. Other methods, often used in maintenance work, involve the towing of brooms and drags as shown in figures 37, 38 and 39. These can be pulled by tractors or lorries, or by draught animals or labourers.

Another type of drag is shown in figure 40. This is common in India. It consists of a timber log 20 to 25 cm in diameter and between 2 and 2.50 metres long cut into two halves longitudinally. These split logs are then braced together by 1-metre-long cross-braces on top of which a platform of wooden planks is constructed. An iron plate is fixed to the vertical face of one of the split logs in such a way as to project about 15 mm below the split log. The drag is attached to an animal by ropes or chains and the operator stands on the wooden platform. The depth and shape of the cutting section of the drag can be regulated by the operator's moving backwards or forwards on the platform. The front log with the iron plate attached makes an angle of 30° to 45° with the cross-section of the road to facilitate the dispersal of the soil or gravel to the side.

Many of these innovations are potentially efficient, but in their existing form they are often clumsy and over-elaborate: more work needs to be done on the design of this type of equipment. The drag or scraper shown in figure 38 is basically an adaptation of an agricultural hoe using pieces of scrap metal.

Figure 37. Broom used to finish a road surface (East Africa)

Figure 38. Drag used for shaping road surface (East Africa)
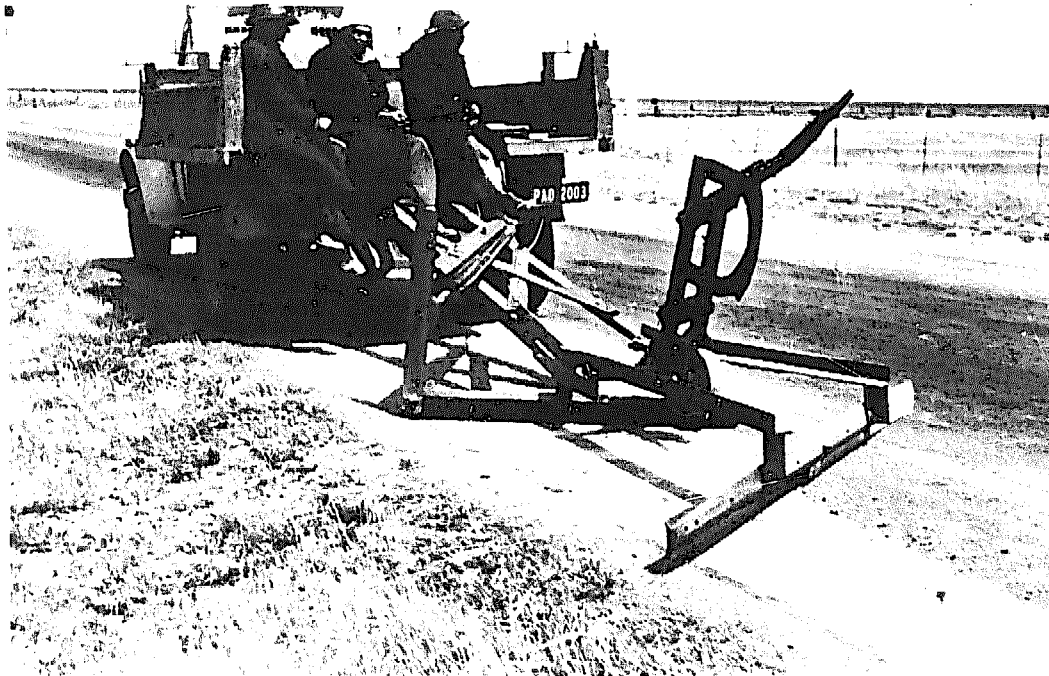
Figure 39. Towing of brooms for spreading (East Africa)
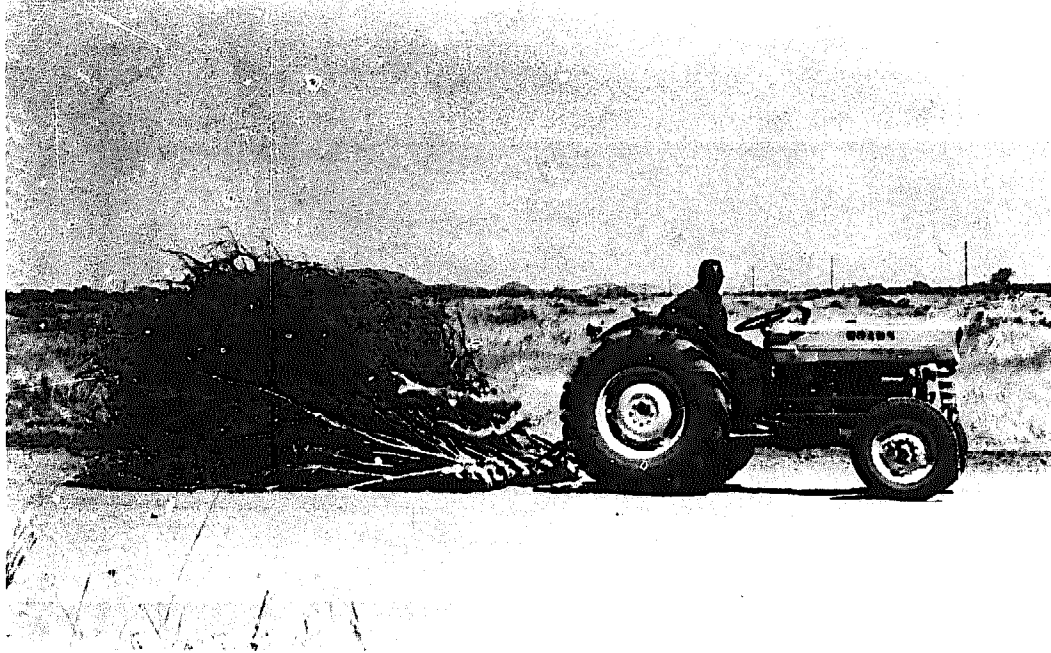
In view of the limited tractive effort available it would be better if the drag had a very light frame; hollow steel or aluminium tubing would be useful.

It is difficult to lay material by labour-intensive methods, particularly in the case of bituminous or flexible pavement materials. Naturally, laying is no problem in the case of hand pitching. The greatest problems emerge in connection with the laying of material that is homogeneous and requires a uniform and standard pattern of laying and of surface finish. A large machine will lay at a standard rate, whereas the 20 workers who could perform the same operation by hand will all have slightly varying output rates and this will lead to variations in the quality of the final product. It is therefore not yet possible to recommend the use of labour-intensive laying methods on major highways, which are generally the only roads that will have this form of construction.

COMPACTING

The effective compaction of soil has been one of the operations in which it has been difficult to achieve the same standard by labour-intensive as by equipment-intensive methods. The depth of effective compaction depends upon the type of soil and the type of equipment being used: the machine is often very

Figure 40. Split-log drag (India); the platform is laid on top
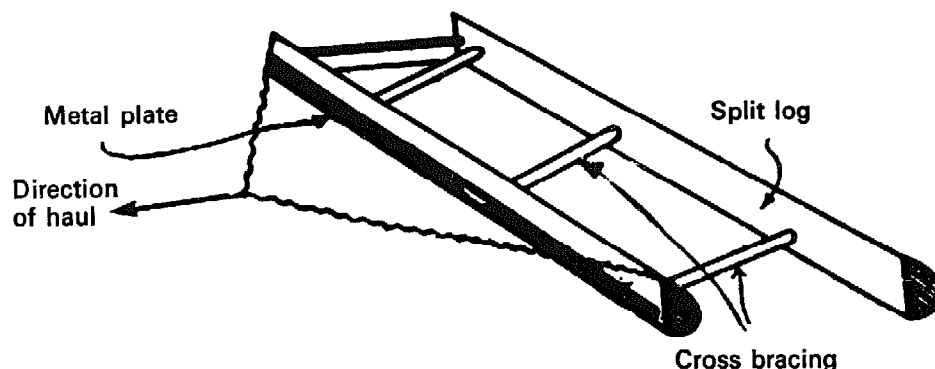
large, and produces a high level of compaction to an appreciable depth. Prior to the advent of large compacting equipment (smooth-wheeled, pneumatic-tyred or sheeps-foot rollers, including vibration rollers), when the speed of construction was slower, the soil was often left to consolidate by itself or under the weight of traffic. This, of course, may still be possible in the case of minor or secondary roads. However, if a road must be completed in a short time some form of positive compaction is required.

The main limitation of the use of manual methods for compaction is that they cannot apply sufficient pressure because the loads that are required are too great to be hauled manually or by animals: if a simple concrete roller is used it must have a diameter of 60 cm to obtain a reasonable pressure of the order of 1 Newton per square millimetre on the soil to be compacted; however, a roller 60 cm in diameter and 90 cm in length is difficult for animals to draw. Rollers of a smaller diameter do not apply sufficient pressure, and shorter rollers do not cover a wide enough area. Such simple rollers are therefore of dubious value except on roads designed to carry only the lowest volume of traffic. Small vibrating plate compactors (figure 41) constitute an alternative. Even the smallest of these are effective with materials that are uniformly graded. Even though vibrating plate compactors are effective, it should be recognised that they are mainly designed for small areas, and that if the area to be compacted is large and several small compactors are used it is difficult to achieve uniform compaction. Moreover their output is only about one-twentieth of that of the large vibrating rollers.

Figure 41.   Vibrating plate compactor
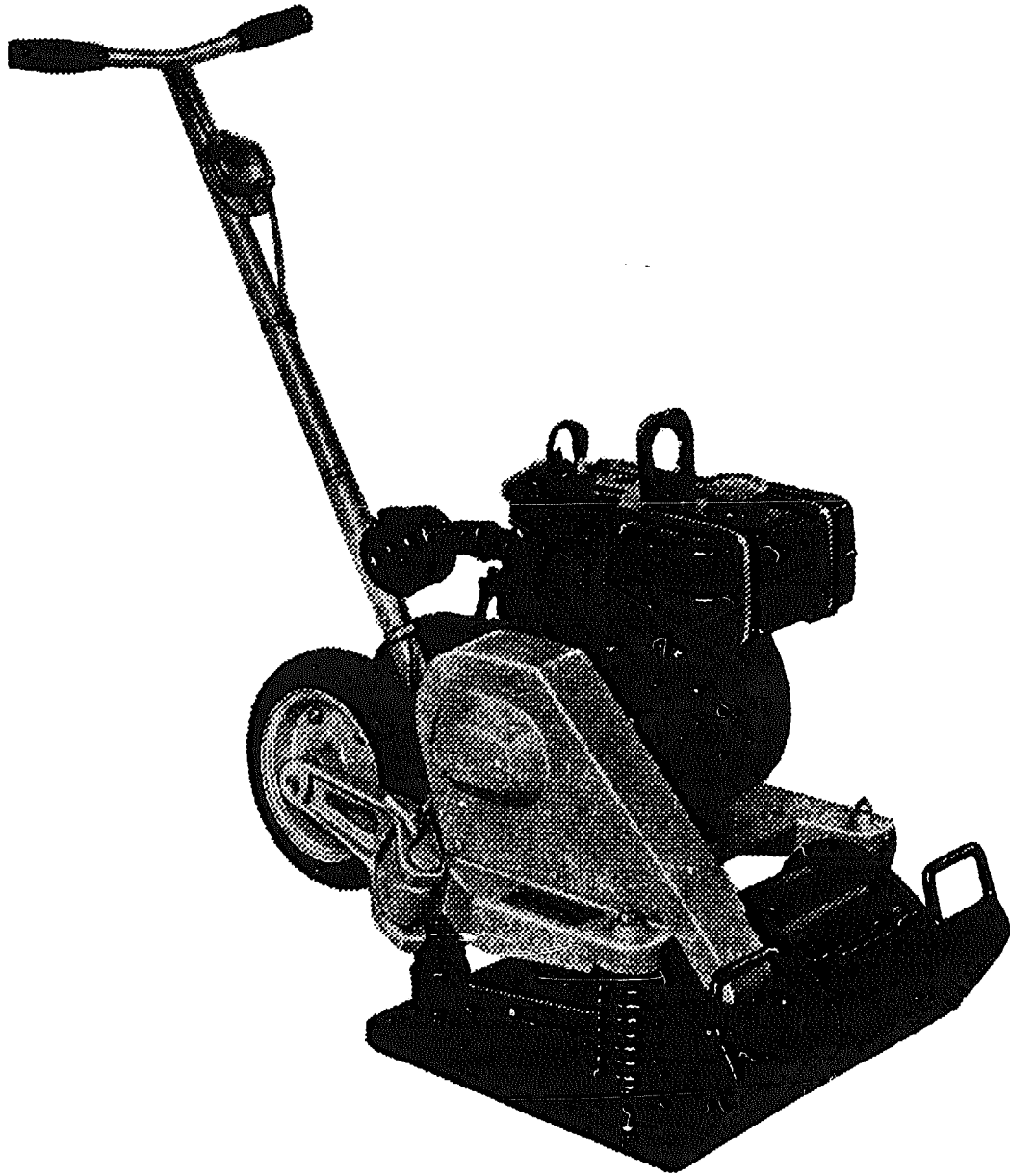
MIXING

Materials for mixing can be divided into those that can be mixed on the roadway and those that have to be mixed before they are spread on the road. The materials that can be mixed on the roadway are chiefly those used for soil stabilisation, whether with bitumen, cement or lime. Either an agricultural tractor or animal-drawn ploughs can be used to mix the lime with the soil. Concrete and bitumen macadam or asphalt have to be mixed before they are spread,

and to produce the required quality mechanical mixers are needed. However, it is not always necessary to have a central batching plant for concrete or paving materials: small mixers spaced along the length of the works may be sufficient. Of course such an arrangement increases the transport cost of the material, but the increase may be offset by the reduction in capital cost required. Small mixers can be, and have been, used for the mixing of bituminous materials. They have to be heated to the required temperature, and quality control and therefore supervision has to be very good. When consideration is given to the use of labour-intensive methods for the production of pavements of high quality for a high volume of traffic, the question is not merely one of substituting small machines for large ones, or labour for equipment: the important point is to define the product required and utilise the materials that are best suited to labour or capital as the case may be. In North America work has been carried out on the use of cold asphalt for high-quality roads. If labour-intensive methods are to be used for the laying and spreading of bituminous materials, it is important to bear in mind the rate of production in each of those two operations: if the workers cannot keep up, there is little point in using an asphalt plant with a high output rate which requires the asphalt to be rolled at an equally high rate. This is one field in which much more research work needs to be done on the type of materials to be used and the plant and equipment to produce them.

ROCK EXCAVATION AND CRUSHING

Rock has to be excavated and crushed where it is encountered in excavation and where aggregate is required for concrete, paving materials or as a construction material in the road base or in drain linings, for example. It is not always necessary to use dynamite and large crushing machines. Big rock masses can be split by burning a fire on them and then suddenly cooling them with water. A jumping bar can be used to make a hole into which a plug and feather can be placed; as these are forced deeper into the rock the wedge action splits the rock. Hammers and chisels can be used to produce smaller aggregates. Sieves and screens can be manufactured locally and can be used for separating aggregates into various sizes.

In India the World Bank experimented with small crushers in local use. By improving the work management at both the input and output stage it was possible to increase the output by at least 10 per cent.[1]

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[1] International Bank for Reconstruction and Development, Transportation Department, Transport Research Division: *Aggregate production*, World Bank study of the substitution of labor and equipment in civil construction, Technical Memorandum No. 25 (1976, mimeographed), p. 13.

OTHER OPERATIONS

Intermediate techniques have also been suggested for various other operations.

The two-handled rake shown in figure 42 is used in India for the spreading and laying of asphalt. The material is more easily spread when two labourers can push and pull alternately.

The ripper shown in figure 43 could be constructed in wood or a lightweight material and pulled by animals, although a small tractor would be preferable. The one illustrated is rather cumbersome, and modifications could be made to streamline the design and reduce the weight.

The water bowser shown in figure 44 is a simple, effective animal-drawn means of distributing water. This model cost US $30 to produce, at 1972 prices, in the Philippines. The rate of spread is 2 litres per square metre and the productivity varies from 1,006 square metres per hour at a haul distance of 50 metres to 272 square metres per hour at a distance of 1,000 metres.

Figure 42.   Two-handled rake (India)
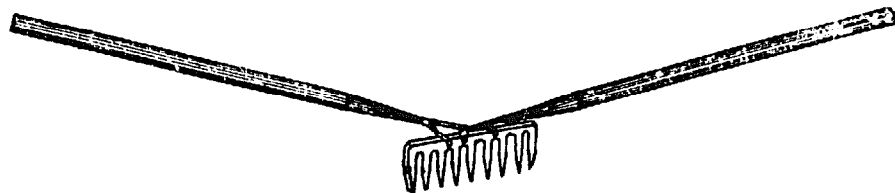
Figure 43.   Ripper
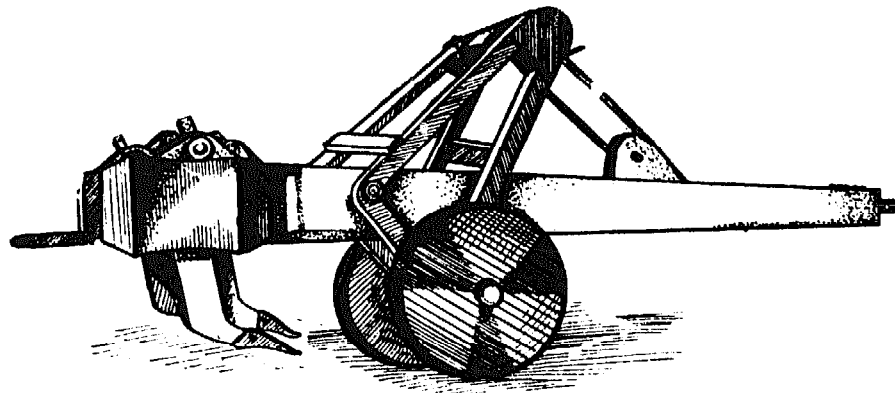
Figure 44.   Animal-drawn water bowser (Philippines)

ROAD CONSTRUCTION COSTS

5

Road costs and benefits may be classified as direct or indirect. The purpose of this chapter is to identify road construction costs and to show how they could be estimated. Chapter 6 will serve the same purpose with regard to maintenance costs as well as indirect project costs and benefits. Estimation procedures will be described in some detail for each item. While these procedures will probably be applicable to many project evaluation cases, there will be other cases in which the evaluator will need to devise other, more appropriate procedures in the light of the type and accuracy of the data available; in such cases it is hoped that the procedures outlined in these chapters will serve as useful examples of how costs and benefits may be estimated. An accurate estimate of all such items is essential when different combinations of design and technology are being compared for any particular project. The differences in profitability between different versions of a single project are less marked than the differences in profitability between different projects, and a higher level of accuracy is therefore needed in the former case than in the latter.

Direct costs are the actual money outlays incurred by the authority in charge of the road project. These direct costs include both road construction costs and road maintenance costs over the life of the road. Direct benefits include actual revenues obtained by the public works department (i.e. the authority in charge of road projects) from the imposition of road users' charges. In some cases direct benefits may also include a saving on maintenance costs as a result of the reduced use of existing roads as traffic is diverted to the new road. The above-mentioned direct costs and benefits are in fact the only items included in the financial analysis of road projects. When roads are built and operated entirely by private concerns seeking to maximise profits, the evaluation of road projects consists of a financial analysis. In developing countries, however, most roads are built and operated by the government, which seeks to maximise social rather than private profitability. The public works department must therefore take

into consideration additional costs and benefits which do not involve money transactions, but which are indirectly linked to the road project and which affect society as a whole. In the present manual these factors will be termed indirect costs and benefits. Their inclusion in project evaluation provides a better measure of the social profitability of road projects than if only direct costs and benefits were taken into consideration. Indirect costs may include road users' costs, as well as a number of negative externalities. The indirect benefits may include a certain number of road users' savings, as well as a number of positive externalities.

It may be noted that while all project costs and benefits must be estimated in order to calculate the social profitability of a road project, certain costs and benefits (namely those common to all technologies under consideration) may not need to be estimated if one's purpose is merely to identify the most appropriate version of a given project. It is not possible, however, to specify in advance which particular costs and benefits will be common to all technologies under consideration for any and every type of road project. For this reason, this manual will show how to estimate all possible costs and benefits; it will then be up to the project evaluator to decide which costs and benefits need to be estimated, for a given road project, in order to identify the most appropriate version of the project.

Construction costs in the narrow sense are those attached to carrying out the various physical operations required for building a road with given specifications and design. These operations have already been described in Chapter 4 of this manual. To estimate such construction costs, project evaluators must be in possession of input data generated by the engineering study. The input data should consist of a detailed inventory of all inputs entering into the various operations involved in the construction process. Strictly speaking, there is in fact no such thing as a construction technology for an entire road project; it will consist of a combination of the differing technologies used for the various individual operations involved. There are cases in which different techniques of widely differing labour and capital intensity could be combined for the construction of a given road (e.g. labour-intensive methods for earthworks and capital-intensive methods for paving). An input inventory should therefore be obtained for each technology available for any major operation.

Example: Input inventory for earthworks using labour-intensive methods

Description of task: Excavation with picks, loading with shovel in wheel-barrows, unloading.

Number of cubic metres of earth: E

Number of man-days: (i) unskilled labour: D_1 man-days
       (ii) gang leaders: D_2 man-days
       (iii) foreman: D_3 man-days

Tools: picks, shovels, wheelbarrows, in terms of the number of fully depreciated tools, i.e. taking into account their working life.

Given unit prices of labour and equipment, construction costs may be estimated from inventories of the type shown in the above example.

It is the prevailing practice for a road engineering study to yield a bill of quantities rather than input inventories. Estimation of construction costs, by a private contractor or the public works department, is then based on the bill of quantities, on input productivity data attached to the construction technology generally used, and on input prices. This estimation procedure is appropriate only if there is only one construction technology in general use for each operation. In this case, past data may be used with some adjustments for inflation and for any special features of the road projects under consideration. However, in cases in which there is more than one technology and the department wishes to identify the most appropriate one it is essential that the project evaluator should obtain an input inventory for each technically feasible design and technology alternative: therefore in addition to designing roads and providing bills of quantities, the design branch of the public works department or the private engineering firm should translate bills of quantities into input inventories for each design and technology alternative.

The estimation of construction costs requires the estimation of the costs of project design and appraisal, land acquisition, set-up and overheads, materials, and labour, the rental rate of engine-powered equipment, and the cost of animal-powered equipment and of tools.

PROJECT DESIGN AND APPRAISAL

Project design costs are those attached to the engineering analysis of road projects. For given road specifications, such an analysis provides a number of technically feasible road designs. It also yields, for each feasible design, possibilities of using a number of construction technologies. Thus the engineering analysis provides, for a given road, a number of different possible combinations of individual designs and technologies.

Project appraisal costs are those attached to the economic evaluation of the various design and technology alternatives generated by the engineering analysis. The economic evaluation may be a straightforward financial analysis or a more complex social cost-benefit analysis.

Project design and appraisal costs may be estimated on the basis of the budget allocated to the department in charge of road studies. If, for example, the budget of this department is B_u and if M_t kilometres of roads are designed and appraised each year, the design and appraisal costs of a road of M_p km is equal to

$$M_p \cdot \frac{B_u}{M_t}$$

Design and appraisal costs represent a small proportion (on the average about 5 per cent) of total project costs. The average proportion may be slightly exceeded if an attempt is made to analyse a larger number of design alternatives than is typically done. The benefits derived from an analysis of additional designs may, however, outweigh the increase in design costs since the additional analysis may permit identification of more feasible and substantially less costly design alternatives.

LAND ACQUISITION

Direct land acquisition costs are the actual money outlays incurred by the public works department for the acquisition of the land over which the road will run. It will be shown later that these direct costs may not reflect the true social cost of land, and adjustments may therefore need to be made in order to compensate for the difference between the social cost and the estimated direct land cost.

Land may be state property, private property, or under joint state and private ownership. Government land is usually transferred without cost to the public works department; rules governing the acquisition of private land differ from country to country. No attempt will be made in this guide to show how the cost of private land may be estimated since the estimation procedure is also specific to each individual country.

SET-UP AND OVERHEAD COSTS

Set-up and overhead costs may cover one or more of the following cost items:

(a) transport of equipment and tools to and from project sites;

(b) daily transport of workers to and from project sites;

(c) the building and dismantling of temporary structures for the storage of materials, tools and equipment, and for equipment maintenance and repair; and

(d) the building, operation and dismantling of workers' camps, including sleeping, eating and sanitary and health facilities.

The importance of set-up and overhead costs depends on the type of road project. Cost items *(a)* and *(c)* usually apply to all road projects. Cost items *(b)* or *(d)* apply only when the project site is situated in an isolated region, far from population centres.

It will now be shown how these costs may be estimated.

Transport of equipment and tools

Once the location of project sites, and thus the transport distances, have been determined, transport costs of equipment and tools may be estimated on the basis of the total tonnage of equipment and tools to be transported, and on unit vehicle transport costs. Project evaluators therefore need the following data:

(a) transport distances;

(b) type and number of vehicles needed for the transport of equipment and tools;

(c) vehicle operation costs per unit of distance; and

(d) number of trips required by each type of vehicle.

Data on items *(a)*, *(b)* and *(d)* are specific to each project, and should be provided by the engineers in charge of the project. Item *(c)* is of a more standard nature: vehicle depreciation, operation and maintenance costs are country-specific rather than project-specific. It will be shown later in this chapter how to estimate those costs for various types of vehicles.

Daily labour transport

Given the locations of the project sites and of the various places where workers are to meet in order to be transported to work, it is possible to estimate an average travel distance between those places and the project sites. If the total number of workers to be transported each day is N_t and if each vehicle can transport N_v workers, the daily transport costs will be equal to

$$2\frac{N_t}{N_v}.M.C_v$$

where M = average one-way distance between the pick-up points and the project sites, and

C_v = vehicle depreciation, operation and maintenance costs per unit of distance travelled.

Given an estimated D working days for the completion of the road project, the total transport costs of workers will be equal to

$$2\frac{N_t}{N_v}.M.C_v.D.$$

M is by far the most difficult item to estimate since it is extremely difficult to know before starting the project where workers will be assembled. Labour transport cost is, however, an important item when it comes to comparing labour-intensive methods with capital-intensive ones, and it is therefore important to estimate the value of M even if the estimated value is not highly reliable. N_v and C_v are standard data, but N_t and D are project-specific. The required daily number of workers is a function of the required daily output (i.e. the road construction schedule), and of labour productivity. Estimation of N_t therefore presupposes knowledge of labour productivity and of the construction schedule.

Storage facilities and workers' camps

The project evaluator must know the number of pieces of equipment and the quantities of materials to be stored in order to determine the size of storage facilities. Similarly, he must know the number of workers who will live on the project sites in order to determine the size of workers' camps. The project evaluator should be able to obtain this type of information from the civil engineers in charge of the project. Once the engineers have indicated, on the basis of their past experience and their analysis of project needs, the number and size of the facilities in question, the building and operation costs of such facilities must be estimated.

With regard to building costs, facilities on project sites usually consist of buildings made in sections, trailers, large canvas tents or shelters made of other light materials. Building costs consist of the following items:

(a) depreciation costs of building sections, trailers, tents or other materials;

(b) transport costs of components and materials to and from the project sites; and

(c) erection and dismantling costs.

In order to estimate depreciation costs the project evaluator must know the price and the durability of the structures to be erected. Since the durabili'y of the structures depends on the conditions under which they are used, ac.urate data may not be available. The project evaluator may have to make a very rough estimate of the depreciation rate of various structures in order to calculate depreciation costs. Cost items *(b)* and *(c)* are fairly straightforward, and should be relatively easy to estimate.

The operating costs of workers' camps include the cost of food, the upkeep of the camp and the operation of health care facilities. Those costs are also fairly standard, and should be relatively easy to estimate.

MATERIALS

The cost of materials includes the purchase or production costs, as well as the transport costs, of such items as gravel, asphalt, cement, lime, building stone, pipes, metal or wooden construction beams and road signs. For many of these the quality specifications vary according to the requirements of the particular road. The engineering analysis provides, for a given road, estimates of the quantities of the particular materials that are required. The next step is to estimate the unit purchase or production cost of those materials, as well as unit transport costs. Total materials costs can then be estimated on the basis of the unit costs and the total quantities required.

The procedure to be used in the estimation of the unit price of materials necessarily depends on their origin. Materials may be imported or be produced locally either by private firms or by the public works department.

Imported materials may be brought in by private trading companies and sold to the public works department, or may be imported by the department itself. In the first case the department may obtain price quotations from the trading company, while in the second case the prices may be estimated by adding the c.i.f.[1] price of materials to port handling charges and customs duties if any. The c.i.f. price may be obtained from the foreign exporter or manufacturer. Port handling charges may be ascertained from officials in the harbour administration, and customs duties from the customs office.

In the case of materials produced locally by private firms, prices may be obtained directly from the local manufacturers.

For materials produced by the public works department, prices are equal to the department's production costs. Such materials usually include gravel of

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[1] C.i.f. here has its customary meaning of "cost, insurance, freight", i.e. the purchase price abroad, transport insurance costs and freight costs.

various grades, building stones and road signs. Of course production costs depend on the production technology used. It is worth mentioning at this point that the department should evaluate the current production technology and compare it to other possible production technologies in order to determine whether the technology currently in use yields the lowest social production costs. For gravel and building stones the production costs include quarrying costs and the cost of processing the quarried materials. Quarrying and processing costs may be readily available from the division of the department that is in charge of the production of road materials. Where no such division exists, however, or when materials production costs are not accounted for separately, they must be estimated on the basis of input and output data. The estimation of materials costs then involves the estimation of the following cost items:

(a) plant set-up cost;

(b) equipment depreciation and operation costs; equipment used may include pneumatic hammers, loaders, rock-crushing plants, mechanical sieves, and diesel power generators;

(c) hand tool depreciation costs; tools may include sledgehammers, picks, shovels and wheelbarrows;

(d) cost of explosives;

(e) unskilled labour costs; and

(f) skilled labour costs.

The cost of explosives may be obtained from the supplier or manufacturer. The other costs must be estimated separately for each product (e.g. building stone, gravel of various grades). However, this may not be possible if accounting procedures do not differentiate among products (i.e. if data are not available on the number of man-hours and equipment hours per unit of production of individual quarry products). In this case, project evaluators may use the average production costs per ton or cubic metre of product. The same unit production cost will then apply to all quarry products. In many cases the average unit production costs for different products will be very close to each other.

Materials may need to be transported either to a few specific locations on the new road or to a large number of points along the road as part of an ongoing construction process. Transport costs of materials may be estimated in the way described for the transport of workers. For a given project, the transport cost of materials is a function of the total amount of materials which is required, and of the distance between the quarry site and the various project sites where materials are unloaded. The total amount of materials required may be estimated from the bill of quantities.

UNSKILLED LABOUR

Unskilled labour costs are estimated on the basis of the bill of quantities, labour productivity data for various operations, and the unit cost of labour (usually expressed as an hourly wage).

It may be recalled that labour productivity was defined in Chapter 3, on the basis of the method coefficient, as the over-all capacity, OVC. That capacity is defined as the productivity of a group of workers engaged in a particular road construction operation. If the group consist of N workers, the average productivity per worker is equal to $\dfrac{OVC}{N}$.

Thus, if the output of a particular task is E (in terms, for example, of cubic metres of excavated rock), the total number of man-hours needed to complete the task is equal to

$$Y_u = \frac{E}{\left(\dfrac{OVC}{N}\right)}$$

where $\dfrac{OVC}{N}$ is defined in terms of cubic metres per man-hour. Y_u does not, however, include a number of idle hours not taken into consideration when estimating OVC. Additional idle time may include, depending on the circumstances, some or all of the following remunerated idle times:

(a) travelling time to and from the worksite;

(b) sick leave;

(c) annual holidays with pay;

(d) public holidays;

(e) work stoppages due to bad weather; and

(f) officially agreed rest periods such as tea breaks, and breaks for meals.

The total number of remunerated man-hours required to obtain output E is then equal to

$$Y_u' = Y_u (1 + x)$$

where $x =$ idle time coefficient.

The Appendix shows how to estimate x. Given Y_u, x and the hourly wage of unskilled labour, w, the cost of unskilled labour, C, for the given task is obtained from

$$C = \frac{E}{\left(\dfrac{OVC}{N}\right)} \cdot (1+x).w = Y_u'.w$$

When estimating wages of unskilled labour the project evaluator must take into consideration the following factors:

(a) how wages are determined;

(b) the origin of the labour force;

(c) the seasons of the year during which work is to take place;

(d) taxes;

(e) insurance costs or disability payments; and

(f) payments in kind.

Project evaluators must first determine whether wages are determined by market forces, or are determined independently by unions or by the government, or by the two together. In the latter cases, project evaluators need simply to find out which public wage will apply to a given project. On the other hand if wages are determined by market forces, project evaluators may need to survey labour market conditions in the area crossed by the future road.

Having decided the wage to be paid, the project evaluator then carries out further calculations on the basis of that figure to arrive at the additional amounts required to cover whatever income taxes, insurance costs and payments in kind may have to be taken into account.

If t = the tax rate applying to unskilled labour income that is borne by the contractor or the public works department,

I = average annual insurance costs, or average annual disability payments for work accidents, and

F = daily payments in kind per worker,

then the hourly wage for unskilled labour will be equal to

$$w = \frac{w'\,(1+t)+\dfrac{I}{365}+F}{T}$$

where $w' = w_p$ in the public wage case and
w_m in the market wage case, and

T = number of working hours per day.

It will now be shown how w', t, I and F can be estimated.

Public wage

When the public works department is directly in charge of a road construction project, the public unskilled labour wage is the one to be used in project evaluation.

In general the public wage (w_p) or unskilled labour wage paid by the government is based largely on socio-economic conditions rather than actual labour market conditions. It is also affected to some extent by the unskilled labour wage paid in the capitalistic sector of manufacturing or services, which is generally higher than that paid in the traditional agricultural sector. Thus, the public wage is nearly always higher than the wages paid in the rural areas to agricultural workers. The public wage is generally the same for all parts of the country unless a regional wage is determined by regional authorities.

The daily take-home wage, w_p, can usually be determined in a fairly straight-forward manner by finding out from the government or the unions what is the wage that applies in the region to be crossed by the road. The project evaluator should take care, however, to ascertain whether the current wage will still apply at the time when the road is to be built. If a wage increase is expected, it should be added to the current wage. Moreover, except when the level of unemployment in the area to be crossed by the road is very high and one can be sure that it will remain so, the project evaluator should carry out a labour market survey, as described below, in order to ascertain whether labour supply will be sufficient to cover project needs.

Market wage

In cases in which construction work is given out on contract to private construction firms, there is no reason to assume that the wage paid by the firms in question will be equal to the public wage: the only cases in which that will happen are those in which the firms are compelled by law to pay a minimum wage equal to the public wage. If there is no such compulsion, the firms will tend to pay the wage prevailing regionally or locally.

Since project evaluators must base cost estimates on wages actually paid, it is necessary to estimate the market wage (w_m) that will prevail in the project area. In other words, the wage must be determined for individual regions of the country as well as for particular seasons of the year (e.g. the peak and the slack agricultural seasons) since wages may vary from region to region and from season to season. Thus a labour market survey in the project area may be needed for either or both of two reasons: it may be necessary to assess the availability of labour so as to determine whether there will be enough unskilled labourers to cover the project's needs; and it may be necessary to determine the regional or local wage. An evaluation of labour supply and demand during the construction period is needed in order to avoid bottlenecks and delays that would increase construction costs. In other words, construction operations should be synchronised with the availability of labour during the peak and slack agricultural seasons. It should be noted that in some areas there may be

no excess labour, and that the use of labour-intensive technologies may consequently be unwarranted. In some cases, therefore, it may be necessary to carry out a labour market survey before adopting a particular construction technology if there are good reasons to believe that unskilled workers may not be available in sufficient numbers.

In most cases regional or local unemployment statistics are not available and it is not possible to obtain a direct estimate of excess labour supply in the project area. Therefore one must first estimate the local or regional labour supply and demand.

First the area from which labour is to be recruited must be determined. If the workers are to be put up in camps, the recruitment area may be more extensive than if the workers are to be transported daily to the worksite, in which case the maximum radius of the recruitment area may not exceed a few kilometres. Once the recruitment area has been determined it is possible to estimate the local labour supply as being equal to a fraction of the population in the area, provided that the composition of the local population corresponds to the national or regional average in such respects as the proportion of active male and female populations and the proportion of the population that constitutes the unskilled labour force. Although estimates of local labour supply obtained in this fashion are not highly reliable, they should be sufficiently accurate for road planning purposes.

Next, labour demand must be estimated for each season of the year. If labour is to be recruited from an agricultural region, one must be in possession of statistics on land use in the region (i.e. of the total area under each type of crop), as well as estimates of the number of man-days of unskilled labour per unit of area and per type of crop. This kind of information is not usually available, and may be difficult to obtain.

If estimates of labour supply and labour demand cannot be obtained from available statistics, a project evaluator must undertake two labour market surveys in the project area, one in the peak agricultural season and one in the slack. Such surveys cannot be avoided unless interviews with local authorities indicate that there is a surplus of labour all the year round.

Once the excess labour supply has been estimated by whatever method, its amount expressed in terms of man-days may then be compared to the number of man-days of unskilled labour that are required for the project during each of the seasons during which construction work is to take place. If the excess labour available exceeds the project labour requirements throughout the year, construction operations may be scheduled in such a way as to reduce the time taken to a minimum; on the other hand if the excess labour supply falls below the project labour requirements for all seasons of the year, it may not be possible to use a labour-intensive technology unless it is possible to prolong the construc-

tion period or to attract the workers needed from agriculture by paying more than the agricultural wage. It should be noted, however, that it is very unlikely that a labour-intensive technology will be economic if the implementation of the road project gives rise to a labour shortage in the project area.

A third possibility is that excess labour supply may be lower than the project labour requirements during only some seasons of the year (e.g. the agricultural peak seasons). In that case a labour-intensive technology may become economic if the scheduling of road construction operations is adjusted to the availability of labour in each season. For example, operations requiring a large number of workers may be scheduled during the agricultural slack seasons, and those in which fewer workers are needed may be scheduled during the peak seasons. If such scheduling is not possible or if it entails a prolongation of the construction period, the cost of such a prolongation, in terms of induced benefits forgone, must be estimated and included in the evaluation of the road project. (Induced benefits in this case are the economic benefits indirectly generated by the road.)

The regional or local market wage (w_m) at various seasons of the year may be estimated by a simple projection from existing data, or data from a labour market survey. A market wage estimated in this manner may, however, be lower than the one that will actually prevail once the road project is under way, if the project is large enough to substantially alter labour demand in the project area. When the excess labour supply is very large, the additional demand for labour generated by a road project will not affect wages, but if the additional demand creates a situation of high employment in the project area, the market wage will reach a peak which may be assumed to be equal to the wage paid during the peak agricultural season (on the assumption that the additional labour demand generated by the project approaches but does not exceed the excess labour supply in each season of the year).

To conclude: if additional labour demand generated by the project is well below the excess labour supply in each season, the seasonal wage may be used for project evaluation. If, on the other hand, the additional labour demand results in high employment during the whole construction period the peak season wage should be used throughout.

In the first case (additional labour demand well below the excess labour supply in each season), one should use a weighted average labour wage obtained from the following relationship:

$$w_m = w_s \cdot x_s + w_p \cdot x_p$$

where w_m = the average market wage,
      w_s = the market wage during the slack season,
      w_p = the market wage during the peak season,

x_s = the fraction of the total number of man-days required during the slack season, and

x_p = the fraction of the total number of man-days required during the peak season.

It may be noted that if the local seasonal wage actually shows a significant increase as a result of the implementation of the road project, workers from outside the project area may be attracted by the high wage. Subsequently, an increase in labour supply may take place which will dampen further rises in the wage level, or actually make wages fall back to the level at which they would have stood in the absence of the road project.

Allowance for income tax, workmen's compensation and part payment in kind

It should be pointed out that, depending on the laws, regulations and practices that prevail in a given instance, there may be no need to make any allowance for income tax, workmen's compensation and payments in kind.

If income tax on wages is borne by the contractor or the public works department, the project evaluator will need to find out the tax rate (t) that is applied.

If labourers are covered by an accident insurance scheme for which the contributions are paid by the contractor or the public works department, average annual insurance costs per worker (I) need to be estimated. In general, however, road construction labourers are not formally insured against work accidents, but receive disability payments paid by the employer. In such cases it is necessary to estimate an average disability allowance per man-year, taking into consideration the frequency of various types of accidents and the average disability allowance attached to each type of accident. If there are no national statistics on work accidents in road construction, project evaluators may need to estimate the frequency of work accidents themselves. One way of obtaining information for such estimates would be to interview contractors or field engineers working for the public works department. The estimation of the disability allowance attached to each type of accident should include both hospitalisation costs and the value of payments made to the injured workers while they are disabled from work.

Payments in kind (F) may include food and clothing. Their value needs to be included in the wage only in the case where the government actually purchases the items. Thus, food or clothing granted by an outside donor under a technical co-operation project need not be considered in estimating the unskilled labour wage, although these items will be taken into consideration when carrying out the social cost-benefit analysis of the project. The cost of

issues of food and clothing may be estimated on the basis of wholesale prices, since those are the prices which the government would generally pay. The value of the daily payment in kind may be defined as follows:

$$F = \sum_{i=1}^{n} P_i \cdot f_i + \frac{C_l}{D}$$

where f_i = daily ration of food item of type i,

P_i = unit wholesale price of food item i,

n = number of food items,

C_l = wholesale price of clothing items, and

D = duration of the construction period in days.

If the construction period is longer than one year and if clothing is provided once a year, D is equal to 365.

PROFESSIONAL STAFF AND SKILLED LABOUR

The determination of the remuneration of professional and skilled labour is a simple matter if the public works department is in charge of the construction work: the department generally has specified standards for the salaries and wages it pays to these categories of personnel. On the other hand if construction work is given out on contract the remuneration due may not be known, since contractors may pay different rates according to their geographical location, their size and their policies. In such a case, project evaluators will need to make a survey of the rates paid by various contractors in order to estimate an average level of remuneration for each category of professional and skilled labour.

The professional staff and skilled labour used in road construction may be sub-divided into three distinct categories:

(a) supervisory and administrative staff, including executive, assistant and junior engineers, supervisors, overseers, surveyors, accountants and clerical and medical personnel;

(b) foremen; and

(c) equipment operators and truck drivers.[1]

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[1] In the interests of brevity, this manual does not cover a fourth category of skilled workers (consisting in particular of masons and carpenters for the building of bridges and culverts) who are needed for road structures.

Supervisory and administrative staff

The size and composition of the supervisory and administrative staff is a function of the size of the project labour force, the location of the project and the method of payment of the unskilled labour. Its size can be expected to be large if, for a given project, one or more or the following conditions prevail:

(a) the road is to be built by labour-intensive techniques;

(b) the location of the road project is such that it requires the building and operation of one or more workers' camps; and

(c) unskilled workers are to receive both money payments and payments in kind (e.g. food rations).

Project evaluators should therefore take the above factors into consideration when estimating the number of supervisory and administrative personnel.

It may be assumed that N_{si}, the number of supervisory or administrative personnel of category i, is constant over the entire construction period. Therefore, for a given N_{si} the number of man-days or man-months of supervisory or administrative personnel of category i is equal to $N_{si} . D$ for the whole project where $D =$ the length of the construction period in days or months. Therefore, given D and individual values of N_{si}, total supervisory and administrative costs are equal to

$$(SA.C) = \sum_{i=1}^{I} N_{si} . D . w_{si}$$

where $w_{si} =$ the gross daily or monthly salary of personnel in category i, and

$I =$ the number of categories of supervisory and administrative personnel.

Foremen

Foremen costs should be estimated for each operation since the number of foremen usually differs from one operation to another. For a given task j, the number of foremen is equal to

$$N_{Fj} = \frac{(N_{UL})_j}{S_j}$$

where $(N_{UL})_j =$ the number of unskilled workers on task j, and

$S_j =$ the number of unskilled workers per foreman on task j.

N_{Fj} may also be estimated on the basis of the total number of road sections, and on the construction operations required for each section.

In terms of man-days or man-months, the number of foremen is therefore equal to $N_{Fj} \cdot D_j$ for task j

and to $\sum_{j=1}^{m} N_{Fj} \cdot D_j$ for the whole road project

where D_j = the length of the construction period for task j, in days or months, and

m = the total number of tasks.

Foremen costs are therefore equal to

$$(FC)_j = N_{Fj} \cdot D_j \cdot w_F \text{ for task } j, \text{ and}$$

$$(FC) = \sum_{j=1}^{m} N_{Fj} \cdot D_j \cdot w_F \text{ for the whole road project}$$

where w_F = the gross daily or monthly salary of the foremen in question.

Equipment operators and truck drivers

The total number of hours of work of equipment operators and truck drivers may be estimated on the basis of the bill of quantities and the average productivity of equipment and trucks. The estimation procedure is the same as the one used to estimate unskilled labour costs. Given the over-all capacity, OVC, of n similar pieces of equipment (in some cases, n may be equal to 1 if OVC was estimated for one piece of equipment only), and the required output, E_j, for operation j (e.g. E_j cubic metres to be excavated and spread out), the total number of equipment operator hours for task j is equal to

$$Y_{E,j} = \frac{E_j}{\left(\dfrac{OVC}{n}\right)_j}$$

$Y_{E,j}$ must then be adjusted in order to include all remunerated idle times such as those listed in the case of unskilled labour. This adjustment gives

$$Y'_{E,j} = Y_{E,j}(1 + x)$$

where x = idle time coefficient estimated as described in the Appendix.

Equipment operator costs, $(EOC)_j$, for a given road construction operation, j, are then equal to

$$\frac{E_j}{\left(\dfrac{OVC}{n}\right)}(1+x) \cdot w_j = Y'_{E,j} \cdot w_j$$

where w_j = gross hourly or daily wage of an equipment operator for operation j.

The total equipment operator costs, *EOC*, are then equal to

$$\sum_{j=1}^{m} (EOC)_j$$

where m = total number of operations.

It should be noted that the idle time coefficient, x, does not include idle time due to equipment breakdown, work stoppages in order to perform periodic equipment maintenance, and work stoppages due to interference from other operations (i.e. necessary waiting), since these latter idle times are already included in the over-all time, *OVT* (see Chapter 3), and are therefore taken into consideration in the estimation of *OVC*.

ENGINE-POWERED EQUIPMENT

For a given road construction operation j, the cost of engine-powered equipment is equal to

$$(EC)_j = \sum_{k=1}^{m} \left(\frac{E_j}{Z_k}\right) C_k \tag{2}$$

where E_j = value of operation j from the bill of quantities (e.g. so many cubic metres of excavated rock),

Z_k = productivity of the piece of equipment k used in operation j while actually in use (i.e. productivity of the piece of equipment excluding idle time periods [1]), in cubic or square metres per hour,

m = number of types of equipment used in a given operation j, and

C_k = hourly cost or rental rate of the piece of equipment k, excluding the cost of the operator.

The total cost of equipment is then equal to

$$(EC) = \sum_{j=1}^{m} (EC)_j$$

where m = total number of activities involved in a road construction project.

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[1] For example, during purely productive time, excluding the method time allowance (Chapter 3).

The hourly equipment cost, C_k, for a piece of equipment k is equal to the sum of hourly depreciation costs and hourly operating costs. That is,

$$C_k = D_k + C_{vk}$$

The procedure used in this manual for the estimation of the hourly equipment cost may be unfamiliar to many project evaluators, and some may question the usefulness of introducing a new estimation procedure. Some of them may indeed be tempted to reject out of hand the procedure developed here, and to use procedures that are more familiar to them instead. It should be pointed out, however, that current estimation procedures generally tend to understate the true cost of equipment; consequently they create a bias towards the use of capital-intensive methods, and are inappropriate for the evaluation of alternative technologies. In the light of this fact, project evaluators should re-assess the estimation procedure they are currently using, and make any modifications that may be required in order to ensure that equipment costs are not significantly underestimated.

Hourly depreciation costs

Before the method of estimating the hourly depreciation costs, D_k, is described, the concept of present value must be defined and explained for the benefit of readers who are not familiar with that concept. Let it be supposed that one unit of money is invested or put in a bank savings account today. In one year's time, the invested unit of money will yield an interest r. Therefore one unit of money available today may be exchanged for $(1 + r)$ units of money in one year's time. Similarly, one year later they will yield $(1+r).(1+r) = (1 + r)^2$ units of money. Therefore, one unit of money invested today will yield $(1 + r)^2$ units of money two years hence. In general, one unit of money invested today may be exchanged for $(1 + r)^n$ units of money n years later, provided that r remains constant over the whole period. Conversely, one unit of money in one year's time is equivalent to $\dfrac{1}{(1 + r)}$ units of money today. $\dfrac{1}{1 + r}$ is known as the "present value" of one unit of money accruing in one year's time. Let it now be supposed that a capital investment today will yield a flow of net earnings (i.e. revenues minus yearly variable costs) for n consecutive years as follows:

$$R_1, R_2, R_3, \ldots R_n$$

The present value of the stream of net earnings is then equal to R, where

$$R = \frac{R_1}{1+r} + \frac{R_2}{(1+r)^2} + \frac{R_3}{(1+r)^3} + \cdots \frac{R_n}{(1+r)^n}$$

or

$$R = \sum_{t=1}^{n} \frac{R_t}{(1+r)^t} \qquad (3)$$

Let it also be supposed that the foregoing investment requires an initial capital outlay K_0. If K_0 were put in a savings account instead of being invested, it would have yielded revenues in the amount $K_0 (1+r)^n$, n years hence. The present value of $K_0 (1 + r)^n$ is equal to

$$\frac{K_0 (1+r)^n}{(1+r)^n} = K_0$$

Therefore the investment will be worth undertaking only in a case in which R, the present value of net earnings, exceeds or is at least equal to K_0. (In fact the present value of net earnings will in general have to be larger than K_0 since a certain degree of uncertainty makes one unit of future net earnings less attractive to the private investor than one unit of capital at hand.)

The role of the concept of present value in the estimation of equipment hourly depreciation costs, D_k, will now be explained. Let it be supposed that a piece of equipment has a useful life of n years. That life may be calculated from the relationship

$$n = \frac{H_t}{H_e} \qquad (4)$$

where H_t = total number of hours during which the equipment may be used before it is scrapped, and

H_e = equipment annual utilisation rate (e.g. 1,000 hours per year, 2,000 hours per year).

Let it be supposed that the purchase price of a piece of equipment k is K_0, and that its salvage value at the end of its useful life (i.e. n years) is S_e. The owner of such a piece of equipment will be willing to rent it out as long as the sum of the present value of the stream of yearly rental rates, A_k, and of the salvage value, S_e, is equal to K_0, i.e.

$$K_0 = \frac{A_k}{1+r} + \frac{A_k}{(1+r)^2} + \frac{A_k}{(1+r)^3} + \cdots \frac{A_k}{(1+r)^n} + \frac{S_e}{(1+r)^n} \qquad (5)$$

or

$$K_0 = \sum_{t=1}^{n} \frac{A_k}{(1+r)^t} + \frac{S_e}{(1+r)^n} \qquad (6)$$

where r = market rate of interest.

A_k may also be defined as the yearly depreciation rate. In the foregoing formulation A_k is assumed to be constant over the life of the piece of equipment. It may be noted that such an assumption is not a realistic one since the yearly rent should decrease as the piece of equipment gets older. However, such an assumption is usually made since it would be extremely difficult to estimate the true depreciation rate for each consecutive year.[1]

Now equation (6) may be rewritten as follows:

$$K_0 = A_k \left[\sum_{t=1}^{n} \frac{1}{(1+r)^t} \right] + \frac{S_e}{(1+r)^n} \tag{7}$$

It can be shown [2] that

$$\sum_{t=1}^{n} \frac{1}{(1+r)^t} = \frac{(1+r)^n - 1}{r(1+r)^n}$$

Therefore,

$$K_0 = A_k \left[\frac{(1+r)^n - 1}{r(1+r)^n} \right] + \frac{S_e}{(1+r)^n} \tag{8}$$

A_k, the equipment annual depreciation cost, is then

$$A_k = \frac{\left[K_0 - \dfrac{S_e}{(1+r)^n} \right]}{\left[\dfrac{(1+r)^n - 1}{r(1+r)^n} \right]}$$

or

$$A_k = K_0 \left[\frac{r(1+r)^n}{(1+r)^n - 1} \right] - S_e \frac{r}{(1+r)^n - 1} \tag{9}$$

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[1] For a detailed discussion of equipment depreciation costs see McCleary *et al.*: *Equipment versus employment*, op. cit., Appendix 2.

[2] If $B = \dfrac{1}{1+r} + \dfrac{1}{(1+r)^2} + \cdots \dfrac{1}{(1+r)^n}$

and $\dfrac{B}{(1+r)} = \dfrac{1}{(1+r)^2} + \dfrac{1}{(1+r)^3} + \cdots \dfrac{1}{(1+r)^n} + \dfrac{1}{(1+r)^{n+1}}$

then $B \left[1 - \dfrac{1}{1+r} \right] = B \left[\dfrac{r}{1+r} \right] = \dfrac{1}{1+r} - \dfrac{1}{(1+r)^{n+1}} = \dfrac{(1+r)^n - 1}{(1+r)^{n+1}}$

and then $B = \dfrac{\left[\dfrac{(1+r)^{n-1}}{(1+r)^{n+1}} \right]}{\dfrac{r}{(1+r)}} = \dfrac{(1+r)^n - 1}{r(1+r)^n}$.

To take a numerical example, suppose that $K_0 = \$20{,}000$; $r = 0.15$; $S_e = \$2{,}000$; and $n = 10$ years; then

$$A_k = 20{,}000 \left[\frac{0.15\,(1+0.15)^{10}}{(1+0.15)^{10}-1} \right] - 2{,}000 \left[\frac{0.15}{(1+0.15)^{10}-1} \right]$$

$$= 20{,}000 \left[\frac{0.15\,(4.046)}{(4.046)-1} \right] - 2{,}000 \left[\frac{0.15}{4.046-1} \right] = \$3{,}887.$$

It is important to recognise that serious errors would result if one were to divide the portion of the price of the equipment which is depreciated ($18,000, i.e. $20,000 — $2,000) by the life of the equipment, 10 years, in order to obtain the annual depreciation costs. This procedure would provide depreciation costs of $1,800 a year (i.e. $18,000 ÷ 10), a substantial underestimate of the true annual depreciation costs. The divergence between $3,887 and $1,800 is due to the fact that the latter estimate is based on the assumption that the interest rate is equal to zero, i.e.

$$K_0 = \frac{A_k}{(1+0)^1} + \frac{A_k}{(1+0)^2} + \cdots + \frac{A_k}{(1+0)^{10}} + \frac{S_e}{(1+0)^{10}} = 10(A_k) + S_e$$

Given that $K_0 = \$20{,}000$ and $S_e = \$2{,}000$, we obtain

$$\$20{,}000 = 10\,(A_k) + \$2{,}000$$

and

$$A_k = \frac{\$20{,}000 - \$2{,}000}{10} = \$1{,}800.$$

Obviously, such an assumption is not tenable in any circumstances; therefore the procedure must not be used when estimating annual equipment depreciation costs.

Given the annual depreciation costs, A_k, the hourly depreciation costs are then

$$D_k = \frac{A_k}{H_e} = \frac{K_0}{H_e} \left[\frac{r(1+r)^n}{(1+r)^r - 1} \right] - \frac{S_e}{H_e} \left[\frac{r}{(1+r)^n - 1} \right] \tag{10}$$

Ways of estimating the various items in equation (10) will now be described. It was shown earlier that

$$n = \frac{H_t}{H_e}$$

where H_t = the life of the piece of equipment; and

H_e = the yearly utilisation rate.

An estimate of H_t may be obtained from the equipment manufacturer's catalogue, but such an estimate may be not very reliable: manufacturers tend to overstate the useful life of a piece of equipment, and their estimates are generally based on conditions (e.g. environmental conditions, equipment operators' performance, availability of maintenance and repair facilities) that are characteristic of the country where the piece of equipment is manufactured. It is therefore recommended that H_t should be estimated on the basis of an analysis of the log books of pieces of equipment that have come to the end of their useful life, spent entirely in the country where the road is to be built, or in a similar country.

The average annual utilisation rate of equipment, H_e, may also be estimated on the basis of an analysis of individual equipment log books. Usually, equipment log books record the number of hours during which a piece of equipment has actually been in operation. This information may then be used in order to estimate H_e for each type of equipment k. ("Type of equipment" is defined here as equipment capable of performing a very specific set of operations. Pieces of equipment of various makes or models may constitute a single equipment type.) The estimation of H_e may be carried out in the following steps. First, as many individual equipment log books as possible should be obtained for each type of equipment. Log books of salvaged pieces of equipment may be used along with log books of pieces of equipment still in use. The number of years, n_k, for which each piece of equipment, k, of a given type has been in use since the equipment purchase date if the piece of equipment is still in operation, or for which the piece of equipment has been in existence even if it is no longer in use, should then be noted. Thirdly, for each piece of equipment the number of hours, h_k, during which the piece of equipment has actually been used should also be noted.

The average annual utilisation rate of each type of equipment is then equal to

$$H_e = \frac{\sum\limits_{k=1}^{e} \dfrac{h_k}{n_k}}{e}$$

where e = number of pieces of equipment of the same type included in the analysis.

It should be noted that the procedure just described for estimating H_e ensures that all equipment idle time periods, whether the piece of equipment is idle while on a project or between two consecutive projects, are taken into consideration in the formulation of the hourly rental rate, C_k. Given estimates of H_t and H_e, one can then estimate n.

The original price of the piece of equipment, K_0, should include the following items:

(a) the sale price of locally produced equipment or the c.i.f. price of imported equipment;

(b) customs duty, if any; and

(c) miscellaneous charges (handling charges, including inland transport of equipment, and administrative charges, if any).

Estimates of these items may be obtained from local importers, foreign or local manufacturers, and the port authority or other agencies of government.

The salvage value of the piece of equipment, S_e, is a function of demand conditions. Scrapped pieces of equipment may be sold locally, or exported if there are no local plants for the processing of such materials. Revenue from the sale of a scrapped piece of equipment, k, is then equal to

$$S_e = Q_k \cdot P_k$$

where P_k = price of a ton of scrapped equipment, and

Q_k = weight of the piece of equipment, in tons.

In some cases S_e can also be estimated as a fraction of the capital cost of equipment K_0. Such a fraction may vary between 0.05 and 0.15 depending on the condition of the piece of equipment when it is sold.

Operating costs

Equipment operating costs, C_{vk}, include the following cost items:

R_e, the yearly maintenance and repair costs of the piece of equipment,

I_e, the yearly insurance costs,

T_y, the cost of tyres or tracks changed during the equipment's lifetime, and

F_u, the hourly fuel and lubricant costs.

Given an equipment life of n years, and an equipment annual utilisation rate of H_e, the hourly equipment operating costs can be obtained from the following relationship:

$$C_{vk} = \frac{R_e}{H_e} + \frac{I_e}{H_e} + \frac{T_y}{n.H_e} + F_u \tag{11}$$

It should be pointed out that C_{vk} does not include operators' costs, such costs being estimated separately. The formulation of C_{vk} in equation (11) assumes that the annual costs of all items are constant over the equipment life, but in

reality the older the piece of equipment, the higher repair costs tend to be, and tyres or tracks are not changed every year. Consequently, the hourly costs of these items are not strictly equal to $\dfrac{R_e}{H_e} + \dfrac{T_y}{n \cdot H_e}$. An estimation of these cost items which takes into consideration their variability over time should not, however, yield significantly different results. Furthermore, the data needed in order to undertake such an estimation are usually either lacking or very unreliable. In view of these facts it is recommended that C_{vk} should nevertheless be estimated on the basis of equation (11). The estimation of the individual elements of operating costs is described below.

Maintenance and repair

Yearly maintenance and repair costs (R_e) consist of four components: labour cost, materials costs, cost of spare parts and overhead costs. Estimates of these costs may be obtained from the following sources in ways that will be described in the following paragraphs:

(a) equipment maintenance and repair manuals;

(b) equipment maintenance and repair log books; and

(c) the expenditure of the equipment repair and maintenance workshops of the public works department.

Equipment maintenance and repair manuals provide a description of the maintenance and repair jobs that are required. In some cases, they also provide yearly maintenance and repair costs as a percentage of the original equipment price. Estimates based on data provided by manufacturers may not, however, be accurate since they reflect conditions in industrialised countries. In particular, wages of mechanics in developing countries may be lower than those in industrialised countries, whereas the frequency of repair and maintenance may be higher in the former countries than in the latter. Manufacturers' data may need to be adjusted in order to reflect conditions in the utiliser's country.

An analysis of equipment maintenance and repair log books usually provides a good estimate of repair and maintenance costs, provided that the data reported in log books are fairly detailed. Whenever feasible, a number of log books referring to the same type of equipment should be examined, so that the cost estimates may represent average values based on a large number of observations.

Estimates of yearly repair and maintenance costs per ton of equipment can be obtained by dividing yearly expenditures of the workshops of the public works department by the total number of tons of equipment processed during a one-year period. This procedure may be used only in cases where the department's workshops operate on a separate budget or under a separate accounting

system. The adoption of this third estimation method requires, for a given one-year period, the following information:

(a) number of pieces of equipment that underwent repair and maintenance, as well as the weight of each such piece;

(b) total cost of spare parts actually used on repair jobs (a yearly inventory of spare parts may be needed in order to obtain this type of information);

(c) total cost of materials used for repair and maintenance jobs;

(d) total amount of wages paid to the personnel of the workshop; and

(e) building and tools depreciation costs.

The yearly repair and maintenance costs per ton of equipment is then

$$R_e = \frac{SP + MA + DE + WM}{\sum_{k=1}^{e} Q_k} \tag{12}$$

where SP = cost of spare parts,

MA = cost of materials,

DE = building and tools depreciation costs,

WM = total amount of wages,

e = number of pieces of equipment processed over a one-year period, and

Q_k = weight of equipment, k, in tons.

The yearly maintenance and repair costs of a given piece of equipment k is

$$R_{ek} = R_e \cdot Q_k$$

This third estimation method provides less accurate estimates of equipment repair and maintenance costs than the second method since costs are not strictly a function of equipment weight. It is therefore advisable to use the second method of evaluation whenever equipment log books are available. The first or third methods should be regarded as stop-gap methods for use while equipment log books are being developed.

Insurance

Yearly insurance costs (I_e) vary with the type of construction equipment. In general they are very low for pieces of equipment other than trucks and cars, whereas insurance costs for the latter items may be high and should be taken into consideration when estimating equipment rental rates. Insurance cost estimates can be obtained without difficulty from insurance companies.

Tyres or tracks

Tyre or track costs over the equipment life time (T_y) are as follows:

$$T_y = S_t . P_t$$

where S_t = number of sets of tyres or tracks that are needed over the lifetime of the equipment, and

P_t = price of a set of tyres or tracks.

The estimation of P_t should cover the same items as are used in the estimation of K_0. S_t is a function of the life of tyres or tracks. Estimates for tyres or track lives may be obtained from equipment log books or on the basis of interviews with equipment operators.

Fuel and lubricants

A general formulation for fuel and lubricant costs is given by

$$F_u = \sum_{j=1}^{4} P_{fi} . Q_{fi}$$

where P_{fi} = unit price of fuel or lubricant of type i,

Q_{fi} = quantity of fuel or lubricant of type i per hour, in litres or kilograms per hour, and

i = type of fuel or lubricant (1 for diesel oil, 2 for petrol, 3 for lubricating oil, 4 for grease).

Unit prices for each type of fuel or lubricant are usually readily available. These prices should, however, be adjusted to take account of site conditions; in particular, the unit cost of transport of these products to project sites should be added to the unit price prevailing at the nearest public or government-operated filling stations.

The average hourly fuel and lubricant consumption of individual pieces of equipment is best estimated from data recorded over a long period of working hours. If such records are not available, project evaluators may use data provided by equipment manufacturers. Such data generally apply to new pieces of equipment and average to favourable site conditions. Thus, data obtained from manufacturers' handbooks may need to be adjusted in order to reflect site conditions and an average equipment age.

Hourly equipment costs

Given D_k and C_{vk}, the hourly equipment costs, C_k, may then be obtained from the following relationship:

$$C_k = D_k + C_{vk} = \frac{K_0}{H_e}\left[\frac{r(1+r)^n}{(1+r)^n - 1}\right] - \frac{S_e}{H_e}\left[\frac{r}{(1+r)^n - 1}\right] + \frac{R_e}{H_e} + \frac{I_e}{H_e} + \frac{T_y}{n.H_e} + F_u$$

(13)

This relationship could be adjusted in order to take into consideration variations in depreciation costs, D_k, repair costs, R_e, tyre costs, T_y, and fuel costs, F_u. It is doubtful, however, whether such adjustments will provide estimates of C_k significantly different from those obtained from equation (13). Furthermore, such adjustments will be warranted only if detailed and accurate information on depreciation costs, repair costs, and tyres and fuel costs is available. In general, such detailed information is very difficult to obtain, and most public works departments may be forced to use the formulation of C_k provided in equation (13).

ANIMAL-POWERED EQUIPMENT

Animal-powered equipment includes various types of carts, ploughs, water bowsers and scrapers that are drawn by animals. Such equipment may belong to the public works department or may instead be rented from local farmers who are employed on the project for wages on the understanding that they bring their equipment with them. Procedures for the estimation of animal-powered equipment should accordingly be worked out according to its ownership, on the assumption that if equipment is owned by a farmer he will operate it but that if it is owned by the public works department or a building contractor it will be operated by unskilled labour hired on the project site.

It is unusual for the department itself to own animal-powered equipment. However, if labour-intensive techniques are increasingly adopted, the department may find it advantageous to acquire its own animal-powered equipment for the following reasons:

(1) Animal-powered equipment owned by local farmers may not be available during agricultural peak seasons, and this may lead to delays in construction.

(2) The department may need to design and produce special pieces of animal-drawn equipment to be used in road construction. In that event it may be advantageous in the interests of full utilisation of the equipment to have always available, and hence own, the most appropriate type and breed of animal as well, instead of using the beasts of the local farmers.

(3) The number of pieces of animal-powered equipment owned by local farmers may be lower than the number needed for road construction.

(4) The hourly cost of rented equipment may be higher than the hourly cost of the same piece of equipment if it were produced by the department.

On the other hand, the owning of animal-powered equipment may be disadvantageous for the public works department or a contractor for the following reasons:

(1) Since equipment drivers are often unskilled workers hired near the project site, they may not be familiar with the driving of animal-powered equipment, and may need to be trained. At first the productivity of these workers may be low.

(2) The transport of animal-powered equipment from the regional depots of the public works department to project sites may be costly and time-consuming.

(3) Shelters for the animals must be built on the project sites. Such shelters would not be needed if the animals belonged to local farmers and were taken back to their farms at the end of the day.

(4) Although the market price of animal-powered equipment rented from farmers in return for part of their wages may be higher than that of equipment owned and operated by the road-building agency (whether it be a public works department or a contractor), the shadow price (i.e. true social price) of rented equipment may be lower than that of equipment which the agency owns. This will be so whenever animal-powered equipment owned by local farmers is found to be lying idle during the agricultural slack seasons.

The project evaluator should compare the advantages and disadvantages of ownership versus rental of animal-powered equipment in order to identify the alternative that is socially more profitable.

Animal-powered equipment costs may be estimated from the following relationship:

$$(APEC)_j = \sum_{k=1}^{a} \frac{A_j}{V_k} P_k$$

where $(APEC)_j$ = costs of animal-powered equipment for operation j,

A_j = number of units of output included in operation j (e.g. E cubic metres of hauled earth),

a = number of types of animal-powered equipment that are used in operation j (a is often equal to 1),

V_k = productivity in cubic or square metres per hour of animal-powered equipment of type k used in operation j [1], and

P_k = hourly cost of animal-powered equipment of type k.

The estimation procedure for P_k varies with the type of equipment ownership. The remaining part of this section will show how to estimate P_k when animal-powered equipment is rented from local farmers and when it is owned by the public works department.

Rented

If animal-powered equipment is rented from and operated by local farmers employed on the project for wages, the rental cost for equipment may be assumed to be equal to the difference between the farmer's wage (which includes the cost of renting the animal and the equipment) and the unskilled labour wage. The hourly cost may therefore be estimated with the help of a survey of the daily wages asked by the farmers. Such a survey should also provide information with respect to the availability, types and number of items of animal-powered equipment in various areas at various periods of the year. Such information is vital in order to determine if such equipment is locally available in sufficient quantities and in order to schedule the road construction properly.

Owned by the public works department

The hourly cost of animal-powered equipment owned by the public works department must cover the following cost items:

(a) capital expenditures on animal-powered equipment; and

(b) maintenance of animals and equipment.

The acquisition of animal-powered equipment (item *(a)*) should be regarded as capital expenditure since the life of such equipment probably exceeds five to six years. Cost item *(a)* should therefore be calculated accordingly. The following definitions will be used in the ensuing analysis:

n = number of years of active life of a given farm animal used in road construction,

P_a = original purchase cost of the animal,

r = rate of interest,

S_a = sale value of the animal when it ceases to be productive (i.e. at the end of n years),

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[1] V_k is actually the method capacity (Chapter 3).

H_a = number of hours a year during which the animal-powered equipment is actually used on construction work,

P_e = original cost of the equipment itself,

M_e = annual maintenance and repair costs of the equipment, and

C_f = daily feeding and maintenance costs per animal.

Transport costs of animal-powered equipment to the project site and the cost of animal shelter construction have already been dealt with in the section of this chapter relating to set-up and overhead costs. It is assumed that equipment has a life of n years.[1]

The formulation of P_k may be derived in the same way as the one used to arrive at C_k, the hourly cost of engine-powered equipment. In other words, the hourly cost of animal-powered equipment is equal to the hourly depreciation costs of animal and equipment plus the hourly operating costs, or:

$$P_k = D_a + C'_v.$$

The formulation of D_a is basically the same as that of D_e. If

$$P_0 = P_a + P_e$$

then
$$D_a = \frac{P_0}{H_a} \cdot \frac{r(1+r)^n}{(1+r)^n - 1} - \frac{S_a}{H_a} \cdot \frac{r}{(1+r)^n - 1}. \tag{14}$$

Similarly the formulation of C'_v is given by

$$C'_v = \frac{M_e}{H_a} + \frac{C_f . 365}{H_a}. \tag{15}$$

Then
$$P_k = D_a + C'_v = \frac{P_0}{H_a} \cdot \frac{r(1+r)^n}{(1+r)^n - 1} - \frac{S_a}{H_a} \cdot \frac{r}{(1+r)^n - 1} + \frac{M_e}{H_a} + \frac{C_f . 365}{H_a} \tag{16}$$

In order to calculate P_k it is necessary to have estimates of M_e, C_f, w, P_a, P_e, S_a, H_a and n.

Estimates of P_a and S_a should be fairly easy to obtain, P_a from a survey of market prices of farm animals and S_a from local stockyards. C_f includes the cost of feed per animal and a fraction of the daily wages of the workers in charge of the feeding and care of the animals. Therefore

$$C_f = p_f . Q_f + \frac{w}{N_a}$$

where p_f = unit price of feed,

Q_f = daily quantity of feed per animal, and

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[1] This assumption is made in order to simplify the formulation of the hourly cost of animal-powered equipment. It may be dropped in case of need.

N_a = number of animals that are taken care of by a single worker receiving a daily wage w.

P_e is equal to the production costs of the piece of equipment if it is manufactured by the public works department itself, or its purchase price if it is produced by local manufacturers. If information on the maintenance costs of equipment is not available, M_e may be assumed to be equal to some proportion of P_e (say 10 or 15 per cent). It is advisable, however, that such data be collected in order to obtain reliable estimates of M_e for future projects.

Interviews with local farmers can easily provide information on n, the working life of the farm animal.

If a piece of animal-powered equipment is being fully used, H_a is equal to $T(365-H_0)$, where T is the number of working hours per day and H_0 the number of non-working days per year (i.e. the weekly day of rest plus other public holidays). The value of H_a obtained from this relationship may, however, be overestimated because animal-powered equipment may remain idle in case of bad weather, while being transported to the project site, or when not in use between two consecutive projects. These idle times should be estimated and H_a adjusted accordingly.

TOOLS

Whereas the cost of road construction tools such as picks, shovels and wheelbarrows accounts for a negligible proportion of the total costs of capital-intensive techniques, their proportion of the total costs of labour-intensive techniques is considerable. A discrepancy between estimated tool costs and true tool costs will therefore have a much greater effect on the total costs of labour-intensive techniques than on those of capital-intensive ones. Overestimation or underestimation of the cost of tools can introduce a serious bias against or in favour of labour-intensive techniques. When comparing labour-intensive techniques with capital-intensive ones it is therefore important to obtain a reliable estimate of tool costs.

For a given activity j, tool costs may be obtained from the following relationship:

$$(TO.C)_j = \sum_{k=1}^{t} N_k . P_k$$

where t = number of types of tools needed for operation j,

  N_k = number of tools of type k used in operation j, and

  P_k = price of a tool of type k.

The total cost of tools for the road project may then be obtained by summing up the tool costs for all operations.

N_k may be estimated on the basis of the duration of operation j, and the average life of a tool of type k, which may be obtained from field engineers. The duration of activity j may be estimated on the basis of the bill of quantities and the average productivity of unskilled labour.

If Z_{jk} = productivity of unskilled labour in operation j using tools of type k, in units of output per hour [1],

    A_{jk} = output of operation j with tools of type k (e.g. so many cubic metres of earth excavated with picks),

    L_k = life of tools of type k, in working days, and

    T = number of working hours per working day,

then
$$N_k = \frac{A_{jk}}{Z_{jk}.L_k.T}$$

It may be noted that estimates of N_k obtained from this relationship should be adjusted upwards in order to allow for tool losses. The adjustment coefficient may be determined on the basis of interviews with the personnel responsible for distributing tools to the workers.

The price of tools (P_k) may be obtained from local manufacturers, or from tool-importing firms if tools are not produced locally. In the latter case, quoted prices should include customs duties and all relevant fees. It should be noted that tools are not regarded as fixed capital, and therefore the estimation of tool costs does not take tool utilisation rates and interest rates into consideration. The reason is that, in contrast to powered construction equipment, tools have relatively short lives which vary between five weeks and six months; they are therefore regarded as construction materials and their cost estimated accordingly. It may also be noted that tools may be repaired during their lifetime; repair costs should therefore be estimated and added to the tool purchase costs.

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[1] Of purely productive time as defined in Chapter 3, i.e. excluding method time allowance.

MAINTENANCE COSTS, USERS' COSTS AND INDIRECT BENEFITS

6

A method of estimating the construction costs of a road project was described in the previous chapter. The present chapter deals with maintenance costs and indirect costs and benefits [1], and explains in particular how some of them can be estimated.

When a new road is built or an existing road improved, three different effects may be expected:

(a) a redistribution of traffic flows between existing roads and the new road, and the generation of new traffic flows;

(b) a transformation of the production structure of the area crossed by the road; and

(c) social consequences linked to increased access to public facilities by the people in the area crossed by the road.

The importance of these effects depends on the type of road project: in some cases, they may have so little influence on the over-all profitability of the project that they may be safely neglected in project evaluation. Each of these effects may be translated into terms of indirect costs and benefits, as shown in table 11.

While the direct, initial road construction costs may be regarded as the fixed capital costs of a road project, the future costs (i.e. the road users' costs and the road maintenance costs) may be regarded as variable costs, largely because they are a function of the use that is made of the road (i.e. of the composition and level of traffic flows). In this respect, therefore, investment in a road may be assessed like an industrial investment involving both capital and variable costs.

To take the three effects in turn, the redistribution and generation of traffic flows resulting from the new road project leads to additional variable costs—

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[1] Direct benefits (e.g. revenue from road tolls) will not be considered since they rarely occur in developing countries.

Table 11. Maintenance costs and indirect costs and benefits of road projects

Effect	Maintenance costs and indirect costs	Maintenance costs forgone and indirect benefits
Redistribution and generation of traffic flows	Maintenance costs of new road: $(MC)_N$ Road users' costs of diverted traffic using the new road $(RUC)_{DN}$ Road users' costs from newly generated traffic $(RUC)_N$	Lower maintenance costs of roads from which traffic is diverted: $(\Delta MC)_E$ Road users' costs of diverted traffic before the new road comes into use: $(RUC)_{DE}$
Transformation of the production structure	Present value of additional production costs: $(DEV)_C$	Present value of the increase of regional output: $(DEV)_B$
Social consequences	Present value of the increase of government expenditures on public facilities such as schools, health centres, and vocational centres: $(GE)_C$	Utility derived from the use of nearby educational, recreational and health facilities: $(GE)_B$

$(MC)_N + (RUC)_{DN} + (RUC)_N$—but decreases past variable costs—$(\Delta MC)_E + (RUC)_{DE}$. The latter, forgone costs may be regarded as benefits of the project. Subsequent sections of this chapter will be devoted to explaining how to estimate road users' costs and maintenance costs in order to obtain estimates of increases and decreases in variable costs. Secondly, some road projects may result in a transformation of the production structure of the area crossed by the road. This transformation may provide net indirect benefits in the amount $(DEV)_B - (DEV)_C$, that is the difference between the value of the increase in output resulting from the road project and the production costs attached to the same increase in output. It may not always be possible to isolate the effect of a road project on output in the area since changes in output may be in part the result of other concurrent investments. This problem will be dealt with later in this chapter. Thirdly, a road project may have various social consequences linked to increased access to public facilities by the people in the area crossed by the road. In general, the associated indirect benefits are not quantifiable: for example, no specific value can be assigned to the benefits derived by people in the area from being able to use nearby educational, health or recreational facilities. In other words, there is usually no market mechanism that helps to quantify $(GE)_B$. On the other hand $(GE)_C$ usually is quantifiable, since it is possible to estimate the additional costs attached to the increased

use of public facilities or to the creation of new facilities as a result of the road project.

The present chapter will focus on the first effect, and provide only a very general methodological framework for the evaluation of developmental benefits due to the second and third effects.[1] The reason for this focus is that in general, when it comes to choosing among different possible construction technologies, effects *(b)* and *(c)* may be safely neglected since their value is not usually a function of the type of technology used (see Chapter 1).

As has also been indicated in Chapter 2 of this manual, labour-intensive technologies are, given the present state of knowledge, recommended mainly for low-standard roads such as those made of stabilised earth or gravel. At first sight it might appear that the design of such roads is essentially predetermined. In most cases the project evaluator would accordingly have to make a choice not among a series of particular combinations of design and technology but purely among a number of construction technologies. If only one design is under consideration, road maintenance costs, road users' costs and road-induced benefits need not be taken into account for the choice of technology.[2] There are, however, many cases in which even a low-standard road can be built to a variety of possible designs. Since the design affects the range of technologies that can be used, it is important in such cases to take into account all the costs and benefits that may be affected by each design under consideration.

TRADE-OFF BETWEEN INITIAL AND FUTURE COSTS

It was shown in Chapter 1 that a project evaluator must identify the most socially profitable design and technology version of each potential road project since that is the version that needs to be ranked for project selection purposes.

Let it be assumed for the moment that the design and technology possibilities for a given road project differ only with respect to construction costs and the costs associated with the redistribution and generation of traffic flows (i.e. effect *(a)* already referred to). In other words, the possibilities differ only with respect to construction costs, maintenance costs and road users' costs. In this

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[1] The reader may obtain additional information on the second and third effects from Arnold C. Harberger: *Project evaluation*, Collected papers (Chicago, Markham Publishing Co., n.d.), Ch. 6; Lionel Odier: *Les intérêts économiques des travaux routiers* (Paris, Editions Eyrolles, 1963), Part II; and Herman S. van der Jak and Jan de Weille: *Reappraisal of a road project in Iran* (Baltimore, Johns Hopkins Press, 1969), Ch. VII.

[2] However, these additional costs and benefits should always be taken into consideration when the over-all profitability of a road project is estimated.

case the most profitable version of the project is the one that gives the lowest total for the three costs referred to above.

As shown in Chapter 2, road construction costs are a function of road design and road construction technology.

Road maintenance costs are partly a function of the following road design variables:

(a) length and width;

(b) composition and thickness of the pavement; and

(c) strength of the subgrade.

Variable *(a)* determines the total area of road to be maintained. Variables *(b)* and *(c)* affect the rate of road deterioration and thus partly determine the frequency and extent of maintenance operations (i.e. the maintenance policy). The rate of road deterioration is also affected by environmental conditions (e.g. climate, vegetation, topography) and the volume and composition of traffic flows.

Road users' costs are partly a function of the following road design variables:

(a) length and width;

(b) vertical and horizontal alignment;

(c) road surface condition (e.g. roughness, rut depth, looseness of materials).

Road users' costs are also a function of non-design variables (variables such as actual vehicle speed—as distinct from the road design speed—vehicle type and size, altitude and rainfall, traffic volume and composition, the driver's behaviour and road maintenance policy). Together these non-design variables and the three design variables determine road users' costs, which can be broken down as consisting in vehicle operating costs and the value of the vehicle occupants' time.

In short, road design affects road construction costs with respect to the quantity and quality of output as well as with respect to the constraint it puts on the range of construction technologies that may be used: in general, as the specified road quality standard improves, the construction costs increase and the range of technically feasible construction technologies narrows; it may not be possible to use labour-intensive technologies for the construction of high-standard roads. Road design also affects road maintenance costs and road users' costs: in general, as the specified road quality standard improves, maintenance costs and road users' costs are lowered.

It may therefore be concluded that there is a trade-off between the initial, road construction costs, on the one hand, and the sum of future costs—road maintenance costs and road users' costs—on the other. The task of the project evaluator is to choose a road design that will reduce to a minimum the sum

of initial and future costs. Since the choice of road design is as important as the choice of construction technology, the project evaluator should investigate the possibility of using different road designs.

A method of estimating road maintenance costs and road users' costs for the evaluation of different road designs will now be described. Indications on the way to estimate indirect road benefits will also be given. Unlike indirect costs, indirect benefits are rarely affected by road design.

MAINTENANCE COSTS

As indicated in the previous section, maintenance costs are a function of the rate of road deterioration, the maintenance policy and the maintenance technology. The relationship between maintenance costs and the above-mentioned variables is analysed in greater detail in the present section.

Maintenance policy

There is to some extent a trade-off between maintenance costs and road users' costs: in general, the lower the maintenance costs the higher the road users' costs. Ideally, the maintenance policy adopted should be one that reduces the sum of maintenance costs and road users' costs, and therefore social costs, to a minimum.

There are, however, two reasons for the fact that the maintenance policy adopted is often not the optimal one. First, it is empirically difficult to determine what the optimal maintenance policy is. Secondly, vehicle operating costs are borne by road users, whereas the road maintenance costs are borne by the public works department. The department's decisions on road maintenance are often based solely on road maintenance costs: road maintenance expenditure is compared with investment needs for new road projects, without taking account of road users' costs. In such circumstances the frequency and extent of road maintenance operations are often based on predetermined levels of road deterioration and on the importance of the road in terms of the type and volume of traffic it carries.

The present value of costs over the life of the road is affected by the length of the time intervals between consecutive maintenance operations, and the cost of each successive maintenance operation, $(MC)_i$. The longer the time intervals, the lower the total number of maintenance operations over the life of the road, and the higher the cost of each consecutive maintenance operation. The estimation of maintenance costs is carried out by summing consecutive values of $(MC)_i$ for a given maintenance strategy. If the goal of the public

works department is to reduce social costs to a minimum it is necessary to determine the optimal maintenance policy, which will reduce to a minimum the sum of maintenance costs and road users' costs.

Road deterioration rates

Road deterioration may take many forms, including an increase in surface roughness, the formation of ruts and pot-holes, road cracking, and a loosening or loss of surface material. Some aspects of road deterioration apply to all types of roads, while others apply only to particular types: for example the loosening and loss of surface material applies primarily to unpaved roads.

As already indicated, road deterioration is a function of environmental conditions (notably climate, vegetation and topography), road design (including road surface and subgrade), and the type and volume of traffic flows. For a given set of environmental conditions and a given road design, it is necessary to estimate levels of road deterioration and to translate these levels into maintenance costs.

The following is a general functional relationship which relates road deterioration to time and to cumulative traffic flows:

$$RD = f(T, CTF)$$

where RD = measure of road deterioration,
      T = time, in months or years, and
   CTF = cumulative traffic flow.

The time variable is included in the above relationship since roads deteriorate even in the absence of traffic flows as a result of the blocking of drains and the growth of vegetation, not to mention the possibility of severely adverse climatic conditions, landslides or natural disasters.

Specific functional forms of the above relationship have been derived mainly for pavements of a high standard in North America, Europe and Australia. Some attempts have been made to derive specific functional forms for roads of a lower standard in developing countries. Altogether, however, little is known about the rates at which roads deteriorate, and the results of the few existing studies [1] cannot be applied to all countries and types of roads. In

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[1] Certain road deterioration relationships have been calculated for a number of roads in Kenya. The study was conducted jointly by the World Bank and the Transport and Road Research Laboratory of the United Kingdom, in co-operation with the Kenya Ministry of Works. The study constitutes one of the very few attempts to estimate road deterioration relationships in developing countries. See International Bank for Reconstruction and Development, Transportation and Urban Projects Department, Transport Research Division: *Highway Design Standard Study Phase II: Background, summary and evaluation of TRRL/IBRD Kenya Study* (mimeographed draft, 1975), subsequently cited as IBRD *Highway Design Standard Study.*

particular, there is very little information with respect to gravel and earth roads. Generally the public works department will have to undertake studies in order to estimate road deterioration relationships for various environmental conditions and road design characteristics.

Road deterioration relationships may be established on the basis of cross-sectional analyses and experimental studies. Cross-sectional analyses may provide reliable estimates of the rate of road deterioration as a function of time and cumulative traffic flows, as well as of design and environmental variables. The first step in such an analysis is to identify the range of environmental conditions, road type and design characteristics to be investigated. The next step is to select a sample of road sections that are representative of each combination of environmental and design variables under study. For each road section included in the sample, information must be obtained with respect to—

(a) the time interval since the last maintenance operation;

(b) the cumulative traffic flows since the last maintenance operation; and

(c) the current level of deterioration of the road.

T e results of the cross-sectional analyses will indicate how the rate of road deterioration varies as a function of time and cumulative traffic flows, for each combination of environment and design that has been examined.

Road deterioration relationships may also be obtained from experimental studies. In this case, specified flows of vehicles are driven over road sections that are representative of the environmental conditions and design characteristics to be investigated. At selected time intervals, measurements are made of the level of deterioration of the road sections. In an experimental study the intervals of observation and the traffic flows are under the control of the researcher, and much more accurate estimates of deterioration rates can be obtained than in cross-sectional analyses. For gravel and earth roads, results may be fairly rapidly obtained from an experimental study. For paved roads, on the other hand, deterioration occurs at such a slow rate that experimental studies may not be a practical possibility.

Estimation of maintenance costs

A reliable way of estimating maintenance costs of a potential road project would be to express road deterioration in terms of the specific maintenance operations required to remedy it, and to cost such operations in the same way as for road construction. For example, looseness of materials and gravel loss could be expressed in terms of blading frequencies to be applied to gravel roads of different designs with given traffic flows. Subsequently, each blading operation

Table 12. Annual maintenance cost formulae in US dollars per kilometre

Type of road	Formulae	Continent or country
Earth	270 + (5.3 ADT)	Congo [2]
	344 + (12 ADT)	Venezuela [3]
Gravel [1]	254 + (6.6 ADT)	Africa [4]
	87.5 + (3.5 ADT)	Africa [4]
	200 + (10 ADT)	Chad [4]
	89 + (3.5 ADT)	Dahomey [4]
	168 + (2.4 ADT)	Kenya [5]
	90 + (3.5 ADT)	Nigeria [4]
	300 + (6.5 ADT)	Nigeria [4]
	262.5 + (1.75 ADT)	Nigeria (North) [4]
	142 + (2.5 ADT)	Swaziland [4]
	372.5 + (5.2 ADT)	Tanzania [4]
	372.5 + (6.9 ADT)	Tanzania [4]
	159 + (4.3 ADT)	Togo [4]
	175 + (5.5 ADT)	Zambia [4]
	1 150 + (4.0 ADT)	Venezuela [3]
Paved	520 + (0.48 ADT)	El Salvador [2]
	1 219 + (0.37 ADT)	Nicaragua [2]
	331 + (0.5 (ADT — 1,000))	Niger [4]
	2 313 + (0.225 ADT)	Venezuela [3]

[1] Because it is often difficult to draw a distinct line between gravel and earth roads, some of these formulae may apply to what are described in the present manual as earth roads. [2] Anthony Churchill, in collaboration with Klaus Huber, Elke Meldau and Alan Walters: *Road user charges in Central America*, World Bank Staff Occasional Papers No. 15 (International Bank for Reconstruction and Development, 1972), pp. 48, 52. [3] Soberman, op. cit., p. 56. [4] F. Moavenzadeh: *Investment strategies for developing areas: Analytic model for choice of strategies in highway transportation* (Cambridge (Massachusetts), Massachusetts Institute of Technology, 1972), pp. 79-80. [5] Churchill, op. cit., pp. 51-52, citing British Road Research Laboratory, East Africa Transport Planning Research Unit: *A study of road maintenance costs in Kenya* (mimeographed, 1966).

ADT = Average daily traffic flow.

would be costed and the present value of maintenance costs over the life of the road calculated. To estimate maintenance costs by this method, road deterioration relationships must be available for each possible combination of design and technology. In general, such relationships are not readily available, and a number of years may be needed in order to ascertain them. In the meantime, the project evaluator may need to obtain rough estimates of maintenance costs from similar existing roads. Such an approach requires that maintenance expenditure on these roads be known, as well as the dates on which it is incurred and the average daily traffic flow.

It should be noted that maintenance costs are partly a function of the maintenance technology used. There is a general tendency to use technologies of the same type as those used in the original construction of the road. For

example, a labour-intensive maintenance technology would generally be used for roads built labour-intensively. This should not be the rule, however. Maintenance differs from construction: in particular, excavation has little or no place in maintenance; it may therefore be found profitable to use a labour-intensive maintenance technology for a road built capital-intensively.

Some idea of the range of maintenance cost formulae arrived at in a number of countries is given by table 12. As one would expect, maintenance costs that are a function of average daily traffic flow tend to decrease as the construction standard of the road improves. These maintenance formulae are purely illustrative and should not be used in specific project evaluation since not only the physical characteristics of roads but also relative input prices differ greatly from country to country.

ROAD USERS' COSTS

Road users' costs include vehicle operating costs and the value of vehicle occupants' time. Each will be analysed in turn. It will then be shown how to estimate total road users' costs on the basis of the composition and volume of traffic flows.

Vehicle operating costs

A numbers of studies [1] of vehicle operating costs have been published. Most of them are compilations of the results of separate primary research studies. The World Bank has reviewed the existing literature on vehicle operating costs and found them to be deficient in a number of ways. The Bank's conclusions [2] are as follows:

Unfortunately, as fully recognised by most authorities, the existing information, despite the vast amount of publications, is highly deficient both in terms of its comprehensiveness and the adequacy of the underlying data base and methodology. This is particularly true for low-standard roads. While extensive information is readily available on vehicle operating costs component by component, research has generally been too limited to establish the relationship of these to road design geometrics, surface design and maintenance standards.

In particular—

(i) fuel consumption and driver/passenger time savings are the only components which have been researched in any detail; much less is known about the relationship

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[1] See for example de Weille, *Quantification of road user savings*, op. cit., and H. Hide, S. W. Abaynayaka, I. Sayer and R. J. Wyatt: *The Kenya Road Transport Cost Study: Research on vehicle operating costs*, Transport and Road Research Laboratory Report 672 (Crowthorne, Berkshire, 1975).

[2] IBRD *Highway Design Standard Study*, op. cit., p. 8.

of other components (tyre wear, vehicle maintenance and depreciation) to decision variables; to a great extent standard references are based on extrapolations from a limited base using engineering judgement to infer more comprehensive results;

(ii) no research (previous to the Kenya study) has attempted to measure costs in response to road maintenance standards and surface conditions;

(iii) the full range of vehicle types and sizes, particularly for the vehicles most common in developing countries, have not been covered;

(iv) much of the research, particularly that for low-standard roads, was done largely in the 1930s; changes in vehicles, tyres and fuels over the years may have altered these relationships significantly;

(v) much of the most important primary research has relied on controlled experiments with a very limited number of vehicles (and experimental conditions) wherein it is difficult to simulate normal or typical driving conditions.

It seems, therefore, that most developing countries need to undertake studies in order to determine road users' costs relationships that apply to their particular conditions, especially in the case of low standard rural roads (gravel or earth roads) for which very little data are available.

Vehicle operating costs comprise the following items:

(a) fuel consumption costs;

(b) lubricating oil consumption costs;

(c) vehicle maintenance costs;

(d) tyre consumption costs; and

(e) vehicle depreciation costs.

A number of relationships have been calculated which relate each of the above cost items to various road characteristics. Of great interest is the World Bank's study in Kenya.[1] The study arrives at relationships between vehicle speed and a number of design variables for various types of roads (e.g. paved roads, gravel roads). Relationships between vehicle fuel consumption and vehicle speed are also established for various types of vehicles. The study also analyses vehicle maintenance costs, tyre consumption and vehicle depreciation.

Value of vehicle occupants' time

The estimation of the value of vehicle occupant's time is desirable but generally difficult from both the conceptual and the empirical point of view. Each of the individual occupants may assign a different value to any given amount of time spent travelling along a road. Such subjective evaluations would seem to be at least as valid in principle as a uniform, professedly objective evaluation by an economist whose values may differ quite markedly from those of most

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[1] IBRD *Highway Design Standard Study*, op. cit., Annex 1.

if not all of the occupants. This difficulty arises, for example, in relation to the principle that a zero value should be attributed to time spent on a road outside working hours, or by travellers who are unemployed.

Furthermore, even if it is assumed that a unit of a vehicle occupant's time spent travelling along a road is equal to the value of the occupant's income for that unit of time it remains empirically very difficult to estimate the value. First, automatic traffic flow counters cannot be used for this purpose since it is necessary to know the number of persons per vehicle, as well as their age and sex, so as to determine whether they are likely to belong to the workforce, and consequently to have incomes. Road interviewers are needed in order to collect this type of information. Secondly, once information regarding the number of the various categories of road users is obtained, it is necessary to adopt values for those categories. Here again it is difficult to define a reliable estimation method. Should one use the national average hourly wage? Should different values of time be used for the occupants of different types of vehicles (e.g. passenger cars, trucks, buses) ? Once again, interviews of vehicle occupants may be needed in order to obtain a reliable estimate of the average value of their time.[1]

Estimation of total road users' costs

Once unit road users' costs have been estimated, the present value of the stream of road users' costs over the life of the road may be calculated on the basis of the composition and volume of present and future traffic flows.

Costs per unit of distance

As shown previously, the items making up the road users' costs per unit of distance are a function of a number of road design characteristics and environmental conditions. Road users' costs accordingly differ from one road to another; moreover, on any given road the variations in the vertical and horizontal alignment have a substantial effect on fuel consumption.

In order to estimate fuel consumption costs, a road should be divided into homogeneous stretches along which fuel consumption will be constant. Vehicle operating costs per unit of distance may then be estimated for individual stretches and for various types of vehicle on the basis of formulations relating fuel consumption to various aspects of road alignment.

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[1] No method for the valuation of vehicle occupants' time is suggested in this manual, and the reader is referred to de Weille, *Quantification of road user savings*, op. cit., and Harberger, op. cit., Ch. 10.

Traffic flows

Traffic flows are not identical throughout a road's length: traffic may leave or enter the road at different points. Traffic counts should therefore be made for the section of road between every two consecutive exit or entry points.[1]

There are five different types of traffic which should be taken into consideration when estimating initial traffic flows (i.e. traffic flows that will occur immediately after the completion of the road project) and future traffic flows.

Initial traffic can be regarded as consisting of two types of traffic—existing traffic and attracted or diverted traffic. Existing traffic relates to road improvement projects; since road users' costs decrease as a result of road improvement, traffic existing prior to road improvement can be expected to continue at the same level once a road has been improved. Whenever it is more economical to use the new or improved road rather than other existing facilities (e.g. other roads, railway lines), there will be attracted or diverted traffic. The level of diverted traffic depends partly on the geographical location of population and production centres and on the extent and quality of the existing transport network.

Future traffic comprises generated traffic, development traffic and traffic increases resulting from normal traffic growth. Generated traffic is traffic that would not have existed if a new road had not been built or if an existing road had not been improved. Most of the generated traffic develops within the first year or two after a new road is opened; it is associated with little or no modification of the existing production structure. Development traffic is due to improvements in the economic situation in areas adjacent to the new road, improvements which would not have taken place in the absence of the new road. Unlike generated traffic, this component of future traffic continues to develop for many years after a new road is built; it is the result of increased land use, the development of new industries, and, in some cases, an increase in the population of the area as a result of internal migration. Finally, normal traffic growth is the increase in traffic volume due to a general increase in the number and utilisation of motor vehicles. Normal traffic growth should, in general, continue over the life of the road, levelling off once a saturation point is reached. At that point, the road should be widened or new roads should be built if traffic is to be permitted to grow.

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[1] Although the types of traffic flows to be expected on a new or improved road will be identified below, readers wishing to obtain information regarding the techniques for estimating such traffic flows are advised to consult Jan G. Heggie: *Transport engineering economics* (London, McGraw-Hill, 1972), Ch. 8.

Present value

The following definitions will be used for the elements of the formulae for estimating the present value of road users' costs:

$(FL)_j$ = fuel consumption costs per km for a vehicle of type j,
$(LB)_j$ = lubricating oil consumption costs per km for a vehicle of type j,
$(MC)_j$ = vehicle maintenance costs per km for a vehicle of type j,
T_{yj} = tyre consumption costs per km for a vehicle of type j,
D_j = vehicle depreciation costs per km for a vehicle of type j,
L_k = length, in km, of road section k,
V_{jk} = average speed of vehicle j on road section k, in km per hour,
$(PT)_j$ = average hourly value of the time of occupant in a vehicle of type j,
N_j = average number of occupants per vehicle of type j,
$(TR)_{jk}$ = annual two-way traffic, in number of standard vehicles, for a vehicle of type j on road section k, and
r = rate of interest.

An average vehicle operating cost per km, (VC), must first be estimated for each of the road sections, k, characterised by a constant traffic flow (i.e. the sections of the road between every two consecutive exit or entry points.) For a given vehicle of type j, this gives a formula of the type

$$(VC)_{jk} = (LB)_j + (MC)_j + T_{yj} + D_j + (FL)_{1,j} \cdot \frac{L_1}{L_k} + (FL)_{2,j} \cdot \frac{L_2}{L_k} + \ldots + (FL)_{n,j} \cdot \frac{L_n}{L_k}$$

where $L_1, L_2, \ldots L_n$ are stretches of road section k with constant vertical and horizontal alignment characteristics [1] such that

$$L_1 + L_2 \ldots L_n = L_k.$$

Then for a given year t and for a vehicle of type j, road users' costs are equal to

$$(RUC)_{tj} = \sum_{k=1}^{s} \left[(TR)_{jk} \cdot (VC)_{jk} \cdot L_k + (TR)_{jk} \cdot \frac{L_k}{V_{jk}} \cdot N_j \cdot (PT)_j \right]$$

where s = number of road sections carrying a constant flow, $k = 1, 2, 3, \ldots s$.

Road users' costs at year t for all types of vehicles are then equal to

$$(RUC)_t = \sum_{j=1}^{v} (RUC)_{tj}$$

where v = number of types of vehicles.

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[1] It is assumed that only fuel consumption varies from one stretch of road to another, and that $(LB)_j$, $(MC)_j$, $(Ty)_j$ and D_j are therefore constant over the whole road.

Road users' costs over the life of the road are therefore equal to

$$(RUC) = \sum_{t=1}^{T} \frac{(RUC)_t}{(1+r)^t}$$

where T = life of the road in years.

INDIRECT BENEFITS

In most of the developed countries indirect road benefits are related primarily to the redistribution of traffic flows and only marginally to development resulting from the transformation of the production structure of the area crossed by the road. In other words, indirect road benefits may be regarded as amounting to roads users' savings and road maintenance savings. These two types of savings constitute a large part of total road benefits, and in the evaluation of a road project they may be safely assumed to account for their entirety. This is particularly true of road improvement projects or road projects designed to shorten the travelling distance between population centres. There are exceptions, of course, but the number of such exceptions is small in relation to the total number of road projects implemented each year. In developing countries, on the other hand, a large part of the total benefits often consist of developmental benefits; therefore in a large number of cases road users' savings and road maintenance savings cannot be equated with total benefits in those countries.

The significance of the developmental benefits of a road project depends on the type of road project. It is useful in that connection to make use of the following classification, already described in Chapter 1:

(a) road maintenance;

(b) road improvement;

(c) new roads that are primarily intended to shorten the distance, and therefore the travelling time, between population centres;

(d) new roads that are part of wider sectoral investment projects; and

(e) "developmental roads", i.e. new roads built under a general regional development policy.

The benefits of projects of types (a) and (b) may be evaluated solely in terms of road users' savings and road maintenance savings.

New road projects in group (d) that are part of wider sectoral investment projects (e.g. agricultural or mining projects) should be regarded as one of the various investment cost items (together with the cost of irrigation systems or

of mining equipment in the two examples just mentioned). On such a view, it is meaningless to assign benefits to the road projects themselves since no benefits would accrue if the building of the roads constituted the only investment: it is therefore the over-all evaluation of the sectoral projects that should determine whether the roads that are part of the projects will be constructed or not. The project evaluator in the public works department is generally not responsible for the evaluation of such projects; his involvement at the project evaluation stage is usually limited to providing road construction cost data to the ministry or other agency that is evaluating the sectoral project as a whole.

Road projects in group *(c)* yield two types of benefits, namely road users' savings and road maintenance savings on the one hand, and developmental benefits on the other. In this case the developmental benefits are usually a by-product of the road project, and of secondary importance. However, they should be estimated since they may in some marginal cases be the decisive factor in determining whether the project should be adopted or not.

Road projects in group *(e)* produce great developmental benefits, together with road users' savings and maintenance savings constituting a by-product of secondary importance; such savings may be equal to zero in the case of penetration roads or rural access roads. Developmental benefits are rather difficult to estimate. The main difficulty lies in the fact that regional development is usually the result of a number of investments in different fields, one of which is the construction of new roads: it is difficult to isolate the effect of road projects on regional development because in most cases such projects are implemented concurrently with other development project relating, for example, to health facilities, schools and irrigation. Yet, unlike new roads that are an integral part of a sectoral investment project—case *(d)* above—roads built for the purpose of regional development—case *(e)*—may yield benefits without significant additional investments. The new roads may, for example, encourage farmers to switch from subsistence crops to cash crops, or to make greater use of nearby health and educational facilities. These road projects should therefore be evaluated and ranked on their own merits, and not as part of a more comprehensive regional investment project as suggested by some authors. If governments are short of money, they may need to choose between a road project and other regional development projects (relating, for example, to schools or hospitals). It is therefore important to estimate the benefits that are specific to road projects so that such projects may be ranked along with other types of projects for comparison and selection purposes.

One way of estimating developmental benefits is to carry out a field study based on a sample of production units or households, or of both. The purpose of such a study is to determine the relationship between the distance of a sample unit from the existing road network, market centres and public facilities on

the one hand and such characteristics of the unit as income, proportion of land area planted with cash crops, proportion of land cultivated, amount of emigration and frequency of members' use of nearby public facilities on the other hand. If meaningful results are to be obtained [1], a study of this kind needs to be based on a large sample of households or production units.

It should be pointed out that developmental benefits should be estimated net of costs (i.e. investment costs, $(DEV)_c + (GE)_c$, in addition to road capital and variable costs); otherwise the profitability of the new road project will be overstated.

EFFECT OF ROAD CONSTRUCTION TECHNOLOGY ON FUTURE COSTS AND BENEFITS

In cases in which a road design is chosen and a choice is then made among possible construction technologies, the effect of choice of technology on road users' costs, road maintenance costs and road benefits is extremely slight. In fact the only possible effect of the construction technology is that relating to the rate of road deterioration, and the extent of such an effect will, in general, be marginal: for any given maintenance policy, the technology chosen will entail maintenance costs that will differ only slightly from those attached to other technologies. Since it would be extremely difficult to estimate, empirically, the extent of any differences in maintenance costs resulting from differences in construction technologies, it may be necessary to assume that road maintenance costs are not affected by the choice of construction technology at all.

On the other hand, in cases in which a choice is made among possible combinations of design and technology, road users' costs and road maintenance costs are affected in the ways described in this chapter. Road benefits are not much affected by the choice of any particular combination of design and technology unless variations in design significantly alter the routing of the road, and consequently its area of influence. Such cases are infrequent.

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[1] Special statistical techniques may also have to be used if the effect of new roads on regional development is to be isolated. Readers interested in the problem of estimating developmental benefits of new roads may refer to Harberger, op. cit., Ch. 10; Odier: *Les intérêts économiques des travaux routiers*, op. cit.; and A. R. Prest: *Transport economics in developing countries* (London, Weidenfeld and Nicholson, 1969).

EVALUATION OF ALTERNATIVE TECHNOLOGIES AT MARKET PRICES

This chapter will show how to identify the most appropriate construction technology for a given road by means of a cost-benefit analysis based on market prices. It should be noted that market prices may not reflect the true social value of project inputs and outputs, and may therefore need to be adjusted if the true social profitability of a project is to be estimated. In other words, project evaluation may need to be based on "shadow" or "accounting" prices instead of market prices. The present chapter is an introduction to the procedure of cost-benefit analysis, as carried out on the basis of market prices. The estimation of accounting prices and their incorporation into the analysis will be described in the next chapter.

There are a number of reasons for beginning with the use of market prices in the evaluation of construction technologies. The most important is that in some cases it is not necessary to use accounting prices even if market prices are distorted. Such cases arise when it is found that the more labour-intensive of two alternative technologies is also the one that is less costly at market prices. In those circumstances the use of accounting prices would do no more than underline the social profitability of the labour-intensive technology. The following example will clarify this point. Let it be assumed that the differences between two construction technologies are limited to the number of man-hours and equipment hours needed to build a given road, the amount of materials being the same for both technologies. If both technologies are technically efficient [1], then

$$m_1 > m_2 \text{ and } h_1 < h_2$$

where m_1 = number of man-hours used in the labour-intensive technology,

m_2 = number of man-hours used in the capital-intensive technology,

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[1] A technology is technically efficient if it does not require more of both man-hours and equipment-hours than any other existing technology.

h_1 = number of equipment-hours used in the labour-intensive techno-
logy, and

h_2 = number of equipment-hours used in the capital-intensive techno-
logy.

Using the following definitions:

w_m = hourly market wage rate,

w_s = hourly shadow wage rate,

R_m = hourly market rental rate for equipment,

R_s = hourly shadow rental rate for equipment, and

M_m, M_s = cost of materials at market prices and at shadow prices,

let it now be assumed that

$$m_1 . w_m + h_1 . R_m + M_m < m_2 . w_m + h_2 . R_m + M_m$$

or $$m_1 . w_m + h_1 . R_m < m_2 . w_m + h_2 . R_m \qquad (17)$$

or, to put it differently, that the labour-intensive technology is less costly at market prices. It will be shown in the next chapter that in most developing countries the shadow wage rate is lower than the market wage rate (i.e. $w_s < w_m$), and that the shadow equipment rental rate is higher than the market equipment rental rate (i.e. $R_s > R_m$). Relationship (17) therefore yields the following relationship:

$$m_1 . w_s + h_1 . R_s < m_2 . w_s + h_2 . R_s \qquad (18)$$

Thus, when it is known that $w_m > w_s$ and $R_m < R_s$, it is not necessary to evaluate construction technologies at shadow prices if it is established that the more labour-intensive technology is also the less costly one at market prices. It should be pointed out, however, that the argument outlined above does not always apply when a road project is financed through a foreign loan or grant. That case will be discussed in the following chapter.

There are a number of other reasons for using market prices in project evaluation. First, a government may prefer to use market prices if it is not fully convinced of the appropriateness of using shadow prices. Secondly, estimates for parameters needed to compute shadow prices may not always be available at the time when projects are being evaluated, and projects may then have to be evaluated at market prices while steps are taken to obtain estimates of the parameters. It should be pointed out that a cost-benefit analysis always takes into consideration indirect cost and benefit items (such as road users' costs and road benefits) that do not enter into a purely financial analysis of projects. Thus even when market prices are used a cost-benefit analysis yields a measure of the social profitability of projects, as distinct from

their private profitability. The use of shadow prices merely permits a more accurate estimate of the social profitability.

RECOMMENDED CRITERIA

Ranking of projects is not a simple matter: there are a number of different criteria by which they may be ranked, and those criteria do not always yield concurrent rankings; it is therefore important to adopt the criterion that will provide the most valid ranking in a particular case. A number of ranking criteria will now be described and their individual merits and drawbacks discussed.

Net present value

Let it be supposed that the life of a project is n years, and that the project yields a stream of yearly benefits

$$B_1, B_2, B_3 \ldots B_n$$

as well as a stream of yearly costs

$$C_1, C_2, C_3 \ldots C_n$$

The stream of yearly net benefits is therefore

$$(B_1 - C_1), (B_2 - C_2), (B_3 - C_3) \ldots (B_n - C_n).$$

The net present value (NPV) of the project is then

$$\frac{(B_1 - C_1)}{(1 + r_1)} + \frac{(B_2 - C_2)}{(1 + r_2)^2} + \frac{(B_3 - C_3)}{(1 + r_3)^3} + \ldots + \frac{(B_n - C_n)}{(1 + r_n)^n} \qquad (19)$$

where r is the discount rate.

The value of r may fluctuate from year to year. If it does not, or if an average value of r is used, equation (19) becomes

$$\sum_{i=1}^{n} \frac{(B_i - C_i)}{(1 + r)^i} \qquad (20)$$

Benefit-cost ratio

A second ranking criterion, the benefit-cost ratio or ratio of the present value of the stream of project net benefits over the present value of the stream of project costs, is obtained from the following relationship:

$$\sum_{i=1}^{n} \frac{(B_i - C_i)}{(1+r)^i} \bigg/ \sum_{i=1}^{n} \frac{(C_i)}{(1+r)^i} \qquad (21)$$

The following example will show in what sort of cases the benefit-cost ratio is a better criterion than net present value, or vice-versa. Let it be supposed that a government department needs to rank projects A to G. Let it also be supposed that the projects are ranked according to their respective net present values and benefit-cost ratios, as shown in table 13.

It can be readily seen from the table that, with the exception of project C, projects are ranked differently according to the ranking criterion adopted. The choices made will differ if there is a budgetary constraint of, for example, 1,000 monetary units. According to ranking R_1, the budget should be spent on projects A and B, the sum of the corresponding net present values being equal to 800 (500 + 300). On the other hand, according to ranking R_2, the budget should be spent on projects G, F, A, C and D (100 + 100 + 500 + 200 + 100 = 1,000), the sum of the corresponding net present values being equal to 1,045 (150 + 120 + 500 + 200 + 75). Therefore, the R_2 ranking is preferable since for the same amount of money, projects adopted under R_2 provide a higher net present value than projects adopted under R_1.

Let it now be supposed that there is a budgetary constraint of 600 monetary units and that it has been decided to spend the full amount. According to ranking R_1, the budget should be spent on projects A and G since other combinations of projects are either less profitable or do not use up the full budget. In this case the sum of the net present values is equal to 650. According to ranking R_2, the budget should be spent on projects G, F, C and E, with the sum of the net present values being equal to 570. (Project A was skipped because its cost, added to those of G and F, would have exceeded the budget constraint.) In this case the R_1 ranking provides a better choice of projects than the R_2 ranking. The general conclusion to be derived from this example is that the benefit-cost ratio should be used whenever it is not necessary to skip projects in order to match the budget amount to the sum of the costs of selected projects. On the other hand, if skipping of projects is needed, it may be necessary to rank projects according to each criterion and select the combination that yields the highest total net present value under R_1 or R_2.

There is one main drawback to the use of these two criteria. The value of the discount rate r may not be accurate: as stated earlier, it may fluctuate from year to year, and a forecast of such fluctuations may be impossible. Furthermore, it is usually difficult to specify accurately the discount rate to be used. Should the government use a discount rate higher or lower than a specified market rate? This is a very difficult question indeed, since market rates tend to

Table 13. Ranking of a hypothetical set of projects by net present value and benefit-cost ratio

Project	$\sum_{i=1}^{n} \frac{C_i}{(1+r)^i}$	$\sum_{i=1}^{n} \frac{B_i}{(1+r)^i}$	$\sum_{i=1}^{n} \frac{(B_i-C_i)}{(1+r)^i}$	R_1	$\sum_{i=1}^{n} \frac{(B_i-C_i)}{(1+r)^i} \bigg/ \sum_{i=1}^{n} \frac{C_i}{(1+r)^i}$	R_2
(1)	(2)	(3)	(4)	(5)	(6)	(7)
A	500	1 000	500	1	1.00	3
B	500	800	300	2	0.60	6
C	200	400	200	3	1.00	3
D	100	175	75	7	0.75	5
E	200	300	100	6	0.50	7
F	100	220	120	5	1.20	2
G	100	250	150	4	1.50	1

Key: Column (2) gives the present value of the stream of costs for each project, and column (3) the present value of the stream of benefits. Column (4) provides the net present value of each project, yielding the ranking R_1 in column (5). Column (6) provides the benefit-cost ratio of each project, yielding the ranking R_2 in column (7).

be distorted by imperfections of the capital market.[1] If the wrong discount rate is used in project evaluation, some of the projects that are selected may in reality be less profitable than some projects that are rejected. In view of that drawback, a number of economists have shown some preference for another criterion, the internal rate of return, for the calculation of which no specific discount rate needs to be used.

Internal rate of return

To assess net present values and benefit-cost ratios, a discount rate must be specified. However, the discount rate can also be regarded as an unknown. In that case projects are ranked according to the value of the discount rate that equates the present value of the stream of benefits to the present value of the stream of costs, that is the discount rate that equates the net present value of individual projects to zero: such a discount rate is called the internal rate of return. For example, let it be supposed that the life of a given project is one year, that total project costs (100) are incurred on the first day of the year, and that total project benefits (120) are achieved on the last day of the year. Since the costs are incurred on the first day of the year, the present value of costs is equal to 100. The present value of benefits is equal to $\frac{120}{1+\rho}$, where

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[1] This subject will be dealt with in more detail in the next chapter in connection with the social discount rate.

ρ = internal rate of return. The value of ρ that equates the present value of project costs to the present value of project benefits is obtained by the solution of the following equation:

$$100 = \frac{120}{1+\rho}.$$

From the above, we obtain $\rho = 0.2$, or 20 per cent. In this example the internal rate of return of the project, ρ, is equal to 20 per cent.

Formally, the internal rate of return of a project, ρ, is obtained by the solving of the following equation:

$$\sum_{i=1}^{n} \frac{B_i - C_i}{(1+\rho)^i} = 0 \tag{22}$$

where B_i and C_i are respectively the benefits and costs at year i.

The solving of equation (22) is not easy when n is large (i.e. $n > 4$); when it is, a good desk calculator may be needed. In general, however, the method used to find ρ is one of trial and error.

The internal rate of return ρ should be regarded as the average discount rate over the life of the project, as in the following example. Let it be supposed that the life of a project is two years and that the net benefit stream is as follows:

-100 (first day, or year 0),
60 (end of year 1),
72 (end of year 2).

The internal rate of return ρ is obtained by solving the equation

$$-100 + \frac{60}{1+\rho} + \frac{72}{(1+\rho)^2} = 0.$$

The value of ρ is found to be 0.2, which yields the following equation:

$$-100 + \frac{60}{1.2} + \frac{72}{(1.2)^2} = 0.$$

However, the discount rate at year 1 may differ from the rate at year 2. For example, the rate could be 50 per cent the first year and 9.545 per cent the second year, yielding the following equation:

$$-100 + \frac{60}{1.5} + \frac{72}{(1.09545)^2} = 0.$$

In this example the 20 per cent internal rate of return is a weighted average of the successive rates of 50 and 9.545 per cent; other combinations of discount rates could be found that would also yield a weighted average

of 20 per cent. In other words, the value of ρ should be regarded as a weighted average of the (unknown) discount rates applying each year.

If a number of potential projects are under consideration, they may be ranked according to their internal rate of return, and the higher-ranking ones selected up to the point at which the budget is fully exhausted.

The main advantage of this criterion is that the internal rate of return can be calculated on the basis of project data alone, there being no need to estimate the opportunity cost of capital. Another advantage is that this criterion allows the government to compare the profitability of public investment projects with the profitability of projects in the private sector. It is conceivable that a government would refrain from investing in some public projects with low internal rates of return, even if such a course of action were to result in incomplete utilisation of the available funds.

As a criterion of choice, however, the internal rate of return has two main defects. First, there are projects for which it is not possible to determine a unique value for that rate, as may be seen from the following example. Let it be supposed that a given project produces the following net benefit stream:

$$- \; 4,500 \; (\text{year } 0),$$
$$10,000 \; (\text{end of year } 1),$$
$$- \; 5,500 \; (\text{end of year } 2).$$

Then the following two equations may be established:

$$-4,500 + \frac{10,000}{(1+0)} - \frac{5,500}{(1+0)} = 0,$$

and

$$-4,500 + \frac{10,000}{(1+0.2222)} - \frac{5,500}{(1+0.2222)^2} = 0.$$

There are thus two possible internal rates of return for the project, namely zero and 22.22 per cent.

In general a project will have multiple internal rates of return if the sign of the stream of net benefits changes more than once. Yearly net benefits may, for example, exhibit the time profile depicted in figure 47. That profile could apply to a road needing to be rehabilitated six years after being built, so that it would yield negative net benefits during the first and seventh years. In such cases it may not be possible to obtain a unique estimate of the internal rate of return.

Another defect of that criterion appears when it comes to evaluating a variety of projects designed to meet the same requirements (e.g. when a road may be built by any of several construction techniques). In that case the use of the internal rate of return as a criterion of choice may not lead to the adoption of the most profitable project, as may be seen from the following example. Let it be supposed that a number of potential projects are ranked according to

Figure 47. Example of time profile for yearly net benefits of a road-building project
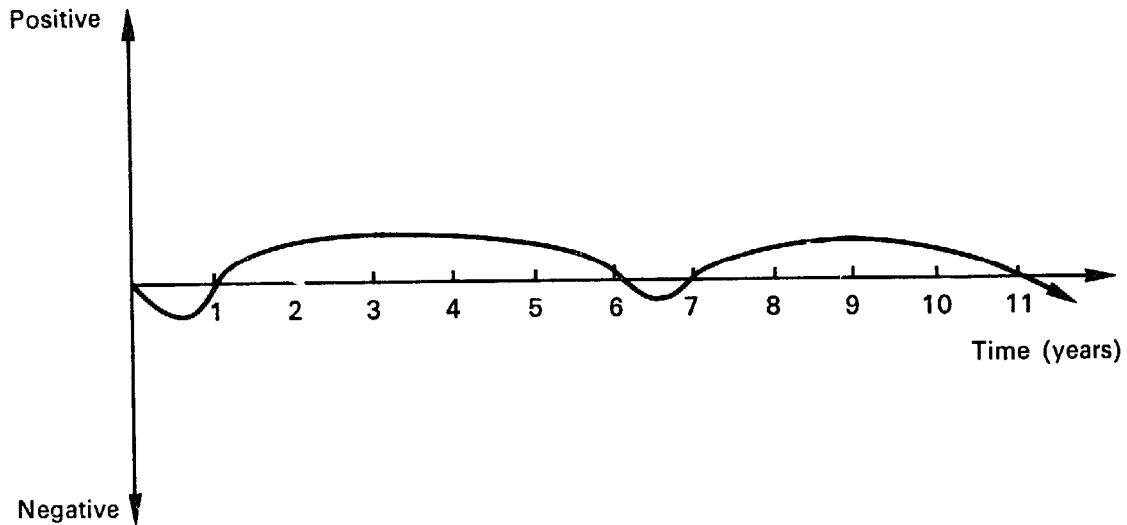
their internal rate of return and that the last project that can be included within the budgetary limits has a rate of 10 per cent. That percentage represents the appropriate opportunity cost of capital (i.e. the appropriate discount rate). Hence the net present value of all projects should be recalculated on the basis of that rate. Let it now be supposed that version A of a road project with an internal rate of return of 20 per cent is adopted, while the alternative B, with a rate of 15 per cent, is not.[1] If, however, A and B are re-evaluated at the appropriate discount rate, 10 per cent, B may be found more profitable than alternative A. Let it be supposed that A and B show the following net benefit streams:

A	B
(IRR = 20 per cent)	(IRR = 15 per cent)
−2,000	−2,000
1,000	100
1,200	300
339.3	2,564.7

It may be noted that the initial investment cost is the same for both A and B, namely 2,000 monetary units. Since the last adopted project has an internal rate of return of 10 per cent, the adoption of A rather than B does not affect the adoption of other projects with an internal rate of return higher than 10 per cent.

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[1] Since A and B are alternatives to each other, only one of them (A, which has a higher internal rate of return than B) is included in the ranking. Thus, adoption of A implies rejection of B.

The net present value of A when discounted at 10 per cent is equal to

$$-2,000 + \frac{1,000}{1.1} + \frac{1,200}{(1.1)^2} + \frac{339.3}{(1.1)^3} = 155.7,$$

whereas the net present value of B when discounted at 10 per cent is equal to

$$-2,000 + \frac{100}{1.1} + \frac{300}{(1.1)^2} + \frac{2,564.7}{(1.1)^3} = 265.7.$$

Version B should therefore have been adopted instead of A. In this case the criterion of the internal rate of return leads to the adoption of the less profitable alternative.

It is therefore recommended that projects should be ranked by their benefit-cost ratios, as well as by their net present values when the need arises, instead of by their internal rates of return. This recommendation is based on the fact that the two main defects of the internal rate of return as a criterion are particularly serious when evaluating road projects: it is often necessary to consider alternatives of a given road project, and the streams of net benefits of such projects often change their sign more than once.

Others

Some governments may wish to consider other aspects of projects before making a final choice. Two important aspects that may be taken into consideration are employment generation per unit of investment (L/K) and the balance-of-payments effect expressed as the ratio of local costs to total project costs (M/K).[1] These two additional aspects of projects are fairly important to planners in developing countries because such countries are usually short of foreign exchange and have high rates of unemployment.

Weighted ranking

Planners can rank projects simultaneously according to their social profitability (net present value, benefit-cost ratio and internal rate of return) as well as according to their L/K and M/K ratios. An example of such a multiple ranking is shown in table 14.

If projects A to G cannot all be implemented owing to budgetary constraints, project evaluators must attach a weight to each of the three ranking

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[1] If a project yields foreign exchange revenues, the balance-of-payments effect may be expressed as the ratio of foreign exchange revenues over foreign exchange costs. In this manual the M/K ratio is used instead because most road projects do not produce a direct yield in terms of foreign exchange and, that being so, then the higher the M/K ratio, the higher the ranking of a project with regard to the balance-of-payments effect.

Table 14. Multiple ranking of a hypothetical set of projects by benefit-cost ratio, balance-of-payments effect and employment generation per unit of investment

Ranking factor		Projects						
Designation	*Weighted multipli-cator*	A	B	C	D	E	F	G
Benefit-cost ratio	*0.5*	1	2	3	4	5	6	7
Balance-of-payments effect (*M/K*)	*0.3*	7	5	6	3	4	2	1
Employment generation per unit of investment (*L/K*)	*0.2*	6	7	4	5	3	1	2
Weighted combined ranking		*3.8*	*3.9*	*4.1*	*3.9*	*4.3*	*3.8*	*4.2*

criteria so as to arrive at a single weighted ranking of projects. In this example, the benefit-cost ratio (BCR) is given a weight of 0.5, the balance-of-payments effect (M/K) a weight of 0.3 and the employment generation per unit of investment (L/K) a weight of 0.2. The weighted combined ranking of each project is then as follows:

weighted rank = (BCR rank × 0.5) + (M/K rank × 0.3) + (L/K rank × 0.2).

On the basis of the weighted ranking, the projects in the above example are ranked as follows: A, F, B, D, C, G, E.

The defect of weighted ranking is that the weights are subjectively determined by project evaluators, i.e. they are based on educated guesses about the relative importance of the various aspects of the projects to be considered. Such a procedure is therefore recommended only in cases in which differences in the social profitability of projects as expressed by their benefit-cost ratios, net present values or internal rates of return are small by comparison with the differences in their M/K or L/K ratios. Another, much more accurate means of assessing the employment and foreign exchange implications of project choice will be described in the following chapter.

APPLICATION TO DIFFERENT KINDS OF PROJECTS

The remainder of this chapter is devoted to explaining how the general project evaluation criteria and methods just described can be applied to the five types of road project identified in a previous chapter.[1] To some readers, the steps involved in the identification of the most appropriate combination

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[1] See Chapter 1, pp. 17 ff.

of design and technology (or policy and technology in the case of maintenance) may seem too involved, too time-consuming, and possibly of limited practicality: some may object that it is extremely difficult to estimate all the various streams of benefits and costs attached to the different types of road projects. Yet such complications cannot be avoided if a rational choice is to be made among different combinations. The project evaluator should therefore set up a systematic data collection programme (relating, for example, to unit construction costs, maintenance costs and road users' costs) in order to be able to apply the identification procedure developed in this manual. As accurate data are accumulated, the project evaluator will find the procedure increasingly easy to apply; indeed, with time, it may appear too rudimentary, and some evaluators may start developing procedures of their own that will provide them with a more reliable basis for decision.

Maintenance

There are three types of road maintenance—emergency maintenance, routine maintenance and major road rehabilitation. Emergency maintenance is needed whenever stretches of road are made unfit for traffic as a result of floods, landslides, or other adverse conditions that result in the closing of a road or in a considerable slow-down of traffic flows. In such cases maintenance is needed as a matter of urgency in order to restore traffic to normal. Routine maintenance is undertaken at regular intervals in order to restore to an acceptable quality standard the condition of roads that undergo a certain amount of deterioration as a result of normal use. Routine maintenance operations may be divided into those concerning the road shoulders and those concerning the carriageway. Costs attached to the repair of the road shoulders usually occur at fixed intervals of time, and are mostly a function of the climatic conditions prevailing in the area crossed by the road. On the other hand, costs attached to the repair of the carriageway are a function both of the climatic conditions and of the level and composition of traffic flows. Major road rehabilitation is warranted whenever routine maintenance is not sufficient to restore the road to an acceptable quality standard. It may consist in the resurfacing of a paved road or the regravelling of a gravel road. It should be pointed out that in a road rehabilitation project, unlike a road improvement project, the original design and quality standard of the road are not altered. It should also be noted that major road rehabilitation cannot be dissociated from routine maintenance since the routine maintenance frequency affects the number of times major rehabilitation is needed over the life of the road. The means of identifying the most appropriate maintenance technology for each of these various kinds of road maintenance will now be described.

Emergency maintenance

Emergency maintenance is needed either to re-open a road to traffic or to restore traffic flow to the original design speed. It may include one or both of the following operations:

(a) clearing stretches of a road pavement of silt or boulders deposited by floods, landslides, or other calamities; and

(b) reconstructing stretches of road that have been washed away by floods, or on which the carriageway may have subsided for some other reason.

The range of potential technologies may be quite narrow when an important road has been closed to traffic and must be quickly reopened. For example, a road may constitute the only link to some settlements. If road damage is excessive, a capital-intensive technology may have to be used in order to enable the road to be re-opened quickly. In general, the public works department will use the resources at hand in order to restore traffic flows, and construction equipment is usually preferred to unskilled labour because the use of equipment may shorten the construction period; but whenever the equipment cannot be quickly transported to the site the use of a labour-intensive technology may be preferred if unskilled labour is available locally.

Routine maintenance and major rehabilitation

Maintenance of road shoulders is usually undertaken at intervals depending on the climate, but at least once a year. To identify the most appropriate (i.e. least costly) technology for this purpose, there is no need to estimate the present value of all maintenance operations over the life of the road since the frequency of such maintenance operations is the same whatever technology is adopted. The steps involved are—

(a) establishment of a bill of quantities (e.g. Y square metres of grass to mow, removal of Z cubic metres of silt from drainage ditches);

(b) identification of technically possible maintenance technologies;

(c) estimation of total amount of inputs for each possible maintenance technology; and

(d) estimation of total maintenance costs with each technology.

Once the appropriate technology has been identified, it should be used over the life of the road unless relative input prices (e.g. wages or equipment rental rates) fluctuate over the years. When there is fluctuation of the ratio W/R (W being the unskilled labour wage and R the equipment rental rate), the technology identified as most appropriate for a particular year may be less appropriate than others for subsequent years. A reassessment of maintenance

technologies for road shoulders may therefore be warranted from time to time in order to ensure that the technology used is always the most appropriate.

It is difficult to identify the most appropriate technology for the maintenance of the carriageway. That technology will be the one that yields the lowest present value (PV) of the time stream of maintenance costs and road users' costs over the life of the road. The present value is obtained from the following relationship:

$$(PV) = \sum_{i=1}^{T} \frac{(MC)_i + (RUC)_i + (RC)_i}{(1+r)^i} \qquad (23)$$

where $(MC)_i$ = maintenance costs at year i,
$(RUC)_i$ = road users' costs at year i,
$(RC)_i$ = cost of road rehabilitation at year i,
T = life of the road in years, and
r = rate of interest.

If, in any particular year, no road maintenance or rehabilitation is carried out, $(MC)_i$ or $(RC)_i$ for that year is equal to zero. If maintenance is carried out more than once in any one year, $(MC)_i$ for that year is the sum of the costs of all maintenance operations undertaken during the year.

For a given road and traffic flow, the sum of the annual maintenance costs is a function of both the maintenance technology adopted and the extent and frequency of maintenance operations, or more formally

$$\sum_{i=1}^{T} \frac{(MC)_i}{(1+r)^i} = f \text{ (tech., } F, O)$$

where tech. = the technology adopted,
F = the frequency of maintenance operations, and
O = the extent of each maintenance operation, or the specified output.

The value of F may be low during the first years following the building of a road, and then gradually increase. In some cases it may be affected by the type of technology adopted: for example, the maintenance of a minimum quality standard of the road may require a higher frequency of maintenance operations if the technology adopted is more labour-intensive than capital-intensive.

The sum of road user costs is a function of the average level of road deterioration between two consecutive maintenance operations, and is therefore a function of the variables tech., F, and O, defined above:

$$\sum_{i=1}^{T} \frac{(RUC)_i}{(1+r)^i} = f \text{ (tech., } F, O).$$

The same relationship also applie to the sum of road rehabilitation costs:

$$\sum_{i=1}^{T} \frac{(RC)_i}{(1+r)^i} = f \text{ (tech., } F, O).$$

Therefore

$$(PV) = f \text{ (tech., } F, O).$$

Given the above relationship, (PV) must be estimated for each combination of the variables tech., F, and O in order to identify the socially most profitable combination of these variables (i.e. the most profitable combination of maintenance technology and maintenance policy). Since the number of combinations may be very large, a simplification that does not seriously affect the validity of the findings may be introduced. It may be assumed that the value of the variable O (the output of the maintenance operation) is the same for all technologies, and that this result may be achieved through an adjustment of the value of F. For example, if the maintenance frequency is higher, the same output may be obtained with a labour-intensive technology as with a capital-intensive one. Consequently, the present value of the stream of road users' costs over the life of the road will be the same for all maintenance technologies.

To identify the most appropriate combination of maintenance technology and maintenance policy (i.e. that with the lowest present value) the procedure is as follows:

(a) specification of the road life, T, i.e. the number of years that elapse between the adoption of the maintenance policy for an existing road and the time at which the road must be improved as a result of traffic saturation;

(b) specification of minimum road quality standards (e.g. maximum road roughness, maximum gravel loss), to be maintained over the life of the road;

(c) identification of the technologies that could technically ensure the desired maintenance;

(d) specification of alternative road maintenance policies (designed to meet alternative road quality standards), for each maintenance technology;

(e) estimation of the total inputs per maintenance operation for each combination of maintenance technology and maintenance policy;

(f) estimation of total costs per maintenance operation for each combination of maintenance technology and maintenance policy (i.e. estimation of maintenance costs in individual years—$(MC)_i$—for each combination);

(g) estimation of the present value of maintenance costs over the life of the road for each combination of maintenance technology and maintenance policy, i.e.

$$\left(\sum_{i=1}^{T} \frac{(MC)_i}{(1+r)^i} \right);$$

(h) estimation of yearly road users' costs for each road quality standard to be maintained over the life of the road;

(i) estimation of the present value of road users' costs over the life of the road for each road quality standard, i.e.

$$\left(\sum_{i=1}^{T} \frac{(RUC)_i}{(1+r)^i} \right);$$

(j) identification of the least costly road rehabilitation technology, to be used for all combinations of maintenance technology and maintenance policy;

(k) estimation of the present value of road rehabilitation costs over the life of the road for each combination of maintenance technology and maintenance policy, i.e.

$$\left(\sum_{i=1}^{T} \frac{(RC)_i}{(1+r)^i} \right); \text{ and}$$

(l) estimation of the present value of the sum of road maintenance costs, road rehabilitation costs and road users' costs over the life of the road, for each combination of maintenance technology and maintenance policy.

Table 15 gives an example of the steps that have just been outlined. The table gives the maintenance, rehabilitation and road users' costs for three combinations of maintenance technology and maintenance policy. In the interests of simplicity it is assumed that only the policy varies from one combination to the other: in other words, the example deals with the identification of the most appropriate maintenance policy for a given maintenance technology. The road is assumed to have a 10-year life subdivided into ten equal periods of one year each. Under the first policy there are no maintenance operations, and the maintenance cost is therefore zero throughout. In this case the road must be rehabilitated every three years. Under the second policy maintenance takes place in the second, fourth, eighth and tenth years, and the road needs to be rehabilitated once only, viz. in the sixth year. Under the third policy, maintenance is carried out once a year, and there is never any need for rehabilitation. Under all three policies road users' costs are computed on the basis of estimated traffic flows and the estimated average level of road deterioration for each year. The present value of the sum of maintenance costs, road rehabilitation costs and road users' costs is the total in the bottom row of the

Table 15. Calculation of present values with a view to identifying the most appropriate maintenance policy for a given maintenance technology

Years	First policy			Second policy			Third policy		
	Mainten-ance costs $(MC)_i$	Reha-bilita-tion costs $(RC)_i$	Road users' costs $(RUC)_i$	Mainten-ance costs $(MC)_i$	Reha-bilita-tion costs $(RC)_i$	Road users' costs $(RUC)_i$	Mainten-ance costs $(MC)_i$	Reha-bilita-tion costs $(RC)_i$	Road users' costs $(RUC)_i$
1st	0	0	1 000	0	0	800	1 500	0	600
2nd	0	0	1 000	3 000	0	800	1 500	0	600
3rd	0	10 000	1 000	0	0	800	1 500	0	600
4th	0	0	1 200	4 000	0	1 000	2 000	0	700
5th	0	0	1 200	0	0	1 000	2 000	0	700
6th	0	12 000	1 400	0	8 000	1 000	2 000	0	800
7th	0	0	1 400	0	0	1 200	2 500	0	800
8th	0	0	1 500	5 000	0	1 200	2 500	0	1 000
9th	0	14 000	1 500	0	0	1 300	2 500	0	1 000
10th	0	0	1 500	6 000	0	1 300	3 000	0	1 200
Whole decade (present value)	0	36 000	12 700	18 000	8 000	10 400	21 000	0	8 000
	48 700			36 400			29 000		

table for each of the three maintenance policies. In this particular example the third policy yields the lowest present value. Similar tables could be constructed for all the possible maintenance technologies under consideration in order to identify the most appropriate combination of maintenance technology and maintenance policy.

The procedure just described calls for accurate information on traffic flows and reliable road deterioration relationships. If such data are not available, it will not be possible to identify the most appropriate combination, and the public works department may decide to adopt a certain maintenance policy on the basis of past experience, or availability of labour and equipment. Different maintenance technologies may then be evaluated with respect to the policy adopted, and the most appropriate maintenance technology identified. In this case, however, there is no certainty that the combination adopted will be the optimal one.[1]

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[1] It should be pointed out that in any event the procedure for choice of maintenance technology and maintenance policy presented in this section is not the most rigorous one possible. A more comprehensive treatment of the subject would, however, be outside the scope of this manual. Readers who wish to acquire a better grasp of the subject may refer in particular to P. W. Abelson and A. D. J. Flowerdew: "Economic evaluation of road maintenance", in *Journal of Transport Economics*, May 1975.

Table 16. Present value of road costs according to whether a road is improved or not (in notional monetary units)

Nature of road	Year of road's life									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Non-improved	50	60	70	80	90	100	110	120	130	140
Improved	200	30	35	40	45	55	65	75	85	100

Road improvement

Timing

In the absence of budgetary constraints, road improvement projects are justified whenever it can be shown that the total costs (i.e. the sum of improvement costs, road maintenance costs, road users' costs) of an improved road are lower than would be the total costs of the same road without improvement (i.e. allowing as well for the benefits that may have to be forgone owing to the frequent closing of the road). Since the costs and forgone benefits are spread over a number of years, one must first determine when a road improvement project should be undertaken. The following example will clarify the idea of project timing. Let it be assumed that the remaining life of an existing road is ten years. (In this very simplified example it is assumed that the existing road will be closed and a new road built in its stead at the end of the tenth year.) Let it also be assumed that the discounted (i.e. present) value of the yearly costs is as indicated in table 16 according to whether the road is improved or not. Since a substantial sum is disbursed for improvement costs, improvement of the road results in a higher cost (200) in the first year than if the road were not improved. Road improvement is nevertheless worth undertaking in that year since the present value of the stream of costs for the improved road (730) is lower than that for the non-improved road (950). It may, however, be more profitable to postpone road improvement for one or more years. In order to make an optimal choice of the year in which the road should be improved, the present value of the stream of costs if the road is not improved must be compared with the present value of the stream of costs that would result if the road were improved at various dates. Such a comparison is summarised in table 17. The table gives the present value of the stream of costs which apply if road improvement is undertaken in any of ten particular years. The computations are based on the costs reported in table 16. For example, if the improvement is made in the first year—

$(PV)_I = 200 + 30 + 35 + 40 + 45 + 55 + 65 + 75 + 85 + 100 = 730,$
$(PV)_N = 50 + 60 + 70 + 80 + 90 + 100 + 110 + 120 + 130 + 140 = 950.$
Then $(PV)_N - (PV)_I = 950 - 730 = 220.$

Table 17. Optimal timing of a road improvement project

Year	Present value of costs		Difference ΔPV
	If road is improved $(PV)_I$	If road is not improved $(PV)_N$	
1st	730	950	220
2nd	680	950	270
3rd	655	950	295
4th	650	950	300
5th	665	950	285
6th	700	950	250
7th	755	950	195
8th	825	950	125
9th	910	950	40
10th	1 010	950	−60

If the improvement takes place in the fifth year—

$$(PV)_I = 50 + 60 + 70 + 80 + 200 + 30 + 35 + 40 + 45 + 55 = 665.$$

In this second case, the present values of the costs for the first four years are those applying to the non-improved road, while the values for the fifth to the tenth year are those applying to the improved road. Thus

$$(PV)_N - (PV)_I = 950 - 665 = 285.$$

It can be seen from table 17 that the optimal year for road improvement is the fourth, since in that year the difference between $(PV)_N$ and $(PV)_I$ is the highest. It can also be seen that road improvement will not be profitable if undertaken in the tenth year since in that case $(PV)_N$ is lower than $(PV)_I$, the difference between the two present values being equal to 60.

The formula for identifying the optimal starting date of a road improvement project is obtained as follows. The first step in the identification process is to estimate the life of the improved road, T_I years, partly by analysing the growth of traffic flows. Other relevant factors are defined as follows:

$(RUC)_{I, i}$ = annual road users' costs that apply to the improved road in year i (road users' costs should include vehicle operation costs and vehicle occupant's opportunity cost);

$(MC)_{I, i}$ = annual maintenance costs that apply to the improved road in year i;

$(RC)_{I, i}$ = road rehabilitation costs that apply to the improved road in year i;

C_I = road improvement costs;

$(RUC)_{N,i}$ = annual road users' costs that apply to the non-improved road in year i;

$(MC)_{N,i}$ = annual maintenance costs that apply to the non-improved road in year i;

$(RC)_{N,i}$ = road rehabilitation costs that apply to the non-improved road in year i; and

$(FB)_{N,i}$ = road benefits forgone as a result of the closing of the non-improved road to traffic in year i (it being assumed that the improved road will remain open all year round and that there will be no losses of road benefits).

The next step is to estimate $[(PV)_N - (PV)_I]$ for different road improvement dates. The differences between present values without or with improvement—ΔPV, or $(PV)_N$ minus $(PV)_I$—are as follows:

$$(\Delta PV) = [(PV)_N - (PV)_I] = \sum_{i=1}^{T_I} \frac{(MC)_{N,i}+(RC)_{N,i}+(RUC)_{N,i}+(FB)_{N,i}}{(1+r)^i}$$

$$-\sum_{i=1}^{T_s-1} \frac{(MC)_{N,i}+(RC)_{N,i}+(RUC)_{N,i}+(FB)_{N,i}}{(1+r)^i}$$

$$-\sum_{i=T_s}^{T_I} \frac{(MC)_{I,i}+(RC)_{I,i}+(RUC)_{I,i}}{(1+r)^i}$$

$$-C_I \tag{24}$$

where $(PV)_N$ = costs attached to the non-improved road, and

$(PV)_I$ = costs attached to the road if improved.

The first summation term in equation (24) represents $(PV)_N$, the costs that would accrue if the road were not improved. The second summation term represents the costs that accrue from the current year (year 1) to the year preceding that of road improvement (year $(T_s - 1)$). These costs are therefore equal to the costs attached to the non-improved road from year 1 to year $(T_s - 1)$. The third summation term represents the costs that would accrue if the road were improved at year T_s. The sum of the last two terms and C_I is equal to $(PV)_I$. With this equation it is possible to identify the optimal road improvement date by assigning different values to T_s ($T_s = 1, 2, 3 \ldots T_I$) and calculating the corresponding ΔPVs, the highest of which denotes the optimal road improvement date.

Evaluation criteria

Unless there are budgetary constraints, a road improvement project should be adopted whenever it would reduce the net present value of the stream of costs (i.e. whenever ΔPV is positive).[1] If there are such constraints, the profitability of the road improvement project must be compared to that of other projects under consideration within the public works department, or within other agencies of government according to the kind of constraint. In the case of road improvement the criteria developed earlier for the evaluation of projects will take the following specific forms:

1. Net present value. Road improvement projects must be ranked along with other projects according to the present value of the stream of their net benefits, ΔPV, obtained from

$$\Delta PV = (PV)_N - (PV)_I$$

where present value is defined as in the preceding section on the timing of these projects. It should be noted that ΔPV is estimated on the basis of an optimal improvement date.

2. Benefit-cost ratio. It can be shown from the foregoing section on timing that the present value of road improvement benefits [2] is equal to

$$(PV)_B = \sum_{i=1}^{T_I} \frac{(MC)_{N,i}+(RC)_{N,i}+(RUC)_{N,i}+(FB)_{N,i}}{(1+r)^i} \tag{25}$$

The present value of road improvement costs is equal to

$$(PV)_C = \sum_{i=1}^{T_s-1} \frac{(MC)_{N,i}+(RC)_{N,i}+(RUC)_{N,i}+(FB)_{N,i}}{(1+r)^i}$$

$$+ \sum_{i=T_s}^{T_I} \frac{(MC)_{I,i}+(RC)_{I,i}+(RUC)_{I,i}}{(1+r)^i}$$

$$+ C_I \tag{26}$$

Therefore the benefit-cost ratio can be expressed as

$$\frac{(PV)_B-(PV)_C}{(PV)_C}.$$

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[1] The ΔPV to be taken into consideration is one based on the optimal starting date for the project.

[2] Road improvement benefits are, in this case, forgone costs.

3. Internal rate of return. If projects are to be ranked according to their internal rate of return, an unknown, ρ, is substituted for the discount rate, r, in the foregoing formulation of the benefit-cost ratio. The value of ρ is then calculated by solving the equation

$$(PV)_B = (PV)_C.$$

Range of designs and technologies

The estimation of the social profitability of a road improvement project, as well as the determination of its optimal starting date, should be based on the most appropriate (i.e. profitable) combination of design and technology for the project. The first step towards identifying that combination is to identify, for a given road, all the improvement designs that could be implemented. The range of potential designs will obviously be limited by a number of factors, including the current state of the road, topography and climate, and current and future traffic flows. A potential improvement design may differ from the original road design in a number of respects, including road carriageway and shoulder widths, horizontal and vertical alignments, subgrade strength and type of paving. For the present purpose a road improvement project does not include a major rerouting of the road: if a major rerouting is to take place, the road project should be regarded as relating to the construction of an entirely new road.

Potential construction technologies should next be identified for each possible road design in the light in particular of the time at which the improvement must be carried out. The road improvement costs for each potential combination of design and technology should then be estimated. It is assumed that the construction technology used for the road improvement project does not affect road users' costs, road maintenance costs and road rehabilitation costs. In other words, all potential construction technologies must satisfy required road quality standards. Maintenance costs, road rehabilitation costs, and road users' costs are therefore assumed to be a function of the road design only. The most profitable (i.e. least costly) maintenance policy for each possible road design must also be identified. This step yields an estimate of maintenance costs, road rehabilitation costs and road users' costs.

Socially, the most appropriate combination of design and technology is one that reduces to a minimum the present value of the sum of road improvement costs, road maintenance costs, road rehabilitation costs and road users' costs. It should be noted that the identification procedure just outlined rests on the assumption that road benefits are not affected by the design adopted, and therefore need not be taken into consideration when evaluating different versions of road improvement projects. This assumption should, however, be

dropped in cases in which it is expected that the road design adopted will have a significant effect on road benefits.

New roads forming part of sectoral projects

As already stated, new road projects forming part of sectoral investment projects (e.g. agricultural projects and mining projects) need not be ranked and evaluated along with other road projects, since their adoption results from the adoption of the larger projects of which they are part. Similarly, the timing of the construction of a road that is part of a sectoral project is closely linked to the timing of the sectoral project as a whole. The most appropriate combination of design and technology for a project of this type reduces to a minimum the present value of the sum of construction costs, maintenance costs, rehabilitation costs and road users' costs, $(PV)_c$, which is obtained from the following equation:

$$(PV)_c = C_s + \sum_{i=1}^{T} \frac{(MC)_i + (RC)_i + (RUC)_i}{(1+r)^i} \qquad (27)$$

where T = life of the new road project in years, and

$\quad C_s$ = new road construction costs,

$(MC)_i$, $(RC)_i$, $(RUC)_i$ and r being defined as above.

The life, T, of the new road is the same as the life of the new public investment project of which it is a part.

It should be noted that road benefits need not be included in the evaluation of different combinations of design and technology since they are the same for all. The identification of the most appropriate combination is therefore more a matter of reducing cost than an exercise in social cost-benefit analysis.

The steps involved in the identification of the most appropriate combination are the same as those applying to road improvement projects, namely—

(a) identification of possible designs;

(b) identification of possible construction technologies for each design;

(c) estimation of road construction costs for each possible combination of design and technology; and

(d) identification of the most profitable maintenance policy for each design.

New roads to shorten travelling distances

When the main aim in building a new road is to shorten travelling distances the project has the following effects, which should be taken into account for the purposes of evaluation:

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(a) lower road users' costs;

(b) lower maintenance costs of existing roads from which traffic is diverted towards the new road; and

(c) generation of benefits in the areas crossed by the new road.

If it has been decided to build a road which will shorten the travelling distance between two population centres, it can be assumed that part of the traffic flowing on existing roads will be diverted to the new road. The present value of net benefits to be derived from the new road is equal to

$$(NPV) = X_1 - X_2 - X_3 - X_4 + X_5$$

where X_1 = sum of maintenance costs, road rehabilitation costs and road users' costs, which would apply to the existing roads if the new road is not built;

X_2 = sum of maintenance costs, road rehabilitation costs, and road users' costs which apply to existing roads if the new road is built;

X_3 = the construction costs of the new road;

X_4 = the sum of maintenance costs, road rehabilitation costs, and road users' costs which apply to the new road; and

X_5 = benefits derived from the new road.

Costs and benefits are then:

$X_1 - X_2$, the present value of forgone costs (i.e. benefits) resulting from the building of the new road,

$X_3 + X_4$, the present value of the new road costs, and

X_5, the present value of benefits derived from the new road.

The following further terms occur in the equation for the present value of net benefits for a new road:

$(MC)_{N, i}$ = maintenance costs of new road at year i,

$(RC)_{N, i}$ = rehabilitation costs of new road at year i,

$(RUC)_{N, i}$ = road users' costs which apply to the new road at year i,

$C_{N, i}$ = construction costs of new road at year i,

B_i = benefits derived from the new road at year i,

$(MC)_{E, i}$ = road maintenance costs at year i for existing roads, if the new road is not built,

$(RC)_{E, i}$ = road rehabilitation costs at year i for existing roads if the new road is not built,

$(RUC)_{E, i}$ = road users' cost at year i for existing roads if the new road is not built,

$(MC)'_{E,i}$ = road maintenance costs at year i for existing roads if the new road is built,

$(RC)'_{E,i}$ = road rehabilitation costs at year i for existing roads if the new road is built,

$(RUC)'_{E,i}$ = road users' costs at year i for existing roads if the new road is built,

T = life of the new road in years,

T_s = starting year for the construction of the new road, the current year being counted as year 1, and

t = duration of the construction period, in years.

The net present value of the new road project is then as follows:

$$(NPV) = \sum_{i=1}^{T_s+t+T} \frac{(MC)_{E,i}+(RC)_{E,i}+(RUC)_{E,i}}{(1+r)^i}$$

$$- \sum_{i=1}^{T_s+t} \frac{(MC)_{E,i}+(RC)_{E,i}+(RUC)_{E,i}}{(1+r)^i}$$

$$- \sum_{i=T_s+t+1}^{T_s+t+T} \frac{(MC)'_{E,i}+(RC)'_{E,i}+(RUC)'_{E,i}}{(1+r)^i}$$

$$- \sum_{i=T_s}^{T_s+t} \frac{C_{Ni}}{(1+r)^i}$$

$$- \sum_{i=T_s+t+1}^{T_s+t+T} \frac{(MC)_{N,i}+(RC)_{N,i}+(RUC)_{N,i}}{(1+r)^i}$$

$$+ \sum_{i=T_s+t+1}^{T_s+t+T} \frac{B_i}{(1+r)^i} \tag{28}$$

The equation can be used to identify T_s, the year in which the construction of the new road should start, by calculating the T_s that will yield the maximum value for (NPV). (NPV) should therefore be calculated for consecutive values of T_s, starting with $T_s = 0$. The calculations may be stopped once the value of (NPV) decreases when T_s is increased by one year.

New road projects may be ranked according to their net present value, as defined in equation (28). Alternatively, they may be ranked according to the value of their benefit-cost ratios, as follows. The present value of road benefits, $(PV)_B$, is equal to $(X_1 - X_2 + X_5)$. The present value of road costs, $(PV)_C$, is equal to $(X_3 + X_4)$. Therefore the benefit-cost ratio of the new road project is equal to

$$\frac{X_1 - X_2 + X_5 - X_3 - X_4}{X_3 + X_4}.$$

It may be safely assumed that neither the benefits derived from roads built mainly to shorten travelling distances, nor the effects of such roads on the existing road network, are affected by the particular combination of design and technology that is adopted. That combination affects only road construction costs, road maintenance costs, road rehabilitation costs and road users' costs. The steps required for the identification of the most appropriate combination are therefore the same as those applied to new roads that are part of sectoral projects, namely—

(a) identification of all possible road designs;

(b) identification of the various construction technologies available for each possible road design;

(c) estimation of the costs of each combination of design and technology; and

(d) identification of the most appropriate maintenance policy for each possible design, and estimation of the costs (i.e. maintenance costs, road rehabilitation costs and road users' costs) that apply to the most appropriate maintenance policy for each design.

The costs attached to the most appropriate combination of design and technology are used when estimating the project profitability for ranking purposes. These costs should also be used for the purpose of establishing the appropriate timing of the project.

Developmental roads

The main purpose of developmental roads is to increase the density of the road network in regions where development is hampered by lack of communication facilities. Such roads may therefore be regarded as part of integrated regional development plans. It is unusual for a developmental road to be ranked along with other public investment projects before a decision is taken to build it, since the decision is usually taken at the time when an over-all regional investment plan is worked out. On the other hand, the timing of the construction of a developmental road is a function of budgetary constraints and of the relative profitability of the other public investment projects that are part of the regional plan. Decisions concerning project timing are not the responsibility

of the project evaluator in the public works department and should be left to the staff in charge of implementing the regional plan.

However, the road project evaluator and the regional development planner do both have an interest in the routing and other aspects of the design of a developmental road, which should ideally be chosen so as to achieve the maximum difference between the costs and benefits derived from the road. Road routing may affect the value of benefits to be derived from the road, and certainly affects construction costs, maintenance costs and road users' costs. On the other hand, for a given road route, road design affects only the above-mentioned costs, provided that the design adopted does not restrict future traffic flows. The road project evaluator and the regional development planner should therefore work closely together in order to identify ranges of possible road routings and designs. The road project evaluator may then identify the most appropriate road routing and combination of design and technology.

It is not always possible, however, to apply this procedure. As suggested in Chapter 1, it is extremely difficult, if not impossible, to obtain an accurate estimate of the benefits to be derived from a developmental road. It is even more difficult to estimate such benefits for different road routings, and so they are often determined on the basis of general expectations concerning their effect on social and economic progress in the area. The range of possible road routings identified on the basis of such considerations is generally narrow.

The project evaluator may then identify different combinations of design and technology for each road routing, and cost each of the combinations (i.e. estimate the sum of road construction costs, road maintenance costs, road rehabilitation costs, and road users' costs). The least costly combination of design and technology is identified for each road routing. The planner may then adopt one of the routings on the basis of cost information provided by the road project evaluator, and on the basis of his subjective evaluation of benefits attached to each. In short, if the road benefits are not quantifiable, the most appropriate combination of design and technology for developmental roads can be identified as follows:

(a) identification of the range of possible road routings on the basis of socio-economic expectations, some of which are not quantifiable;

(b) identification of the different possible combinations of design and techno-logy for each routing;

(c) estimation of road construction costs for each combination of design and technology;

(d) identification of the most appropriate road maintenance policy for each road design; estimation of costs attached to the most appropriate mainte-nance policy;

(e) identification of the most appropriate combination of design and technology for each road routing on the basis of information gathered at stages *(a)* to *(d)*;

(f) evaluation of each possible routing on the basis of information gathered under steps *(a)* and *(e)*, and identification of the most profitable alternative.

BREAK-EVEN ANALYSIS

Project evaluators may not always be able to obtain accurate estimates on a number of variables included in the evaluation of different combinations of design and technology. The main variables for which it may not be possible to obtain accurate estimates are unskilled labour productivity, Z, the wages of unskilled labour, w, and equipment rental rates, R.[1]

In some cases estimation errors in these variables may be considerable and can lead to the adoption of an inappropriate combination of design and technology. It is therefore important for project evaluators to regard such variables as unknowns and to undertake a break-even analysis in order to identify the combination that should be adopted. The following example will show how to perform such an analysis. Let it be supposed that the exact values of Z, w, and R are not known but that project evaluators can provide an accurate range of values for each of the above variables, such that—

$$Z_1 \leqslant Z \leqslant Z_2$$
$$w_1 \leqslant w \leqslant w_2$$
$$R_1 \leqslant R \leqslant R_2$$

Let it now be supposed that a labour-intensive technology is being compared with a capital-intensive one for a given road activity, and that the cost of the activity is obtained from the following respective relationships:

$$C_C = M + A_C . Z . w + E_C . R$$
$$C_L = M + A_L . Z . w + E_L . R$$

where C_C = costs attached to the capital-intensive technology;
C_L = costs attached to the labour-intensive technology;
M = cost of materials;
E_C = equipment inputs, in hours, for the capital-intensive technology;
E_L = equipment inputs, in hours, for the labour-intensive technology;
A_C = part of activity output obtained through the use of manual labour when the capital-intensive technology is used (e.g. cubic metres of earth excavated);

[1] Estimates of equipment rental rates are very sensitive to the value assigned to equipment utilisation rates (see Chapter 5). Estimation errors on R are mainly the result of estimation errors in equipment utilisation rates.

A_L = part of activity output obtained through the use of manual labour when the labour-intensive technology is used;

Z = labour productivity in man-hours per unit of output (e.g. man-hours per cubic metre of rock excavated); the greater the value of Z, the lower the productivity of labour;

w = wage rate for unskilled labour; and

R = equipment rental rate.

Break-even analysis may now be used in order to determine minimum and maximum values for the variables Z, w, and R that will equate C_C to C_L. These minimum and maximum values may be obtained in the way described in the following sections.

Unskilled labour productivity

Equating C_C to C_L gives

$$M + A_C.Z.w + E_C.R = M + A_L.Z.w + E_L.R$$

or,

$$Z(A_C.w - A_L.w) = R(E_L - E_C).$$

Then

$$Z = R \cdot \frac{E_L - E_C}{A_C.w - A_L.w} = \frac{R}{w} \cdot \frac{E_L - E_C}{A_C - A_L}.$$

The maximum value of Z that equates C_C to C_L is obtained by achieving the maximum value for the ratio $\dfrac{R}{w}$, that is, by using a maximum value for R (i.e. $R = R_2$) and a minimum value for w (i.e. $w = w_1$):

$$Z_{max} = \frac{R_2}{w_1} \cdot \frac{E_L - E_C}{A_C - A_L}$$

Similarly, the minimum value of Z will be equal to

$$Z_{min} = \frac{R_1}{w_2} \cdot \frac{E_L - E_C}{A_C - A_L}.$$

Z_{min} and Z_{max} are, respectively, the maximum and minimum break-even unskilled labour productivities (i.e. labour productivity that will equate C_C to C_L), Z_{min} applying to the assumed pair of values (R_1, w_2) and Z_{max} applying to the assumed pair of values (R_2, w_1). Let us now suppose that it has been decided to use a labour-intensive technology whenever

$$C_L \leqslant C_C$$

In this case we must have

$$Z_1 \leqslant Z_{min}$$

or

$$Z_1 \leqslant Z_{max}$$

depending on which pair of values, (R_1, w_2) or (R_2, w_1), is assumed when calculating Z.

Wages of unskilled labour

Using the same procedure as in relation to unskilled labour productivity, the following relationships can be obtained:

$$w_{max} = \frac{R_2}{Z_1} \cdot \frac{E_L - E_C}{A_C - A_L}$$

and

$$w_{min} = \frac{R_1}{Z_2} \cdot \frac{E_L - E_C}{A_C - A_L}.$$

A labour-intensive technology should then be used whenever—

$$w_1 \leqslant w_{min}$$

or

$$w_1 \leqslant w_{max}.$$

depending on which pair of values, (R_1, Z_2) or (R_2, Z_1), is assumed when calculating w.

Equipment rental rates

If C_C and C_L are equated,

$$Z(A_C \cdot w - A_L \cdot w) = R(E_L - E_C).$$

Then

$$R = Zw \frac{A_C - A_L}{E_L - E_C}.$$

Then

$$R_{max} = Z_2 w_2 \frac{A_C - A_L}{E_L - E_C}$$

and

$$R_{min} = Z_1 w_1 \frac{A_C - A_L}{E_L - E_C}.$$

A labour-intensive technology should be adopted whenever it can be shown shown that

$$R_1 \geqslant R_{min} \text{ or } R_2 \geqslant R_{max}$$

depending on which pair of values, (Z_1, w_1) or (Z_2, w_2), is assumed when calculating R.[1]

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[1] It should be realised, however, that there is no need to calculate a break-even value for all variables that cannot be accurately estimated. Because Z, w and R are all inter-related, it is sufficient to calculate break-even values for a single variable and to make a choice among different combinations of design and technology on the basis of these values.

EVALUATION OF ALTERNATIVE
TECHNOLOGIES AT SHADOW PRICES

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Most of the projects dealt with every day in various government agencies are still evaluated on the basis of a purely financial analysis and market prices. In some cases the project evaluator is not aware of the approach to project evaluation used in social cost-benefit analysis, and does not realise that public projects—and, indeed, private investment projects as well—should be judged in terms of their effect on the economy as a whole in the light of national goals and social objectives. In other cases the evaluator mistrusts the social cost-benefit approach and prefers the usual financial analysis. In any event there is little doubt that at present the use of shadow prices for project evaluation is an alien and little-used procedure. It is hoped that the present manual will make that procedure a little more familiar, and that project evaluators will begin to apply it in project evaluation. In fact there are already signs that social cost-benefit analysis will ultimately become the foundation of all such operations: just as the concept of externalities was little used in the past but is now very familiar and often used in this context, the application of social cost-benefit analysis should become widespread, particularly in developing countries where it is most needed.

The estimation of shadow prices and of the social rate of discount is a fairly complex matter. The arguments on the subject are not yet fully settled, and project evaluators may therefore be puzzled by the number of alternative formulations found in works dealing with the subject. Furthermore, the data needed for the estimation of shadow prices are often not available. This being so, when shadow prices are being estimated a number of assumptions often have to be made regarding the value of some of the coefficients included in the formulation; a certain amount of guesswork is often necessary, and needless to say, the validity of the assumptions is often unproven. Thus estimated shadow prices may not be entirely accurate expressions of the true social value of inputs and outputs; but they do constitute a better measure of that value than is

provided by market prices. They represent, in other words, the best available measure of the value of a project's inputs and outputs.

At present there are two main approaches to the formulation of shadow prices, namely those of the United Nations Industrial Development Organisation (UNIDO) [1] and of the Organisation for Economic Co-operation and Development (OECD).[2] A great deal has been said about these two approaches, and points are still made for and against each of them.[3] In the present manual the UNIDO approach to project evaluation is used, because it is better suited to the problem at hand (i.e. choice among alternative versions of road projects): for the particular case of road construction, the UNIDO approach seems more flexible and more manageable—in terms of the data needed in order to estimate shadow prices—than the OECD approach. The latter part of this chapter will provide a brief account of the evaluation methodology included in the UNIDO guidelines, with a view to showing project evaluators how the main cost and benefit items of road projects should be adjusted in order to compensate for the distortions resulting from the use of market prices. It will be assumed that the adjustment coefficients are provided to project evaluators by the national planning agency, or in other words that project evaluators need know only how to use such coefficients in project evaluation; since the present chapter was written on those assumptions, it does not include enough information to enable project evaluators themselves to estimate the coefficients that are needed.

Adjustment coefficients would usually have to be estimated by a team of trained economists working closely with public planners. Furthermore, the decision to adopt shadow prices rather than market prices in project evaluation is one to be taken by the highest authorities in the country, inasmuch as it is partly a political decision. The consequence of such a decision is that all public investment projects are evaluated on the basis of shadow prices. Indeed, it does not make sense to let the evaluators of individual projects make their own estimates of the adjustment coefficients needed to arrive at shadow prices: this would constitute unnecessary duplication of estimation work and could lead to uneven evaluation of public investment projects since different evaluators might arrive at different estimates for the same coefficients.

When a public works department wishes, independently of other govern-

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[1] United Nations Industrial Development Organization: *Guidelines for project evaluation*, by Partha Dasgupta, Stephen Marglin and Amartya Sen, Project Formulation and Evaluation Series, No. 2 (New York, United Nations, 1972; sales no. E.72.II.B.11), subsequently cited as "UNIDO guidelines".

[2] I. M. D. Little and J. A. Mirrlees: *Project appraisal and planning for developing countries* (London, Heinemann Educational Books, 1974).

[3] For a good summary of the criticisms, see the February 1972 issue of the *Bulletin of the Oxford University Institute of Economics and Statistics*, which contains nine papers on the OECD and UNIDO approaches.

ment agencies, to use shadow prices in project evaluation, project evaluators in the department should refer to the UNIDO guidelines for information on the way to estimate the adjustment coefficients that are required; unless they are themselves economists with experience in this field, they may need to call on specially trained economists for assistance. The present chapter provides general formulations of shadow prices based on a number of assumptions which must be analysed before adoption. If they are found to be invalid, the shadow price formulations given in this manual must be modified, although the over-all approach to shadow pricing that is followed in the manual may none the less guide the project evaluator in his attempts to develop a more appropriate formulation. If the assumptions used in the manual are found to be valid, the project evaluator may use the shadow price formulations it provides.

Ideally, as already indicated, the evaluator should be provided with all adjustment coefficients and value parameters by the national planning agency. In some cases, however, the agency may be unable to estimate the coefficients because it lacks data, or it may be unsure about the values to be assigned to certain parameters. In such cases another approach may be adopted. Under this second approach the project evaluator regards adjustment coefficients and value parameters as unknowns. He then undertakes a break-even analysis and obtains break-even values (also called "switching" values) for these items.[1] The break-even values of coefficients or parameters are communicated to the public planner, and a decision may then be taken on which project alternative to adopt on the basis of informed guesses regarding the probable ranges of these coefficients or parameters. This procedure is defined in the UNIDO guidelines as a "bottom-up" procedure as opposed to the "top-down" procedure whereby the flow of information is provided to the project evaluator by the government decision makers. The guidelines describe the "bottom-up" procedure as follows [2]:

The Cen   ning Organisation (CPO) indicates to formulators and evaluators the objectiv   ant to the project at hand. The formulators and evaluators indicate to the CPO   e sensitivity of project design to the weights on objectives and the social rate of discount, and the CPO presents variants that are optimal in different ranges of parameter values to policy makers for explicit choice. Policy makers then choose one from among a set of alternatives. The CPO must make policy makers aware of the critical role of national parameters by spelling out the implication for parameter magnitudes of choosing one variant over another.

Gradually, as the awareness, interest and understanding of policy makers grow, it may be possible to move from the bottom-up methodology to a top-down methodology in which policy makers weight and determine the shadow prices in advance of project formulation and evaluation.

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[1] Break-even values equate the profitability of alternative versions of the same project. See p. 169.

[2] UNIDO guidelines, op. cit., p. 153.

SOCIAL VALUATION OF INPUTS AND OUTPUTS

Two criteria of project profitability were recommended in Chapter 7—the net (discounted) present value and the benefit-cost ratio. Both require the estimation of the present values of project costs and benefits, which may be obtained from the following two relationships:

$$\text{present values of costs} = \frac{C_1}{1+r} + \frac{C_2}{(1+r)^2} + \ldots + \frac{C_n}{(1+r)^n} = \sum_{t=1}^{n} \frac{C_t}{(1+r)^t};$$

$$\text{present value of benefits} = \frac{B_1}{1+r} + \frac{B_2}{(1+r)^2} + \ldots + \frac{B_n}{(1+r)^n} = \sum_{t=1}^{n} \frac{B_t}{(1+r)^t}$$

where r = market rate of interest or discount rate,
$\quad C_t$ = costs at year t,
$\quad B_t$ = benefits at year t, and
$\quad n$ = life of the project, in years.

The two criteria were applied to various types of road project, and it was suggested that, as a first approximation, market prices should be used in the estimation of project costs and benefits. It was also suggested that in order to calculate the present value of the streams of costs either the market rate of interest or the rate of interest applying specifically to an individual road project should be used. It will now be shown that in most cases these market prices and market rates are not appropriate if what the project evaluator wishes to estimate is the true social profitability of different versions of road projects. Market prices may also need to be adjusted in order to help attain income distribution objectives.

Inappropriateness of market wages and prices

It was shown in Chapter 7 that the main items to be taken into consideration when comparing alternatives of a road project are construction costs, maintenance costs and road users' costs, and that benefits rarely need to be included in such a comparison. These costs can be conveniently disaggregated as follows:

(a) unskilled labour costs (local labour);

(b) skilled labour costs (local labour);

(c) costs of local materials;   ·

(d) land costs; and

(e) foreign exchange costs (foreign labour and imported equipment and materials).

In order to estimate the latter five costs, project evaluators may as a first approximation use market wage rates, market prices, and the official foreign exchange rate. Estimations made on this basis may, however, lead to the adoption of inappropriate versions of projects since the prices on which these costs are based are in general distorted and fail to reflect the true social value, or relative scarcity, of inputs used in the projects; in other words market prices cannot be relied upon to allocate material resources among investment projects in such a way as to maximise social welfare. Price distortions produce a misallocation of scarce resources such as capital and foreign exchange: they tend to favour the unwarranted adoption of capital-intensive technologies, they are often responsible for the wastage of scarce foreign exchange, and last but not least they generate unemployment.

Public project evaluators may therefore need to use adjusted market prices, generally referred to as "shadow" or "accounting" prices. The following two examples illustrate the need to use shadow prices instead of market prices in public project evaluation. Let it be supposed first that unemployed workers in a given country receive daily unemployment benefits amounting to the current daily unskilled labour wage. The government may contemplate using some of the unemployed workers on productive investment projects, such as the building of rural roads or the planting of trees. To the question how should the government value labour when evaluating the above projects, the answer is that labour costs should be valued at zero since the government is committed to pay unemployment benefits amounting to the current daily wage whether unemployed workers are hired on the proposed projects or not. If labour costs were valued at the current market wage the government would be double-counting costs. While it makes sense in this case, therefore, for public project evaluators to use a shadow wage of zero, it also makes sense for a private entrepreneur to use the current market wage. A private entrepreneur must pay the hired labour out of his pocket since the government will stop paying unemployment benefits once the workers find a job. Thus, unless the government decides to reimburse him for such payments, he cannot value labour at a shadow wage of zero.

The second example is one in which the government decides to hire currently self-employed workers for a road project. Let it be supposed that these workers will be paid the current market wage of US $2 a day. Let it also be supposed that each of the above workers, before being hired on the road project, used to pick wild berries which he sold at the end of the day on the market place for US $1.50.[1] In this case, the public project evaluator will value daily

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[1] It is assumed, in this example, that the obtention of wild berries calls for no capital investment and no labour other than that used to pick them.

labour wages at US $1.50, since by hiring the workers for the road project society must give up only US $1.50 of output. Yet, the private entrepreneur must, again, value labour at the current daily market wage of US $2. As shown in these examples, shadow wages of unskilled labour constitute a better measure of the true social value of labour than do market wages.

Distortions between the market and shadow wages of unskilled labour occur for various reasons. First, market wages tend to be distorted upward by a number of so-called "institutional" factors. For example, statutory minimum wage rates raise market wage rates above the levels corresponding to labour productivity, so that the prevailing wage is usually higher than the opportunity cost of labour. Secondly, the wages of unskilled labour may be kept below the opportunity cost of labour by custom or a lack of labour mobility. In general, custom or government policy are responsible for the discrepancy between market wages and the social value of unskilled labour as expressed by the shadow wage. Evidence of such a discrepancy is provided by the massive unemployment or underemployment that are characteristic of many developing countries. This observation does not imply that labour should necessarily be paid a wage equal to its opportunity cost, but that projects should be evaluated as if labour were paid at that rate, since for the nation as a whole the correct measuring rod is opportunity cost.

The wages of skilled labour may also be distorted, being either higher or lower than they would be in the absence of distortions. Skilled workers may not be able to bargain for higher wages with their employers if they are not organised in trade unions or if employers enjoy a monopsony power in the skilled labour market (i.e. if employers can dictate the wage level as a result of being the sole employers in a particular field or area). Conversely, trade unions may be strong enough to obtain for their members wages that are higher than labour opportunity cost.

Another very common distortion in developing countries is that of foreign exchange rates. In such countries the national balance of payments is almost always a problem, and in most of these countries there is a so-called "foreign-exchange gap". When exports grow at a lower rate than imports, governments sometimes devalue the national currency, or more frequently take a variety of other steps such as the imposition of tariffs and quotas on imports and the granting of subsidies and tax exemptions for exports. When such measures interfere with free trade, there is a divergence between the official exchange rate and the exchange rate that would have obtained under free trade, and the official exchange rate does not adequately reflect the gains and losses to the economy from obtaining or giving up an additional unit of foreign exchange. In general, it can be shown that the local currency is overvalued. Distortions of the foreign exchange rate may be found in industrialised countries as well.

However, since the economies of these countries tend to be less dependent on foreign trade than do those of developing countries, and since the level of tariff duties is usually not as high in industrialised countries as in developing countries, distortions of the foreign exchange rate are usually much more severe in the latter countries than in the former. It is outside the scope of this manual to review and discuss the various arguments for or against the maintenance of official exchange rates, but it should be noted that such rates tend to encourage the choice of technologies that require a high proportion of imported resources and a low proportion of domestic resources: in the case of road construction, low rates of exchange favour the use of capital-intensive construction technologies since they favour the import and use of construction equipment.

The market prices of local materials may also be distorted for a number of reasons. First, the production of such materials requires the use of labour and foreign exchange. Distortions in the prices of these two inputs will be reflected in the prices of the materials produced: if the proportion of unskilled labour costs in total costs is high the market prices of materials may be higher than their shadow prices, whereas if it is the proportion of foreign exchange costs in total costs that is high the market price of materials may be lower than their shadow price. Secondly, there may be a monopoly in the supply of materials and the producer may fix market prices at will, usually higher than they would be in a free market. Thirdly, the government may subsidise investors by allowing them to obtain loans at low interest rates; production costs are reduced as a result of such a policy, and the prices of materials may thus be lower than they would be if interest rates had not been artificially lowered.

The price of land may also be higher or lower than its true social value (i.e. its shadow price), depending on the circumstances in which the government acquires land for the purpose of building a new road. The shadow price of land should be equal to its opportunity cost expressed as the present value of the net benefits that can be obtained from the land in its next best possible use (e.g. the production of some crop). However, the rules governing the acquisition of land by the government may not be based on the concept of opportunity cost: the government may, for example, be obliged to pay a price for private land even if it has no other potential use and should therefore on purely economic grounds be valued at zero; conversely, the government may put a ceiling on the price it will pay for land to be used in public investment projects, and thus acquire land below its shadow price.

It may be concluded that market prices generally need to be adjusted if project evaluators intend to estimate the true social profitability of projects. In many cases the chief prices to be adjusted are those of labour (skilled and unskilled) and of foreign exchange, since the costs of materials and land do not usually differ from one version of a project to another.

The analysis thus far has not provided an answer to one question which may be puzzling the reader, viz. whether instead of adjusting market prices to take account of distortions it would not be better to do away with the distortions altogether. Indeed, it would undoubtedly be desirable. Doing away with distortions, however, means changing the existing institutions. This may need a very long time, and in fact it may not be politically or economically feasible at all: market imperfections are found even in the most developed countries. Unless and until the institutional framework is improved, investment projects must be selected on the basis of adjusted or shadow prices.

Inappropriateness of the market rate of interest

Because the market rate of interest does not constitute an adequate measure of the rate of decline of the value of consumption over time for society as a whole, benefits and costs should be discounted on the basis of the "social rate of discount".[1] One of a government's main goals is to use national resources in a way which will maximise the citizens' consumption. The amount of consumer goods that are available at any one time is largely a result of past investment. Conversely, current investment yields its fruits in the future. Let it be supposed that a given current investment yields the following stream of net benefits (i.e. gross benefits minus costs) from year 0 to year T, where T is the life of the investment project:

$$B_0, B_1, B_2, \ldots B_T$$

What then is the over-all consumption derived from the project? At first sight, over-all consumption might seem to be as follows:

$$B = B_0 + B_1 + B_2 + \ldots + B_T \tag{29}$$

where B is defined as the net aggregate consumption benefit. Equation (29) implies that it does not matter to society whether units of consumption are made available today or at any other future time: society will be willing to give up one dollar's worth of consumer goods today and invest the dollar instead, provided that it gets one dollar's worth of consumer goods at some future time.

It is obvious, however, that this is not what happens in practice. In general, a higher value is put on current consumption than on future consumption. This is especially true in developing countries where current consumption is low. In those countries current consumption usually consists of essential con-

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[1] The following formulation of the social rate of discount is based on that provided on pages 155 and 156 of the UNIDO guidelines, op. cit.

sumption such as that of a subsistence diet and the occupation of rudimentary housing. In such countries most individuals will resist cutting down on their already low consumption in order to allow future generations to enjoy a higher level of consumption, particularly since in extreme cases a reduction of essential consumption today may be tantamount to making available more luxury goods for future generations. In these circumstances the net aggregate consumption benefit of an investment project is better represented by the following relationship:

$$B^* = V_0 . B_0 + V_1 . B_1 + V_2 . B_2 + \dots \quad V_t . B_t + \dots \quad V_T . B_T \qquad (30)$$

where $\qquad$ $B^* =$ discounted or present value of net aggregate consumption benefits, and

$V_0, V_1, V_2 \dots V_T =$ weights attached to the net benefits accruing in consecutive years.

These weights are called "discount factors": they indicate the amount by which future net benefits must be discounted to make them comparable to current net benefits. The weight V_0 is, by assumption, equal to 1, which gives

$$B^* = B_0 + V_1 . B_1 + V_2 . B_2 + \dots \quad + V_t . B_t \dots + V_T . B_T \qquad (31)$$

Since consumption one year hence is valued more than consumption two years hence, and consumption two years hence is valued more than consumption three years hence, and so on, the following relationship must hold good:

$$1 > V_1 > V_2 > \dots > V_T.$$

Let it now be assumed that the weights decline over time at a constant percentage rate, such that

$$\frac{V_t - V_{t+1}}{V_{t+1}} = \text{Constant} = i.$$

Then $\qquad$

$$\frac{V_t}{V_{t+1}} - 1 = i,$$

and $\qquad$

$$\frac{V_t}{V_{t+1}} = 1 + i$$

or $\qquad$

$$\frac{V_{t+1}}{V_t} = \frac{1}{1+i}.$$

By a purely mathematical operation, equation (31) may be rewritten

$$B^* = B_0 + \frac{B_1}{1+i} + \frac{B_2}{(1+i)^2} + \cdots \frac{B_t}{(1+i)^t} + \cdots + \frac{B_T}{(1+i)^T} \qquad (32)$$

That is

$$B^* = \sum_{t=0}^{T} \frac{B_t}{(1+i)^t} \qquad (33)$$

In the above relationship, i is what is known as "the social rate of discount". It is the rate by which consumption, as valued by society, declines over time. Equation (33) is very similar to those used in the previous chapter for the estimation of the present value of the net benefit of a project. The only difference between equation (33) and those used in the previous chapter are differences in the meaning and significance of benefits and costs (i.e. the use of shadow prices instead of market prices), and differences in the meaning and significance of the rate by which benefits and costs are discounted (i.e. the use of a social rate of discount instead of a market rate of interest).

It is a well known fact that there are a number of market rates of interest in existence at the same time. Partly to meet the cost of the financial expertise required, savers usually earn a much lower interest on the money they lend than the interest that is paid by borrowers. Moreover, imperfections abound in the capital market, partly as a result of ceilings imposed by governments on the interest rates applied by the country's financial institutions: such ceilings, imposed to encourage investments by small borrowers, result in the creation of capital "black markets" in which ceilings on interest rates are often exceeded. The market rate of interest is therefore defined here as a weighted average of the various prevailing market rates of interest. Some may argue that the market rate of interest so defined is equal to the social discount rate. Such an argument is based on the assumption that individuals act rationally when planning their current and future levels of saving and consumption. A similar assumption is made with respect to the way individuals allocate their expenditure among different kinds of consumer goods. The former assumption is, however, less justified than the latter.

Individuals who allocate part of their budgets among various consumer goods learn through trial and error how to maximise their welfare by purchasing the right mix of goods. Experience is gained whenever purchases are made, and it is not entirely unrealistic to assume that, in time, individuals reach a certain level of sophistication (or "rationality") as consumers. The same reasoning cannot, however, be applied to savings behaviour. Savings is a subject on which little can be learnt by mere trial and error because the consequences of savings decisions emerge only after a long time. and the human life span is too short to

allow people to make much significant application of any knowledge they may have acquired by trial and error in this field. It may also be pointed out that in most cases the proportion of their income that people will be able to save in the course of their lifetime is a matter over which they do not have full control, since it will be affected by events such as wars, economic crises, and the like. That being so, it is not altogether unreasonable for people to allow their savings decisions to be swayed by momentary impulses that lie outside the realm of economics. It may therefore be concluded that market rates of interest, however they may be estimated, usually differ from the social rate of discount.[1] It should be pointed out at this stage that, on the average, market rates of interest are lower than the social rate of discount, and consequently tend to be biased towards the use of capital-intensive technologies.

The redistribution objective

A government is usually concerned not only with the growth of aggregate consumption but also with the redistribution of consumption, especially among income groups and regions: in particular, it may wish to increase the consumption of the poor faster than that of the rich; similarly, it may wish to increase consumption in poor regions at a faster rate than in wealthier regions. In order to take account of income distribution objectives, project evaluators may weigh costs and benefits differently from private entrepreneurs. The assignment of weights to various costs and benefits—the value of these weights depending on the income groups to which the costs are charged or the benefits accrue—causes a further divergence between market and shadow prices since these weights are explicitly included in the formulation of the latter prices.

A government's income redistribution goals may be fulfilled by assigning weights to the consumption of various parts of the nation. For example, heavier weights are assigned to the consumption of the poor than to that of the rich. Such a weighting procedure tends to introduce a bias in project choice. Projects that yield higher net benefits to the poor than to the rich are favoured since the heavy weights attached to consumption by the poor increase the social profitability of such projects. These projects therefore have a better chance of being selected than if the same weight were assigned to all income groups. For example, when it comes to choosing between two construction technologies, the more labour-intensive of the two has a better chance of being adopted if a heavy enough weight is assigned to the consumption of unskilled labourers. There is no way of estimating these weights purely on the basis of factual

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[1] The calculation of the social rate of discount is dealt with later in this chapter, where the use of that rate in the formulation of shadow prices is also described.

information because the values expressed by the weights are subjective: they are based on the economic planner's personal assessment of socio-economic conditions and on the social pressures to which he is subjected. It may be noted in this context that the objective of redistribution of income may conflict with that of economic growth: a more equitable distribution of income usually results in higher current aggregate consumption since the poor tend to save less of their income than the rich; a more equitable distribution thus tends to favour current consumption as against future consumption, and therefore may limit the investment needed for economic growth.

SHADOW PRICES

Investment

Prior to the formulation of the shadow prices of specific inputs and outputs the shadow price of investment, P^{inv}, must first be defined and formulated since that parameter is generally included in all shadow price formulations. To take a simplified example first, let it be supposed that an additional current unit of saving gives rise to q additional units of income in each future period for a very large number of years, and that all of the additional income in each period is consumed. If the present value of the aggregate consumption stream is defined as P^{inv}, then

$$P^{inv} = \frac{q}{1+i} + \frac{q}{(1+i)^2} + \ldots + \frac{q}{(1+i)^n} \tag{34}$$

If P^{inv} is multiplied by $(1 + i)$, this multiplication gives

$$P^{inv} \cdot (1+i) = q + \frac{q}{1+i} + \frac{q}{(1+i)^2} + \ldots + \frac{q}{(1+i)^{n-1}} \tag{35}$$

Then a subtraction of the terms in equation (34) from those in equation (35) gives

$$P^{inv} \cdot i = q - \frac{q}{(1+i)^n}.$$

Since n is assumed to be very large, $\frac{q}{(1+i)^n}$ is very close to zero. Then

$$P^{inv} \cdot i = q$$

and

$$P^{inv} = \frac{q}{i}$$

where q = aggregate marginal rate of return on investment, and
i = social rate of discount.

If a unit of current savings is invested in project A the cost of that unit of savings to society is equal to the present value of aggregate consumption forgone by not using that unit of savings on a marginal public investment project that would have provided a stream of additional income, q, indefinitely. Let it be supposed that K units of current savings are used in project A. Then the cost of the project, expressed in terms of aggregate consumption forgone, is equal to

$$C = K \cdot P^{\text{inv}}.$$

Let it also be supposed that project A provides the following stream of net benefits from year 1 to year T:

$$B_1, B_2, B_3 \ldots B_T.$$

The present value of the gross aggregate consumption that is generated is then equal to

$$B = \sum_{t=1}^{T} \frac{B_t}{(1+i)^t}.$$

Then the present value of the net aggregate consumption derived from the project is equal to

$$B^* = B - C = \sum_{t=1}^{T} \frac{B_t}{(1+i)^t} - K \cdot P^{\text{inv}} \tag{36}$$

It may be noted that equation (36) is based on the assumption that K would have been fully used on other projects if project A were not chosen. Another, more realistic formulation for P^{inv} will now be provided. In the foregoing simplified example it was assumed that the q units of additional income were wholly consumed in each consecutive period. Such an assumption is not very realistic: a more realistic one is that a fraction s of q is saved and reinvested, and a fraction $(1 - s)$ is consumed. In this case

$$P^{\text{inv}} = q \, \frac{(1-s)}{i} + \frac{P^{\text{inv}} \cdot q \cdot s}{i} \tag{37}[1]$$

The first term on the right-hand side of equation (37) gives the present value of aggregate consumption of the fraction of q that is consumed instead of being

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[1] The steps by which equation (37) is obtained are indicated in the UNIDO guidelines, op. cit., pp. 173-175.

reinvested. The second term gives the present value of aggregate consumption of the fraction of q that is saved and reinvested. From equation (37) one can obtain

$$P^{\text{inv}} = \frac{q\,(1-s)}{i-q\,.\,s}.$$

If $s = 0$ (i.e. if all q units are consumed), then

$$P^{\text{inv}} = \frac{q}{i}.$$

The simplified formulation of P^{inv} in equation (34) may then be regarded as a special case of the more general formulation given in equation (37).

In order to estimate P^{inv} one must be in possession of estimates for q, s and i. The aggregate marginal rate of return on investment, q, may be estimated on the basis of an analysis of existing market rates of interest, taking into consideration official rates as well as non-official rates. Imposed ceilings on market interest rates may create complications, and a number of assumptions may need to be made regarding the functioning of the capital market; in the absence of institutional constraints q might be approximately equated to the weighted average of existing market rates of interest. Ideally, q should be estimated on the basis of the following formulation:

$$q = Y - w\,.\,n$$

where Y = the increment in value added per unit of net investment (i.e. the incremental output-capital ratio), and

$w\,.\,n$ = the incremental wage bill per unit of investment (i.e. incremental employment, n, multiplied by the wage, w).

Y is usually easy to estimate from a country's national accounts. However, in many developing countries there are no statistics from which one can estimate $w\,.\,n$. This method of estimating q is therefore not feasible unless some realistic assumptions can be made regarding the value of $w\,.\,n$. It is advisable, in addition, to analyse current market rates of interest in order to ascertain that the value for q estimated on the basis of the method just described is not too different from that estimated from current market rates.

Of the other two values, s, the aggregate marginal propensity to save, may be estimated on the basis of data from national income accounts or household expenditure surveys; generally, estimates for s are readily available from the national planning agency. The social rate of discount, i, is a value parameter and is therefore not amenable to estimation on a purely objective basis; the project evaluator should obtain values for i from public planners.

A numerical example will now be provided with regard to the estimation of P^{inv}. Let it be supposed that q is 0.225 and s is 0.22. Then, if i is 0.15,

$$P^{inv} = \frac{0.225\,(1-0.22)}{0.15-(0.225 \times 0.22)} = 1.75.$$

If $i = 0.10$, then

$$P^{inv} = \frac{0.225\,(1-0.22)}{0.10-(0.225 \times 0.22)} = 3.48.$$

It can be seen from this example that the value of P^{inv} is very sensitive to the value assigned to i by public planners.

Before the use of the shadow price of investment, P^{inv}, in project evaluation is described, it is of interest to explain the link that exists between the value of P^{inv} and the savings behaviour of a country. Let it be supposed that a country can afford to raise the level of aggregate investments to the point where the present value of aggregate consumption derived from the last unit of savings that is invested is equal to 1. In other words, P^{inv} for the last (i.e. marginal) unit of savings is equal to 1. Society is therefore indifferent to the choice between consuming the last unit of savings during the current period or investing it and enjoying, in the future, higher consumption such that the present value of the stream of future consumption is equal to 1. In this case we have

$$P^{inv} = 1 = \frac{q\,(1-s)}{i-q.s}.$$

Therefore if P^{inv} is equal to 1, q must be equal to i, or in other words the social rate of discount must be equal to the aggregate marginal rate of return on investment. Such a situation arises in the case in which a country's aggregate saving is said to be optimal. Needless to say, no country has ever reached this ideal stage: in general, the richer a country is the closer it is to the ideal stage in question; in all cases, however, saving is sub-optimal, which means that P^{inv} is greater than 1, and therefore q is greater than i; this is particularly true of poor countries in which the government cannot afford to use fiscal measures to increase the level of savings, given the low incomes of the majority of the people.

The use of the shadow price of investment in project evaluation can be summed up as follows: let it be supposed that the cost of a given project is equal to K; the question is then how to value K when estimating the present value of the net aggregate consumption derived from the project. The formulation of criteria for project evaluation depends on the type of fiscal and budgetary policies adopted by the government. In other words, the present value of K units of savings expressed in terms of aggregate consumption costs invested in a project will depend on the way which the project is financed. Projects may be financed

in three ways. Under the first method public investment projects are ranked, and the government then transfers funds from the private sector, through taxation, so as to cover the cost of all public investment projects with a rate of return higher than the aggregate marginal return on investment in the private sector, q. The implementation of a public investment project thus affects investment and consumption in the private sector only. Under the second method levels of taxation are determined independently of project investment needs. The implementation of some public investment projects therefore requires that other items of public expenditure—in particular other public investment projects—should be given up, because in most developing countries public investment needs exceed the sums which the government can obtain through taxation of the private sector. The third method of financing is to make use of foreign loans and grants.

The present value of K in terms of aggregate consumption costs can be estimated for each of the three methods described above. Under the first method a project's cost, K, is covered at the expense of both private investment and private consumption. Where the fraction of private income that is saved is s and that which is consumed is $(1 - s)$, the present value of aggregate consumption costs is equal to

$$C = K (1-s) + P^{inv} . s . K \qquad (38)^{[1]}$$

The present value of the net aggregate consumption benefits derived from the project is then equal to

$$B^* = \sum_{t=1}^{T} \frac{B_t}{(1+i)^t} - K(1-s) - P^{inv}.s.K \qquad (39)$$

Under the second method of financing a more complex formulation of the aggregate consumption costs of a project is required. No attempt will be made to describe the formulation here; it will only be noted that the shadow price of investment used in this case combines the marginal propensity to save, s, and the marginal rate of return on investment, q, of both the public sector and the private sector into a single formulation (i.e. s^g, s^t, q^g, q^t). No significant difference in results is yielded by such a formula by comparison with those yielded under the formula for the first method of financing unless s^g is significantly

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[1] Equation (38) assumes that all costs are incurred during the first year of the project. If costs are spread over a number of years T, then

$$C = \sum_{t=1}^{T} \frac{C_t}{(1+i)^t}$$

where $C_t = K_t (1-s) + P^{inv}.s.K_t$.

different from s^t or q^g is significantly different from q^t. If differences are assumed to be small, aggregated consumption costs may be estimated as for the first method of financing; on the other hand if differences are assumed to be large the estimates of s and q may be so crude and so highly aggregated that it is impossible to distinguish between public and private s and q. In view of these hard realities it may be assumed that $s^g = s^t$ and $q^g = q^t$, and projects may always be evaluated as if the first method of financing were used.

If a project is financed by foreign loans and grants, the present value of its cost in terms of aggregate consumption should be calculated as shown on pp. 206-209.

For projects financed by the first method (transfers from the private to the public sector as required by the individual projects), the following reasoning can be applied to the evaluation of alternative construction techniques. A comparison of alternative versions of a road project is in the main a comparison of the sum of road construction costs, road maintenance costs and road users' costs for one version with the sum of those costs for another version. Benefits need rarely be compared since in most cases they are not affected by the choice that is made. (If benefits are affected by the choice that is made, some of the benefits, in the form of profits or savings, may be reinvested. Then the estimation of the present value of benefits in terms of aggregate consumption should be estimated in the same way as costs.) A comparison between different versions of a road project therefore involves the identification of the version with the lowest cost C^*, where

$$C^* = C + RUC + MC \qquad (40)$$

where C = construction costs,
RUC = road users' costs, and
MC = maintenance costs.

If construction is spread over a number of years T_1

$$C = \sum_{t=1}^{T_1} \frac{C_t}{(1+i)^t}$$

where $C_t = K_t (1 - s) + p^{inv} . s . K_t$ and K_t = money outlay at year t.

As far as road users' costs are concerned, it may be assumed that if private funds were not used to cover vehicle operating costs, they would have been used for consumption purposes. Then

$$RUC = \sum_{t=1}^{T} \frac{(RUC)_t}{(1+i)^t} = \text{present value of consumption forgone,}$$

where T = life, in years, of the road project.

Finally, road maintenance costs, expressed in terms of the present value of aggregate consumption, are equal to

$$MC = \sum_{t=1}^{T} \frac{(MC)_t}{(1+i)^t}$$

where

$$(MC)_t = K_t'\,(1 - s) + P^{inv}\,.\,s\,.\,K_t'$$

and where K_t' = monetary outlay during year t.

It is assumed in this case that S and P^{inv} remain constant over time.[1]

Unskilled labour

The shadow wage of unskilled labour is a measure of the true cost to society of hiring an unskilled worker on a public project. Some neo-classical economists have suggested that given a fairly competitive labour market, the market wage should be equal to the marginal productivity of labour. In such a case the market wage is a measure of the opportunity cost of labour to the public sector. However, this reasoning is not applicable to developing countries where unemployment (whether open or disguised) is fairly widespread, and where savings are below their optimal level. In such countries the market wage is not an appropriate measure of the cost to society of hiring an unskilled worker on a public project. Divergence between the market wage and the shadow wage is the result of two factors which are predominant in a surplus labour economy. First, the market wage does not reflect the opportunity cost of an unemployed or underemployed individual: in other words, the value of the output forgone by hiring such an unemployed individual is lower than the market wage.

Secondly, the monetary cost of labour hired for a public project is financed by a transfer of funds, in the form of fiscal revenue, from the private to the public sector. Since the marginal propensity to consume of taxpayers as a body is lower than that of unskilled workers, this transfer of funds affects the present value of over-all aggregate consumption: in other words the loss of aggregate consumption by taxpayers generally differs from the gain of aggregate consumption by unskilled workers.

The shadow wage of unskilled labour, w^*, is the algebraic sum of the cost and gains just referred to, which are symbolised as follows. First, the shifting

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[1] It is extremely difficult to estimate future values of P^{inv} and s. Therefore, unless there are some very good reasons to believe that they will vary in a significant way over the life of the project, it may be safer to assume that these two parameters remain constant over time.

of a worker from his current occupation to a road project means that his current output O_p will be sacrificed. The social cost of this forgone output is equal to a decrease in aggregate consumption valued at O_p. (It is assumed that the market price of the output is approximately equal to its shadow price. O_p is therefore the value of forgone output as estimated on the basis of market prices.) Secondly, the worker is paid a wage, w, which is financed by a tax imposed on the private sector. Let it be supposed that the aggregate marginal propensity to save of the private sector is s^t. Then if there had been no tax, $w(1 - s^t)$ would have been consumed and $w . s^t$ would have been invested. The imposition of a tax of w causes a decline in the aggregate consumption of taxpayers equal to

$$w(1 - s^t) + w(s^t . P^{inv})$$

where the first term is the value of current consumption that is sacrificed, while the second term is equal to the present value of the aggregate consumption that would have been generated if $w . s^t$ had been invested. Thirdly, if it is assumed that the unskilled worker consumes the totality of his wage (i.e. that his marginal propensity to save, s^w, is equal to zero), w expresses the gain to workers, and therefore to society, in terms of aggregate consumption. (It is also assumed that the prices of consumer goods are approximately equal to their shadow prices.)

The shadow wage rate, w^*, may then be obtained from the following relationship:

$$w^* = O_p + w (1 - s^t) + w (s^t . P^{inv}) - w = O_p + s^t (P^{inv} - 1) w \qquad (41)$$

It may be noted that if savings are optimal, P^{inv} is equal to 1 and w^* is equal to O_p; in other words the shadow wage is equal to the output forgone. It may also be noted that if unemployment is very high, O_p may be equal to zero. In that case

$$w^* = w (1 - s^t) + w (s^t . P^{inv}) - w.$$

To put it differently, the shadow wage is equal to the net transfer costs (or redistribution costs) only. Finally, if O_p is equal to w,

$$w^* = w (1 - s^t) + w (s^t . P^{inv}).$$

In this case the shadow wage is equal to the loss of aggregate consumption by taxpayers, and society neither gains nor loses in terms of output forgone.

In developing countries with high unemployment, w^* will tend to be lower than w. If O_p is equal to zero, equation (41) gives

$$P^{inv} - 1 = \frac{w^*}{w . s^t}.$$

Let it be supposed that $s^t = 0.2$. Then for w^* to be equal to w, we must have $P^{inv} = 6$. If P^{inv} is lower than 6, w^* must be lower than w. Furthermore, if s^t is lower than 0.2, P^{inv} must be higher than 6 so that w^* may be equal to w. In most developing countries the marginal propensity to save cannot exceed 0.2, and P^{inv} is generally less than 6. Cases in which w^* is equal to or larger than w will therefore be very rare. The following two examples illustrate this point:

Example 1

$$s^t = 0.2, P^{inv} = 1.5, w = 1, O_p = 0.5 \, w;$$

then $\quad w^* = 0.5(1) + 0.2(1.5 - 1)(1) = 0.5 + 0.1 = 0.6;$

in this example $w^* = 0.6 \, w$.

Example 2

$$s^t = 0.1, P^{inv} = 3.0, w = 1, O_p = 0.3 \, w;$$

then $\quad w^* = 0.3(1) + 0.1(3 - 1)(1) = 0.3 + 0.2 = 0.5;$

that is, $w^* = 0.5 \, w$.

The formulation of w^* in equation (41) rested on two assumptions:

(a) the marginal propensity to save of unskilled workers is equal to zero $(s^w = 0)$; and

(b) forgone output is the only direct cost to society resulting from the employment of workers on a public project.

The first or both of these assumptions are dropped in the following more general formulations of w^*. If there are good reasons to believe that assumption *(a)* is not valid, the shadow wage may be reformulated to take account of workers' savings. w^* is then obtained from the following relationship:

$$w^* = O_p(1-s^w)+O_p s^w . P^{inv})+w(1-s^t)+w(s^t . P^{inv})-w(1-s^w)-w(s^w . P^{inv})$$

$$= O_p[(1-s^w)+s^w . P^{inv}]+w[(s^t-s^w)(P^{inv}-1)] \tag{42}$$

This equation implies that a fraction s^w of O_p would have been invested and a fraction $(1 - s^w)$ consumed if output O_p had been produced. Similarly, it implies that a fraction, s^w, of the wage w is invested while the remaining fraction is consumed.

While assumption *(a)*, that $s^w = 0$, may be valid under some conditions, assumption *(b)* is rarely tenable. An unemployed or underemployed worker who is hired for full-time public employment must give up some leisure time; he may dislike working under strangers rather than under members of his family; he may need to be separated from his wife and children for long periods of time

if the job requires that he live in a workers' camp: all such factors constitute a cost to the workers. In these circumstances a worker may not be willing to change his current situation unless he is paid a wage sufficiently large to cover not only output forgone (O_p) [1], but also the "psychological" cost (P_c) in question. In other words an unemployed or underemployed worker will refuse to work on a given public project unless he is paid a wage large enough to induce him to accept employment on the project. This minimum wage is the marginal supply price of labour, L $(L = O_p + P_c)$. The public project wage, w, must therefore be at least equal to L if a worker is to be induced to work on a given public project. In general, w is larger than L since wages paid in the public sector are very much influenced by the high wages paid in the capitalist sector (e.g. modern industry and services). Thus, the value of L usually lies somewhere between O_p and w.

If both assumptions underlying the first formulation of w^* (equation (41)) are dropped, the shadow wage is given by the following relationship:

$$w^* = L\left[(1 - s^w) + s^w \cdot P^{inv}\right] + w\left[(s^t - s^w)(P^{inv} - 1)\right] \tag{43}$$

The only difference between equations (42) and (43) is that L is substituted for O_p in the formulation of the shadow wage. It is recommended that this last formulation of w^* be used since it is based on more realistic assumptions than are either of the other two formulations.

The estimation of w^* requires that the parameters L (or O_p), P^{inv}, s^w and s^t be estimated, w being the public project wage. P^{inv} and s^t are national parameters whose values apply regardless of the region in which projects are carried out. The manner of estimating them has already been described. On the other hand L (or O_p) and s^w are parameters that apply to the particular pool of unskilled labour from which project workers are to be hired. For road projects this labour pool generally consists of unemployed or underemployed rural workers, and the following discussion of the estimation of s^w and L will be focused on such workers.

The values of parameters s^w and L may vary from one region of the country to another. Furthermore the value of L may vary from season to season: during peak agricultural seasons the supply price of labour, L, may be high as a result of high demand for unskilled labour, and conversely L may be low during the agricultural slack seasons as a result of low demand for labour. (If a worker is completely unemployed during a slack season, his supply price L is equal to the psychological cost P_c described earlier.) Estimates of s^w and L by region and

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[2] O_p is the output that the worker's family must give up if the worker is hired for a public project.

by season may therefore be needed. The estimation of s^w may be obtained from regional household expenditure surveys. If no such surveys have been carried out, a project evaluator may assume that s^w is equal to zero or to a fraction of s^t, the aggregate marginal propensity to save. Estimation of L requires that output forgone, O_p, and the psychological cost, P_c, be known. Needless to say, P_c is very difficult, if not impossible, to estimate. O_p is also extremely difficult to estimate since the estimation of O_p requires a knowledge of production functions in the agricultural sector. In many cases project evaluation cannot wait for the completion of the studies that would be needed to obtain estimates of P_c and O_p. It is therefore suggested that wages paid in rural areas be used as a proxy for the supply price of labour, L. It is probable that such wages exceed the value of L, but they nevertheless constitute the best available estimates of L when data pertaining to O_p and P_c are lacking.

The project evaluator may estimate rural wages (assumed here to be equal to L, the supply price of labour) from existing surveys of the labour market whenever such surveys classify labour by skill levels and by location. In the absence of such surveys, the project evaluator may need to carry out his own survey in the project area. For this purpose he may use the help of field engineers or local authorities. It may be noted that such a survey should be conducted for various seasons of the year if there are good reasons to believe that wages vary from one season to another. Surveys of this kind will also be useful for the scheduling of construction activities in cases in which it is intended to use labour-intensive techniques. Indeed, if he wishes to ensure that construction activities will be properly scheduled (e.g. that no construction activities will be scheduled to take place during the peak agricultural season where labour may be scarce), a project evaluator should conduct such a survey regardless of whether market wage rates for the area are known or not.

Once the project evaluator has obtained all necessary parameters from the planning agency or a field survey, the shadow price of unskilled labour may be calculated and the unskilled labour costs of a project estimated. If road construction covers more than a single agricultural season, the estimation procedure should take into consideration variations of the rural wage in the project area.

The formulation of the shadow wage, w^*, provided in equation (43) ignores income distribution considerations. However, the government may wish to attach greater weight to the aggregate consumption of the poor than to that of the rich. The benefits and costs of a public investment project must then be disaggregated in terms of their contribution to the gains and losses of various income groups, and a weight assigned to each of these gains and losses. That procedure will favour the adoption of public investment projects that yield relatively greater benefits to members of income groups whose aggregate consumption the government wishes to increase. Let it be supposed that the

government attaches more weight to the aggregate consumption of unskilled workers than to that of persons in the middle to high income groups. What form should then be given to the formulation of the shadow wage?

It was shown that the shadow wage w^* may be estimated on the basis of the following relationship:

$$w^* = L(s^w.P^{inv}) + L(1-s^w) + w(s^t.P^{inv}) + w(1-s^t) - w(s^w.P^{inv}) - w(1-s^w) \quad (44)$$

The first two terms in equation (44) refer to output forgone, and therefore constitute a cost to society; the third and fourth terms refer to the cost resulting from the transfer of funds from the private sector to the public sector; the fifth and sixth refer to the gains that accrue to the rural workers. All these costs and gains are expressed in terms of aggregate consumption. The foregoing formulation assumes that the gains and losses of any group are treated alike. If a neutral weight [1] is attached to the aggregate consumption of taxpayers, their losses are accurately reflected in the foregoing formulation. Those losses are equal to

$$w(s^t.P^{inv}) + w(1-s^t).$$

The net gains to unskilled labour are equal to

$$w(s^w.P^{inv}) + w(1-s^w) - L(s^w.P^{inv}) - L(1-s^w) = (w-L)\left[(1-s^w)+s^w.P^{inv}\right] \quad (45)$$

Let it now be supposed that the government wishes to attach a weight u (where $u > 0$) to the net gains of unskilled workers. The shadow wage of unskilled workers is then equal to

$$w^{**} = w\left[s^t.P^{inv}-(1-s^t)\right] - (w-L)\left[(1-s^w)+s^w.P^{inv}\right](1+u)$$

or

$$w^{**} = w\left[s^t.P^{inv}+(1-s^t)\right] - (w-L)\left[(1-s^w)+s^w.P^{inv}\right] -$$
$$- u(w-L)\left[(1-s^w)+s^w.P^{inv}\right]$$

The first two terms in the above equation are equal to w^*. Therefore

$$w^{**} = w^* - u(w-L)\left[(1-s^w)+s^w.P^{inv}\right] \quad (46)$$

It may be seen from equation (46) that when income redistribution is taken into consideration, the shadow wage is further lowered since $(w-L)$ is positive and

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[1] A neutral weight may be defined as a weight of zero. If a neutral weight is attached to a group's aggregate consumption, the value of the group's aggregate consumption does not change; if a higher weight is placed on a group's aggregate consumption, the value of its aggregate consumption increases.

the terms between brackets are also positive. The inclusion of income redistribution considerations in the formulation of the shadow wage therefore tends to favour the adoption of labour-intensive technologies.

As stated earlier, the weight u is a value parameter and therefore cannot be estimated on the basis of factual data. The project evaluator should obtain values of u from the public planners. Another approach may be used whenever a labour-intensive technology is being compared to a capital-intensive one. Under this alternative approach, u is regarded as an unknown. The project evaluator calculates the value of u that will equate the profitability of the two technologies. He may then communicate this value to the public planners. If they decide that the value of u is too high, the labour-intensive technology will be rejected. If they approve the value of u, the labour-intensive technology will be adopted. In other words, the approach consists in a break-even analysis of the type described in the previous chapter.

Skilled labour

The skilled workers employed on road construction projects include foremen, equipment operators, mechanics and surveyors. Skilled workers are usually scarce in developing countries, and their wages tend to be high whenever the private sector competes with the public sector to employ such workers. A formulation of the shadow wage of skilled labour may be obtained by modifying the formulation, w^*, provided for unskilled labour, as follows:

$$w^* = L\left[(s^w . P^{inv})+(1-s^w)\right]+w\left[s^t . P^{inv}+(1-s^t)\right]-w\left[s^w . P^{inv}+(1-s^w)\right] \quad (47)$$

If the market for skilled labour is competitive (i.e. if it is free of constraints such as government wage ceilings or floors, union monopoly power or the monopsony power of large firms, which might distort the market wage), the opportunity cost of skilled workers may be equated to their market wage. In other words, skilled workers are paid their marginal product, which equals the value of their output. In this case

$$L = w = w_s$$

where w_s = the market wage of skilled labour.
The shadow wage of skilled labour is then

$$w_s^* = w_s\left[s^t . P^{inv}+(1-s^t)\right] \quad (48)$$

since the first and last terms in equation (47) cancel out. The shadow wage of skilled labour therefore equals the cost, in terms of aggregate consumption, of transferring funds in the amount w_s from the private to the public sector.

The formulation for w_s^* provided in equation (48) may not always be valid. There are two main circumstances in which w_s^* may fail to represent the true social cost of hiring a skilled worker in a public project. First there is the case in which the project requires that labour be specially trained. If training is required, training costs must be added to the formulation of the shadow wage. Training also increases the skilled worker's productivity, and these gains in productivity must be subtracted from w_s^*. In other words the net effect of training —whether positive or negative—must be included in the formulation of w_s^*. Secondly, various constraints on the free movement of wages in the labour market may lead to a divergence between the market wage, w_s, and skilled worker's supply price (L). Equation (48) should therefore be supplemented by terms equivalent to the first and third terms in equation (47) since those no longer cancel out. In either of the two cases just mentioned, the shadow wage, w_s^*, must be reformulated. No attempt will be made in this manual to provide other formulations of the shadow wage of skilled labour. Such formulations would include parameters that are in practical terms very difficult to estimate. Moreover, the formulation provided in equation (48) should apply in most cases.

The estimation procedure for w_s^* is similar to that described in the case of w^*, and does not require further elaboration.

Foreign exchange rate

The reasons for the overvaluation of the local currency in a large number of developing countries have already been indicated.[1] In general a local currency is overvalued if the number of units of local currency that are officially exchanged for a unit of foreign currency is lower than it would be if there were no government control of the foreign exchange market and no import duties and quotas. Overvaluation of the local currency is usually accompanied by a scarcity of foreign exchange due to government control of the foreign exchange market (i.e. people are not allowed to use foreign exchange freely).

Let it be supposed for a moment that the only government action that interferes with free trade is the imposition of tariffs on imported goods. P_i^d, the clearing price of an imported good i on the domestic market, in local currency, is the price consumers are willing to pay for an imported good; that price is assumed to be equal to the sum of the c.i.f.[2] import price, P_i^{cif} (in foreign currency), and the tariff duty, $P_i^{cif} \cdot t_i$, that is[3]

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[1] See pages 178-179.

[2] In its usual sense of cost, insurance and freight. The c.i.f. price is therefore the import price, including handling from one port to the other.

[3] It is assumed that the number of importers is such that trade in imported goods is not monopolised.

$$P_i^d = P_i^{cif} \cdot P^f + P_i^{cif} \cdot t_i \cdot P^f = P_i^{cif} (1 + t_i) \cdot P^f \qquad (49)$$

where P^f = official foreign exchange rate (i.e. the number of units of local currency that are officially exchanged for a unit of foreign currency).

P_i^d is thus expressed in terms of the local currency. If a single good i is imported into a country, the shadow price of foreign exchange is equal to

$$S^f = \frac{P_i^d}{P_i^{cif}} = P^f (1 + t_i) \qquad (50)$$

If, for example, $P^f = 10$ and $t_i = 0.2$, then

$$S^f = 10(1 + 0.2) = 12.$$

In this case the shadow price of foreign exchange is 20 per cent higher than its official price. It may be concluded that the difference between the official price of foreign exchange and its shadow price results from a difference between the import price, expressed in terms of the local currency, and the price consumers are willing to pay for the imported goods. It is assumed here that this difference is adequately expressed by the tariff imposed on the imported good.

The procedure just outlined can be applied to any number of goods. Let it be supposed that n commodities are imported into a country, and that the fraction of foreign exchange allocated to the ith commodity is f_i [1], so that

$$f_1 + f_2 + f_3 \ldots + f_n = 1.$$

The shadow price of foreign exchange is then given by the following relationship:

$$S^f = P^f \left[f_1 (1 + t_1) + f_2 (1 + t_2) + \ldots + f_n (1 + t_n) \right]$$

or

$$S^f = P^f \sum_{i=1}^{n} f_i (1 + t_i) \qquad (51)$$

In other words the shadow price of foreign exchange is equal to a weighted average of n shadow prices. If

$$\sum_{i=1}^{n} f_i (1 + t_i) = 1 + t^f$$

then

$$S^f = P^f (1 + t^f)$$

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[1] Since a country deals in more than one currency, foreign currency owned by the country may be expressed in terms of a single foreign currency; f represents, in terms of a single foreign currency, a fraction of the total amount of foreign currency used for imports.

where t^f represents the foreign exchange premium. Equation (51) may be expanded to include exports whenever export subsidies are paid or exports are taxed. Such an expansion of equation (51) is straightforward and needs no further elaboration.

On the other hand equation (51) should not include imported capital goods, for reasons which would take too long to explain in this manual.[1] In other words, the f_i represents the fraction of foreign exchange allocated to an imported consumer good only, the sum of these fractions being equal to 1.

This formulation of the shadow price of foreign exchange is subject to criticism. First, a major assumption underlying this formulation, namely that imports are not restricted, is rarely valid. Many governments use import licensing, or import quotas which in fact limit imports of consumer or capital goods. This difficulty can be by-passed by not including restricted commodities in equation (51). However, if a very large proportion of imports is subject to restrictions, the validity of that equation becomes questionable. Secondly, if foreign trade is dominated by a very small number of importers, distortions may take place that will partly invalidate the formulation of the shadow price of foreign exchange provided by the equation. In addition to these two criticisms of the shadow price provided by equation (51), other objections, some of them quite esoteric, have also been made.[2] The project evaluator need not be concerned by these criticisms, however, since as stated on page 186 he will be provided with the market price adjustment coefficients (in this case, t^f) by the public planner. It is therefore up to the public planner to decide which formulation to use for the shadow price of foreign exchange.

The estimation of the shadow price of foreign exchange on the basis of equation (51) is relatively easy to carry out since tariff duties (individual t_is) and the composition of imports (reflected in individual f_is) are usually readily available from national trade statistics. Individual t_is and f_is should be estimated on the basis of trade statistics for the year in which a project is being evaluated, or for the preceding year if current statistics are not available. In cases in which it is not possible to estimate the shadow price of foreign exchange on the basis of a valid formulation of S^f, the project evaluator may undertake a break-even analysis in which the price of foreign exchange is regarded as an unknown. Given alternative construction technologies, the project evaluator should determine the price of foreign exchange which would equate the cost (or the profitability) of the two; i.e. he should determine the break-even price of foreign exchange. If the break-even price falls within the range of probable

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[1] But are explained in Chapter 16 of the UNIDO guidelines, op. cit.

[2] See E. Bacha and L. Taylor: "Foreign exchange shadow prices: A critical review of current theories", in *Quarterly Journal of Economics*, May 1971, pp. 197-224.

prices of foreign exchange (provided by the national planning agency), either technology may be adopted; in that case the break-even price P_b^f must be more than the minimum P_{min}^f and less than the maximum P_{max}^f. If $P_b^f < P_{min}^f$, the more capital-intensive of the two technologies should be adopted; if $P_b^f > P_{max}^f$, the more labour-intensive of the two technologies should be adopted.

Equipment rental rate

Since the foreign exchange cost is usually the largest element in the shadow rental rate of equipment, this is the appropriate place to deal with the calculation of that rate. The market rental rate of equipment may be disaggregated into the following five main cost items:

C^f, the foreign exchange cost;

C^d, the distribution costs (e.g. port handling charges, storage and delivery charges);

C^p, profits (i.e. mark-ups over the cost of local distributors);

C^t, import duties and income and other taxes; and

C^l, local costs (e.g. maintenance and repair costs, insurance costs and local materials).

Whenever one of the above cost items does not exist in a country, it may be equated to zero. The market rental rate, C_k, of a piece of equipment k is equal to

$$C_k = C^f + C^d + C^p + C^t + C^l \tag{52}$$

It should be recalled that C_k is equal to

$$C_k = \frac{K_0}{H_e} \cdot \frac{r(1+r)^n}{(1+r)^n - 1} - \frac{S_e}{H_e} \cdot \frac{r}{(1+r)^n - 1} + \frac{R_e}{H_e} + \frac{I_e}{H_e} + \frac{T_y}{n \cdot H_e} + F_u \tag{53}$$

In order to obtain the shadow rental rate of equipment, C_k^s, one must first disaggregate each of the cost items in equation (53) (K_0, S_e, R_e, I_e, T_y and F_u) into cost components C^f, C^d, C^p, C^t and C^l, as applicable. The cost components of C_k, expressed in terms of market prices, are then adjusted in order to obtain cost components at shadow prices. Finally, C_k^s is obtained by discounting the relevant cost components at the social rate of discount i, instead of the market rate r. In general, all the cost components except local costs apply to K_0, T_y and F_u. S_e is a revenue which is subtracted in equation (53); it is adjusted in the same way as a local cost if the scrapped piece of equipment is processed and sold locally, and it is adjusted in the same way as a foreign exchange cost if the scrapped piece of equipment is exported. I_e should be regarded as a local cost. R_e includes local labour costs as well as the cost of imported parts and materials; it therefore includes all the cost components.

In order to obtain the true social value of individual cost components, their market value must be adjusted. Disregarding for the moment the cost of transferring funds from the private to the public sector (i.e. transfer costs), the following adjustments are made to individual cost components. C^f must be multiplied by $(1 + t^f)$ in order to obtain the foreign exchange cost of imported equipment, parts anJ materials in terms of the shadow price of foreign exchange. C^d may be assumed to represent the true social value of distribution costs, and therefore does not need to be adjusted; even if this assumption were invalid, distribution costs generally represent such a small percentage of C_k that one need not bother adjusting them. C^p does not need to be adjusted: it may be regarded as a true social cost since it is a return to entrepreneurial labour and equity involved in the distribution process. (If the local distributor is a foreigner and repatriates a fraction x of his profits, then $C^p (1 - x)$ is not adjusted, but $C^p . x$ must be multiplied by $(1 + t^f)$ since it involves the transfer of foreign exchange.) C^t is not a real cost but a transfer payment to the government. It should therefore not be included in the formulation of C_k^s, since transfer costs are not being taken into consideration for the moment. C^l covers the cost of skilled labour, local materials, and local insurance costs. Since transfer costs are being neglected for the moment, C^l may be regarded as a true social cost: the transfer of skilled labour from the private to the public sector does not entail a social cost [1]; the shadow prices of local materials may be assumed to be equal to their market prices; and insurance costs may also be assumed to represent a real social cost.

A formulation can now be provided for C_k^s. Consideration of the above adjustments gives the following equation:

$$C_k^s = \frac{1}{H_e} \left[C_{K_0}^f (1 + t^f) + C_{K_0}^d + C_{K_0}^p \right] \left[\frac{i(1+i)^n}{(1+i)^n - 1} \right] - \frac{C_{S_e}^l}{H_e} \left[\frac{i}{(1+i)^n - 1} \right]$$

$$+ \frac{C_{R_e}^f (1 + t^f) + C_{R_e}^d + C_{R_e}^p + C_{R_e}^l}{H_e} + \frac{C_{l_e}^l}{H_e} + \frac{C_{T_y}^f (1 + t^f) + C_{T_y}^d + C_{T_y}^p}{n . H_e}$$

$$+ [C_{F_u}^f (1 + t^f) + C_{F_u}^d + C_{F_u}^p] \tag{54}$$

where superscripts refer to the type of cost component, and subscripts refer to individual cost items included in the formulation of the market rental rate, C_k (see equation (53)).

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[1] As indicated in the passage dealing with the shadow wage of skilled labour (pp. 196-197). If foreign labour is involved, the proportion of wages that is repatriated should be regarded as a foreign exchange cost and adjusted accordingly.

Labour-intensive road construction

In equation (54)—

K_0, the price of equipment, is subdivided into foreign exchange costs, $C_{k_0}^f$, distribution costs, $C_{k_0}^d$, and profits, $C_{k_0}^p$ (customs duties and taxes are not, for the moment, included in the formulation of C_k^s);

S_e, the salvage value of equipment, is based on the assumption that the scrapped piece of equipment is sold locally, generating revenues net of taxes in the amount $C_{S_e}^l$; in this case $C_{S_e}^l$ is equal to S_e minus taxes, since we have a single cost component;

R_e, equipment maintenance and repair costs, is subdivided into four cost components: foreign exchange cost to cover the import of equipment parts, $C_{R_e}^f$; distribution costs of imported parts, $C_{R_e}^d$; distribution profits, $C_{R_e}^p$; and local cost of labour for equipment maintenance and repairs, $C_{R_e}^l$;

I_e comprises a single cost component, that of local insurance cost, net of taxes; thus $C_{I_e}^l = I_e$ minus taxes;

T_y, the cost of tyres, is subdivided in the same way as K_0;

F_u, fuel costs, are also subdivided in the same way as K_0.

C_k^s could be reformulated whenever the subdivision of cost items into the five cost components differs from that assumed in equation (54).

The formulation of C_k^s in equation (54) does not take into consideration the cost of transferring funds from the private to the public sector in order to purchase and operate a given piece of construction equipment. It has already been shown that the transfer cost, in terms of aggregate consumption, of one unit of income from the private to the public sector is equal to $(1 - s^t) + s^t . P^{inv}$, where $(1 - s^t)$ represents current consumption that is sacrificed, and $s^t . P^{inv}$ represents the present value of the stream of future consumption that would have been generated in the absence of the transfer. If C_k^s is adjusted in order to take this transfer cost into consideration, the shadow rental rate of equipment is equal to

$$(C_k^s)' = C_k^s \left[(1 - s^t) + s^t . P^{inv}\right] \tag{55}$$

Finally, it may be noted that tariffs and taxes transferred from the private sector to the government (i.e. cost component C^t) involve a transfer cost since the marginal propensity to save of taxpayers is usually higher than that of the government. A further adjustment of C_k^s is needed in order to include this transfer cost. If the government's marginal propensity to save is s^g, the transfer cost of taxes and tariffs for cost item i is equal to

$$(C_i^t)^s = C_i^t \left[(1 - s^t) + s^t . P^{inv} - (1 - s^g) - s^g . P^{inv}\right] \tag{56}$$

where C_i^t = the sum of customs duties and taxes levied on cost item i.

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The transfer cost of all taxes and tariff duties per equipment-hour is equal to

$$(C^t)^s = \left[(1-s^t)+s^t \cdot P^{inv}-(1-s^g)-s^g \cdot P^{inv}\right]\left[\frac{C^t_{K_0}}{H_e} \cdot \frac{i(1+i)^n}{(1+i)^n-1}\right.$$

$$\left.-\frac{C^t_{S_a}}{H_e} \cdot \frac{i}{(1+i)^n-1}+\frac{C^t_{R_a}}{H_e}+\frac{C^t_{I_a}}{H_e}+\frac{C^t_{T_y}}{n.H_e}+C^t_{F_u}\right].$$

The shadow equipment rental rate now becomes

$$(C^s_k)'' = (C^s_k)'+(C^t)^s \tag{57}$$

The determination of the shadow rental rate requires that the cost components making up the individual cost items in equation (54) be estimated. The manner of estimating components $C^f_{K_0}$, $C^f_{R_a}$, $C^f_{T_y}$ and $C^f_{F_u}$ has already been described in Chapter 5. It will be recalled that the c.i.f. prices of the various items are expressed in terms of the local currency. Chapter 5 also indicated how to estimate items $(C^d_{K_0})'$, $(C^l_{S_a})'$, $(C^d_{R_e})'$, $(C^l_{R_a})'$, $(C^l_{I_a})'$, $(C^d_{T_y})'$ and $(C^d_{F_u})'$ where the prime means that each item is equal to the corresponding item in equation (54) plus all taxes (e.g. $(C^d_{K_0})' = C^d_{K_0}$ plus taxes). Estimation of the non-primed components in equation (54) requires that taxes be subtracted from the primed components estimated in Chapter 5. Information on taxes may easily be obtained from the government department in charge of taxation. The profit component net of taxes (i.e. $C^p_{K_0}$, $C^p_{R_a}$, $C^p_{T_y}$ and $C^p_{F_u}$) may be assumed to be equal to some fraction p of the total component cost; e.g. $C^p_{K_0} = p(C^f_{K_0} + C^d_{K_0})$. The fraction p may be assumed to be equal to the average return on private investment. The tax on profits for cost item i (e.g. K_0), is then equal to

$$(C^p_i)(t_x)_p$$

where $(t_x)_p$ is the tax on business profits.

Local materials and tools

It will be assumed in this manual that the market prices of locally produced materials and tools adequately measure their value in terms of alternative output forgone (i.e. opportunity cost). This assumption is made for the following three reasons. First, the domestic market for materials and tools is probably fairly competitive. Secondly, the estimation of the opportunity cost of commodities produced in the private sector is extremely difficult to carry out; this additional estimation work is not justified if adjustments to market prices are believed to be of minor importance. Thirdly, in most cases the amount of materials used is approximately the same for all combinations of design and technology; therefore, even if market prices differ from opportunity costs, their use in project evaluation will not create a bias toward any particular

combination. However, the same argument cannot be made in relation to tools, since the number of tools varies greatly from one technology to another. The assumption that the market prices of tools and materials are equal to their opportunity costs does not mean that no adjustment is needed. For the government to acquire tools and materials, funds have to be transferred from the private sector to the government. The market cost of tools and materials must accordingly be adjusted to take account of the transfer cost. The adjustment coefficient is the same as the case of the shadow rental rate of equipment, i.e.

$$(1 - s^t) + s^t \cdot P^{inv}.$$

If the foregoing adjustment coefficient is multiplied by the cost of tools and materials estimated at market prices, the aggregate consumption cost of tools and materials is obtained. This is the cost that should be used when a project is evaluated on the basis of shadow prices.

It may be noted that if some of the materials or tools are imported, their aggregate consumption cost may be estimated in a way similar to that used to estimate the shadow rental rate.

Land

Since the market price of land is usually distorted, it does not constitute a measure of land's opportunity cost. That cost is in any case difficult to estimate. Because the main purpose of this manual is to show how to evaluate different combinations of design and technology, and because the cost of land does not generally differ from one such combination to another, the use of market prices instead of the opportunity cost of land will not create a bias toward any particular combination. In this manual the market price of land will accordingly be treated as if it were equal to land opportunity cost. The aggregate consumption cost of land (i.e. the market price of land adjusted for transfer costs) is then equal to

$$P_L[(1 - s^t) + s^t \cdot P^{inv}]$$

where P_L = the market price of land.

TREATMENT OF TAXES AND FOREIGN LOANS AND GRANTS

Taxes

The formulation of the shadow wages of skilled and unskilled labour and that of the shadow prices of materials, tools, and land provided in this chapter were based on market wages and prices net of tax, including income tax. How

then should taxes be taken into account when the aggregate consumption cost of the inputs used in road construction are estimated? Taxes were already taken into account earlier in this chapter in the particular case of construction equipment. A more general treatment of the problem will now be provided. Let it be supposed that a tax t_x, which may be an income tax or some other tax, is imposed on a private individual or firm. The imposition of such a tax affects consumption and investment in the private and the public sectors. Under this model the government taxes the private sector in order to raise the revenue needed to pay a worker or private firm working for a public project. The aggregate consumption of the private sector therefore decreases by the amount of the tax revenue, R_t, multiplied by the unit transfer cost

$$R_t[(1 - s^t) + s^t . P^{\text{inv}}].$$

The government pays the worker or private firm the revenue from the tax R_t, which is taxed at a rate t_x. The worker or private firm pays taxes to the government amounting to $R_t . t_x$. The government uses the tax revenue $R_t . t_x$ for current government consumption and investments. The aggregate consumption of the government increases by

$$R_t . t_x [(1 - s^\theta) + s^\theta . P^{\text{inv}}]$$

where s^θ = the government's marginal propensity to save.[1]

Thus, the tax or customs duty included in the cost of any input used in a public project is paid, ultimately, not by the individual worker or firm but by the private sector as a whole.

Since s^t usually differs from s^θ, the net effect of the tax is different from zero. The net effect t_x^s, is equal to

$$t_x^s = R_t . t_x [(1 - s^t) + s^t . P^{\text{inv}} - (1 - s^\theta) - s^\theta . P^{\text{inv}}].$$

For example, let it be supposed that the tax rate, t_x, is equal to 0.15, that $s^t = 0.2$, $P^{\text{inv}} = 2$, $s^\theta = 0.05$, and $R_t = 1,000$. Then the net effect of taxing one unit of income or profit, expressed in terms of aggregate consumption, is equal to

$$1,000 \times 0.15 [0.8 + (0.2 \times 2) - 0.95 - (0.05 \times 2)] = 22.5.$$

Thus, the net aggregate consumption cost of the tax, t_x^s, is 22.5. The inclusion of t_x^s in the formulation of the shadow price of any input is straightforward. Let it be supposed that the gross hourly wage (i.e. wage including taxes) is equal to

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[1] If the shadow price of government investments, P^g, is known, it should be substituted for P^{inv} in the above equation.

$w_s [1 + (t_x)_w]$. (It will be recalled that the prices of the inputs, including wages, that were used in the formulation of the various shadow prices were net of taxes.) The shadow hourly wage of the skilled worker may now be defined as follows:

$$(w_s^*)' = w_s [(1-s^t)+s^t.P^{\text{inv}}] + w_s (t_x)_w [(1-s^t)+s^t.P^{\text{inv}}-(1-s^g)-s^g.P^{\text{inv}}]$$

where $(t_x)_w$ = rate of the tax imposed on the wage of skilled workers. The first term in the above equation is equal to w_s^* (i.e. the shadow price of the net wage of skilled labour). The second term represents the net aggregate consumption cost resulting from the transfer of $(w_s) (t_x)_w$. The amount $(w_s)(t_x)_w$ is not specific to any particular project but is used for current government consumption and investment in general. Other shadow prices may be adjusted for taxes in a similar fashion. Information on tax rates should be easy to obtain from the government department in charge of tax collection.

Foreign loans and grants

Foreign loans and grants provided for the building of new roads or the improvement of existing ones are usually made on the basis of an analysis of road investment needs. Such assistance may take one of the following forms:

(a) loans or grants tied to particular road projects, the recipient country being free to spend the money on those projects in any way it wishes;

(b) loans or grants tied to particular road projects, with the additional condition that the money may be used only to pay for imports of construction equipment;

(c) loans or grants specifically tied to imports of construction equipment without being tied to any particular project; or

(d) untied loans or grants.

When projects are evaluated at market prices in the case of a loan of type (a), the criterion for choosing among different combinations of design and techno-logy is the same as if the project were locally financed. Equipment rental rates should, however, be estimated on the basis of the rate of interest payable on the foreign loan. It may be pointed out that this type of loan usually imparts a bias towards the use of capital-intensive construction technologies: on foreign loans the interest is usually below the local rates. Consequently equipment rental rates should also be lower when the purchase of equipment is financed through foreign loans than when it is financed by local capital. In the case of a type (a) grant, it may be socially profitable to use labour-intensive construction techno-

logies since social benefits derived from the hiring of otherwise unemployed labour may be obtained at no cost to the country where the road is built.

A country may find it socially profitable to refuse loans of type *(b)* if construction costs are much higher when capital-intensive technologies are used instead of labour-intensive ones. In the case of a type *(b)* grant, equipment depreciation costs should be equated to zero. In that case, capital-intensive techniques become particularly advantageous.

In the case of a loan of type *(c)* the different possible combinations of design and technology should be evaluated in the same way as for loans of type *(a)*. If loans are made at low interest rates, capital-intensive technologies become particularly profitable at market prices. In the case of a type *(c)* grant, it will be difficult for labour-intensive technologies to compete with capital-intensive ones.

In the case of a loan or grant of type *(d)*, governments in developing countries should assign the money to projects for which labour cannot be readily substituted for capital (e.g. industrial projects). Road projects would in most cases be among the last to benefit from such loans, since like agricultural projects they are relatively amenable to the substitution of labour for equipment.

When projects are evaluated at shadow prices, the opportunity cost to the economy of a loan tied to a specific project—type *(a)*—is the present value of the repayments of principal and interest occasioned by the loan. If it covers the whole of the project cost, the loan eliminates all current transfer costs (i.e. $(1 - s') + s' . P^{\text{inv}}$). However, it does not eliminate current output forgone, for example owing to the hiring of an unskilled worker on a public project. Moreover the repayment of principal and interest in the future results in a decrease of future aggregate consumption. The social cost of the loan is therefore the present value of future aggregate consumption forgone. The over-all social profitability of a project depends on how the loan is used (i.e. the way in which the amount of the loan is allocated among the various inputs used in the project), on the repayment currency (local or foreign), on the length of the grace period and the repayment period, and on the rate of interest that is charged: if the loan terms are attractive (e.g. low interest rate, long grace period, repayment in local currency), the present value of the future losses in aggregate consumption may be found to be lower than the value of the loan; in other words as far as the debtor country is concerned, part of the loan can be regarded as a grant. It can be shown that foreign loans tied to a project generally introduce a bias in favour of the use of capital-intensive technologies since the shadow rental rate of equipment is lower than if the project were financed by a transfer of funds from the private sector. The decrease of the shadow rental rate may be easily calculated given the loan terms and the various cost components included in the formulation of the shadow rental rate.

Within category *(a)*, grants are obviously much more attractive than loans since they do not entail any transfer costs. However, they tend to favour the adoption of capital-intensive technologies to a greater extent than do tied loans of the same type, since with these grants the shadow rental rate of equipment is even lower than with tied loans.

In terms of shadow prices the analysis of type *(b)* loans (tied to imports of equipment for a specific project) differs little from that of type *(a)* loans: the same conclusions apply. Tied loans of type *(b)* may, however, lose some of their attractiveness if equipment must be imported from the creditor country at prices higher than they would be if it were imported from other countries.

Grants tied to the import of equipment clearly favour the use of capital-intensive technologies.

The analysis of loans and grants tied to imports of equipment but not to any particular project—type *(c)*—yields basically the same conclusions as those reached in case *(b)*. In general, both loans and grants will favour capital-intensive technologies. There is, however, one difference between cases *(b)* and *(c)*. In the latter case, equipment may be used on road projects of a high standard that must to a large extent be built capital-intensively; on low-standard roads labour-intensive technologies may then be used. In case *(b)*, equipment must be used to build specific roads irrespective of whether they are of a low or a high standard. Loans and grants tied to imports of equipment in general are therefore more beneficial to a developing country than loans and grants tied to imports of equipment to be used for specific projects.

Untied grants and loans of type *(d)* constitute an addition to public revenue. From the point of view of project evaluation, the opportunity cost of the use of an untied grant or loan on a given project depends on what the grant or loan would have been used for in the absence of the particular project under consideration. The opportunity cost of a grant is therefore no longer equal to zero. Nor is that of a loan any longer the discounted present value of the payments of interest and principal, since those payments would have to be made even in the absence of the project. The opportunity cost of untied loans and grants depends on their best alternative use. The opportunity cost is the same for an untied loan or for an untied grant of the same amount: the fact that one requires repayment and the other does not is irrelevant when a project is being evaluated; in both cases, untied funds will be available whether or not a particular project is undertaken, and the only relevant social cost of adopting a given project is the output forgone owing to the use of untied funds on one project instead of on the next best.

To discover the effects of untied loans or grants on the choice of technology, the opportunity cost of the use of one unit of foreign exchange on any given project must first be determined.

If t^f = the foreign exchange premium (i.e. the adjustment coefficient for the official foreign exchange rate),

s^g = the government's marginal propensity to save, and

P^g = the shadow price of government investment,

then the opportunity cost of the use of one unit of foreign exchange is equal to

$$(1 + t^f) [(1 - s^g) + s^g . P^g]$$

(This formulation of the opportunity cost of one unit of foreign exchange is based on the assumption that at the margin one unit of government consumption is as valuable as one unit of private consumption.) If $S^g > 0$ and $P^g > 1$, the value of the above expression exceeds $(1 + t^f)$, and thus the opportunity cost of one unit of untied loan or grant is greater than $(1 + t^f)$. The higher this opportunity cost, the more attractive labour-intensive technologies become. The opportunity cost of one unit of foreign exchange obtained through tied loans or grants is usually smaller than $(1 + t^f)$. Untied loans and grants are accordingly more favourable to the use of labour-intensive technologies than are tied loans and grants. The government of a developing country should therefore urge the governments of other countries to offer it untied grants or loans, which can be used to help to lower the level of unemployment.

THE INSTITUTIONAL SETTING

FISCAL AND FINANCIAL POLICY

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When the different combinations of design and technology for a road project are evaluated, the most appropriate combination identified by the financial analysis may or may not turn out to be the same as the one identified by the social cost-benefit analyris. If it is the same the public works department or the contractor should adopt the most appropriate combination, irrespective of whether the technology it involves is capital-intensive or labour-intensive. If the most appropriate combination identified by the social cost-benefit analysis is not the least costly in terms of the financial analysis, the public works department should none the less adopt that combination, whatever its financial (or private) profitability may be, since the goal of the government, and therefore of the public works department, is to maximise social welfare through a proper choice of projects and production techniques. Financial costs do not constitute a proper measure of social costs.

If a labour-intensive technology involves higher money costs, a private contractor in charge of the implementation of a road project may not willingly adopt a labour-intensive combination since lower profits will result. In order to induce contractors to apply labour-intensive technologies where appropriate, there are a number of measures which a government may take. These measures, of a fiscal or financial nature, are designed to compensate for market price distortions, i.e. they tend to adjust market prices so as to equate them to shadow prices. They include the following:

(a) wage subsidies;

(b) discriminatory tariffs on capital equipment;

(c) discriminatory foreign exchange allocation;

(d) currency devaluation;

(e) adjustment of the market rate of interest;

(f) easier credit for small contractors; and

(g) taxation of owned capital equipment.

Unfortunately, the exact effect of such measures is not easy to predict. Governments must therefore be extremely careful in their choice and application. The difficulty is to identify the kind of measure to be taken and the weight to be assigned to each (i.e. selection of the right mix of measures). The choice should be based on the ease with which measures may be applied and on the degree of accuracy with which the public planners are able to estimate their effects. The latter point is very important since the remedial action taken must not produce greater distortions and more harmful effects than would exist in its absence. Unfortunately, the effects on the economy as a whole of measures that are easy to administer and apply are usually difficult to estimate. Conversely, measures whose effects can be estimated with an acceptable degree of accuracy are usually those that are the most difficult to apply. For example, a system of import quotas is easier to apply and administer than a system of import tariffs; the effects of quotas are, however, more difficult to estimate than those of tariffs. The public planner should therefore resist the temptation of recommending remedial action unless its over-all effects can be estimated with sufficient accuracy. Otherwise the action taken may create distortions that will be more harmful than those which they are intended to eliminate.

Each of seven types of government action will now be described and commented on.

Wage subsidies

If a wage subsidy is granted for each man-hour of unskilled labour used in a road project, the size of the subsidy may be set as the difference between the unskilled labour market wage and the shadow wage. Given such a subsidy, contractors should find it more profitable to use a labour-intensive technology than the capital-intensive ones they are used to. This form of government intervention is not without disadvantages, however. If the capital-intensive technology is cheaper at market prices, it becomes possible for the private contractor to claim the subsidy while actually using a capital-intensive technology. In order to prevent contractors from pocketing part of the subsidy, they should be required to pay unskilled workers a wage equal to the shadow wage while the public works department pays directly to the workers the difference between the market wage and the shadow wage.

Not being very familiar with labour-intensive technologies, some contractors may refrain from bidding, even with a government subsidy, if they are required to use such a technology, because they are afraid of incurring losses by underestimating unskilled labour costs. The public works department might alleviate this fear by proposing to take charge of all unskilled labour costs. The contractor's bid will thus cover supervision costs and equipment

costs only. Such an arrangement does not, however, provide an incentive to contractors to use unskilled labour in the most efficient manner. Contractors could, for example, cut down supervision costs by hiring too few supervisors. The public works department may therefore need to specify a maximum number of man-hours of unskilled labour for the project (determined on the basis of the lowest available estimate of unskilled labour productivity), and offer to pay a bonus to the contractor for each man-hour saved out of this maximum number. It will then be profitable for the contractor to use labour in the most efficient manner in order to obtain the largest possible bonus. He will be willing to use additional supervisory personnel as long as the additional supervision cost is lower than the bonus he will receive.

Discriminatory tariffs on capital equipment

Many developing countries allow investors to import capital goods free of duty, while imposing heavy duties on consumer goods. In particular, local and foreign contractors are often allowed to import construction equipment free of duty. There are two main reasons for such a policy. First, the government may wish to decrease consumption of luxury consumer goods in order to induce people to save and increase the level of investible funds. Secondly, the government may wish to promote industrialisation in order to increase exports, or in order to reduce imports through the development of import-substituting industries. High tariffs imposed on imported consumer goods also protect newly created industries from outside competition. The rationale for this protection is that new industries need time in order to become competitive.

Irrespective of whether these objectives are legitimate and desirable on the grounds already stated, it should be noted that if a government is concerned about the widespread adoption of unwarranted capital-intensive technologies in various sectors of the economy, it should not at the same time encourage that practice by imposing tariffs that systematically favour the import of capital equipment in general: it would be better to modify the tariff structure in such a way as to discourage the import of capital equipment that favours the use of unwarranted capital-intensive technologies, while encouraging the import of capital equipment for which labour cannot be substituted. In the case of road construction a discriminatory tariff system could be instituted whereby no duties, or only low duties, are imposed on equipment that is essential to certain construction activities, while high tariffs are imposed on construction equipment for which manual labour can be substituted in other construction activities. The level of these latter duties should be such as to equate the market rental rate of a piece of equipment to its shadow rental rate.

The application of a system of discriminatory tariffs is, however, very difficult, for two reasons. First, the same level of duty cannot be levied on all pieces of equipment since the ratio of the shadow rental rate to the market rental rate is not the same in all cases. It may be recalled that the equipment rental rate includes a number of cost items in addition to the c.i.f. price of the piece of equipment. The proportion of the rental rate that is accounted for by these items is not the same for all pieces of equipment. Since the tariff applies only to the c.i.f. price, different rates of duty are needed for different pieces of equipment if the market rental rate is to be equated to the shadow rental rate. Secondly, the same piece of equipment may be used for a number of road projects, and its use may be warranted in some but not in others. The tariff would therefore need to discriminate not only among different pieces of equipment but also among the various uses of the same piece of equipment. Obviously, any attempt to meet that requirement directly would create insurmountable administrative difficulties. A second-best solution is to discriminate among types of equipment but not among the various uses of a particular piece of equipment. The drawback of this solution is that construction equipment may, from time to time, be used for projects in relation to which it is an unwarranted substitute for labour.

Discriminatory foreign exchange allocation

Instead of using a discriminatory tariff system, the government may impose an import licensing system whereby contractors must have the approval of the public works department in order to import construction equipment. Just enough equipment will then be imported, and used where needed. When a contractor has been selected to work on a given road project, the public works department will estimate the number of equipment-hours for various types of construction equipment; it will then provide the contractor with an import licence for the number of pieces of equipment that are needed. Another approach is for the public works department to be the sole importer of construction equipment, which is rented to contractors whenever they are selected to work on road projects.

Currency devaluation

Instead of relying on discriminatory tariffs or on control of imports of construction equipment, the government may from time to time devalue the domestic currency in order to bring it up to par with its true international value. (Some governments make frequent use of so-called "mini-devaluation" in order to avoid the destabilising effects of a major devaluation.) One effect of

currency devaluation is to increase the market rental rate of equipment, and thereby favour the adoption of labour-intensive technologies. A drawback of currency devaluation is that it is not selective in its effects, and will affect, in various ways, all imports and exports. Nevertheless, this type of government intervention is generally more desirable than the creation of a system of tariffs or quotas, which tends to result in a serious misallocation of national resources. This does not mean that all tariffs should be done away with; some should remain in order to protect genuine "infant" industries (i.e. industries that will be able to compete effectively on world markets once they have passed the learning stage). However, the scope and rate of duty should be substantially decreased.

Adjustment of the market rate of interest

Many governments impose low ceilings on interest rates in order to prevent private banks from exploiting their monopoly power. However, if the capital market does not function properly low ceilings may have negative effects. Small investors in the unorganised sector are often unable to borrow money since the banking institution prefers to deal with the modern organised sector, where risks of default seem to be lower. Under these conditions, large contractors can easily borrow money to import construction equipment, and find it profitable to do so since the low ceiling on interest rates results in a decrease of the equipment rental rate. In some cases, moreover, given high inflation rates, low ceilings on interest rates imply a negative real interest rate on loans, and imports of equipment and the adoption of capital-intensive technologies become even more attractive. The proper government policy if there are low ceilings on interest rates is to remove the ceilings completely or to set them at much higher levels. One effect of such action would be to decrease the number of low-yielding investments without discouraging investments with a high to average yield. High ceilings on interest rates will also lead contractors to think twice before asking for loans in order to import construction equipment, and may thus induce them to reconsider their position with respect to labour-intensive technologies.

Easier credit for small contractors

Small contractors usually do not own much construction equipment, and are more familiar with labour-intensive technologies than are large contractors. Yet small contractors face a number of difficulties in their attempts to obtain a contract on public projects. Apart from the fact that the usual bidding and contract procedures are biased against small contractors with low assets,

small contractors are often unable to obtain loans to finance labour costs on large public projects. Loans are necessary for small contractors, who have little cash at their disposal and may consequently find it difficult to wait long before receiving payment for their work. Since financial institutions usually refuse to make loans for other purposes than the acquisition of capital equipment, small contractors may be unable to compete with large contractors when it comes to bidding for large road projects. Thus, adoption of capital-intensive technologies is further favoured by the *de facto* elimination of small contractors from large road projects. The government may remedy this situation by asking private and public financial institutions to make loans more readily available to small contractors.

Taxation of owned capital equipment

A number of factors—including low ceilings on interest rates, difficulty ot importing spare parts for construction equipment, lack of proper equipmenf repair and maintenance facilities—tends to make contractors import more pieces of equipment than may be strictly necessary, in order to be sure that construction work will not be slowed down as a result of lack of equipment. (In general, contractors find it less costly to keep some construction equipment idle than to incur construction delays.) The government may put an end to this situation by imposing a tax on owned capital equipment. The cost of keeping construction equipment idle will therefore increase, and contractors will refrain from importing more equipment than is really needed. Furthermore, the imposition of such a tax will increase equipment rental rates. A tax on capital equipment, is, however, difficult to administer. The government must annually ass_s the value of pieces of equipment at various degrees of depreciation. Needless to say, such an assessment is difficult to make and may lead to a large amount of litigation between contractors and the government. This type of government intervention is therefore not very practical and should not be attempted unless other types of action are not politically or economically feasible.

ORGANISATION AND MANAGEMENT

10

The use of labour-intensive methods naturally implies the organisation and management of large labour forces; even if these methods are used exclusively on feeder and secondary roads the labour force involved is quite substantial. In developed countries one accepts the application of sophisticated management techniques to the use of numerous items of equipment on construction sites. If one accepts labour-intensive methods as a viable alternative, then there is every reason to apply the same kind of sophisticated planning to the use of a large labour force.

In view of the problems involved in the management of large labour forces it is a little surprising that so little has been written on the subject. This may be because the problems are so overwhelming, seem so daunting, or because where large labour forces have been used in recent years, it was not done in the conviction that this method could compete efficiently with capital-intensive methods, but simply because it was an alternative that increased employment. Nevertheless, if these methods are to achieve their true potential the level of management must be as sophisticated as on a capital-intensive project.

In this chapter an attempt is made to isolate and examine the main factors involved in the management of large labour forces. Although no rigid rules can be laid down in the matter, it is possible to indicate the important factors, how they are inter-related and how the problems can be tackled together. It is important that the factors discussed in this chapter should be considered at the planning stage, because according to their particular combination in each case each different project will require a different type of management.

LABOUR DEMAND AND SUPPLY

The choice of labour-intensive methods presupposes a supply of workers ready, willing and able to work on a project; therefore a prerequisite for any

labour-intensive project is a full and detailed knowledge of the characteristics of the labour force in the areas through which the road will go. The sort of labour survey that must be carried out for this purpose does not have to be very detailed: what is required is knowledge of the number of workers who are currently unemployed or underemployed; of how this level of surplus labour varies during the year, i.e. in relation to the peaks and troughs of agricultural activity; and of the skills and physical fitness of the workers available. Once some idea has been gained of the potential level of labour supply for the duration of the road project a proper attempt can be made at planning the work. It may be that the labour supply rules out any chance of using labour-intensive methods; that fact should be known at the planning stage.

The level of labour supply throughout the project area should also give some idea of the wage level that is required to entice workers onto the project. This matter is dealt with more thoroughly in Chapter 5. It is necessary to estimate how far workers will be prepared to travel to work at the wage rate that will be paid on the project; this will govern the size of the sections in which the road will be built. The Kenyan Ministry of Works has suggested, for instance, that 3 km is the farthest that rural workers will walk to work. This means either that a road project must pass close to settlements or that there will have to be collecting points for workers, in reasonable proximity to the settlements.

Let it be assumed, then, that the characteristics of labour supply are reasonably well known. It is now necessary to turn to the demand. First, a reasonable estimate should be made of the productivity of the various construction operations, and the quantity of work involved in those operations should then be estimated also. On that basis it is possible to calculate the total man-days of labour required. It is then possible to discover how much labour will be needed at any one time in relation to the sequence, location and timing of the various operations. Unless things are planned otherwise, however, this demand for labour may fluctuate greatly. It is much better if the demand can be kept fairly stable, for various reasons. First, a fluctuating demand for labour can produce serious adverse social consequences for the workers and possibly disastrous effects on themselves and their families. In addition, if workers are being constantly hired and fired a feeling of insecurity arises in the workforce; not only does this make the workers less productive, it will probably also make them hostile to the project. Thirdly, the labour force needs facilities; if the level of employment keeps fluctuating, so does the level of the facilities, and this produces inefficiency and high overheads. And last but not least stable labour demand makes things easier from an administrative point of view.

An attempt can be made to smooth out the peaks and troughs in the demand curve by the use of critical path planning and resource scheduling, and by the use of time and location charts.

Table 18.   Illustration of labour requirements for a road construction project

Operation	Total man-days	Suggested team size
Opening a quarry	144	12
Site clearance	84	12
Excavating and loading	3 450	150
Hauling and dumping [1]	.	.
Spreading, shaping, watering, compacting	450	30

[1] By means of dump trucks.

Critical path planning

Most engineers and planners will be familiar with critical path planning.[1] To indicate its use in the scheduling of labour demand and supply a simple example based on a real situation in Central Africa will be used.

The major operations in a labour-intensive road construction scheme, together with the man-days of labour required to carry them out over a 10 km section, are as shown in table 18.

The construction of 100 km of road will be considered.

From the network produced in the normal way it is possible to draw a demand curve for labour, as shown in figure 48. Most of the labour is employed on excavating and loading.

The operations in the last line have been treated as a group in order to arrive at a more stable demand curve for them. This procedure is perfectly feasible in relation to the critical path network. The demand curve is useful in itself because—

(a) it shows exactly what is the level of resource use at any particular time;

(b) it helps in the organisation and administration of the labour force since it is possible to plan the facilities in relation to the number of workers on the job; and

(c) it gives the level of financial expenditure per week on labour or, for projects under which wages are paid partly in the form of food rations, it shows how much money and food must be available for remuneration purposes.

The next step is to assess the supply of labour and superimpose the supply curve on the demand curve. In figure 48 the trough in the supply curve represents the agricultural peak season, when some of the workers will return

[1] For a detailed description of critical path planning see R. L. Peurifoy: *Construction planning, equipment and methods* (New York, McGraw-Hill, 1970).

Labour-intensive road construction

Labour supply and demand curves for a road construction project
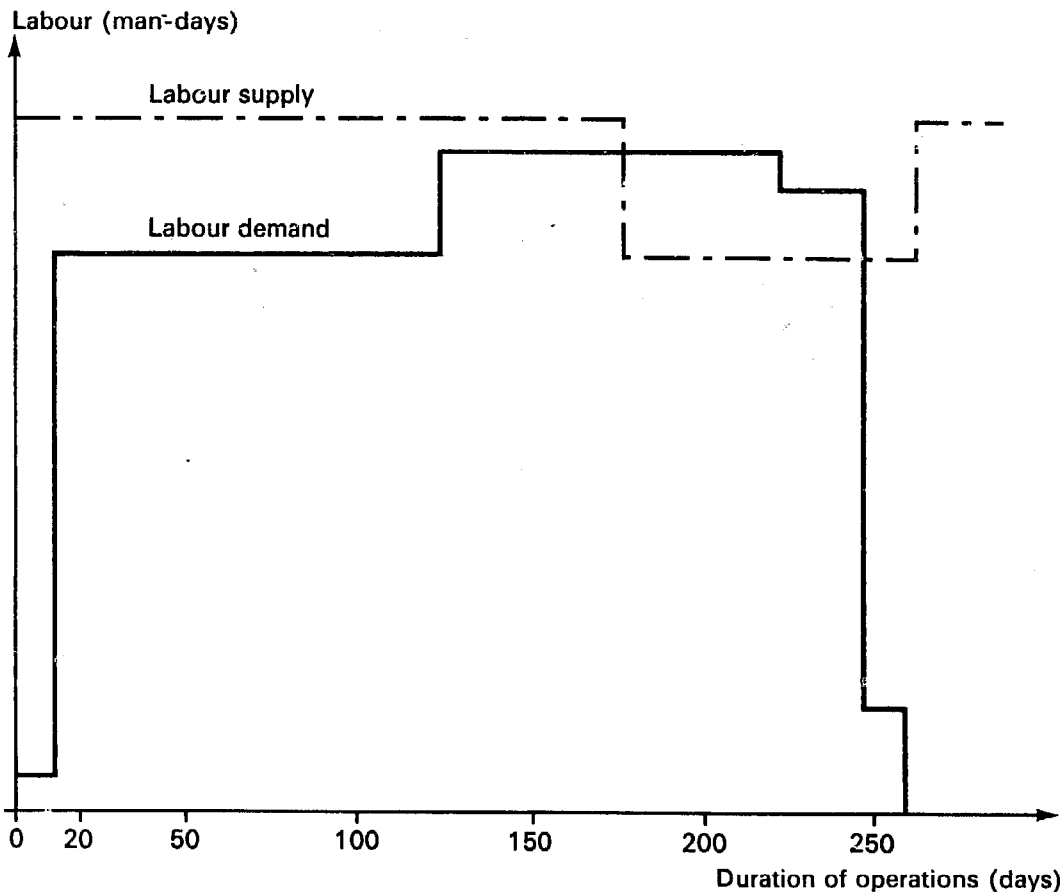
to their farms. It can be seen that this causes a shortfall in supply. In this case various options are available:

(a) machines could be brought in to do some of the work;

(b) the gang size on various operations can be reduced (in which case their duration will be increased);

(c) certain activities, preferably non-critical ones, could be transferred to later dates when there would be a surplus of supply over demand.

The use of option (a) would depend to a great extent on the availability of machines; clearly, it would generally be uneconomic to bring in machines from some distance purely for this short period. The choice between options (b) and (c) depends on various factors. The main consideration will be whether it is feasible to allow the project duration to increase. Other points to consider would be whether it is possible to reduce the gang size and still work efficiently, and how the timing of the project could be better adjusted to the trough in labour supply.

Figure 49.   Effects of changes in duration on the cost of a project
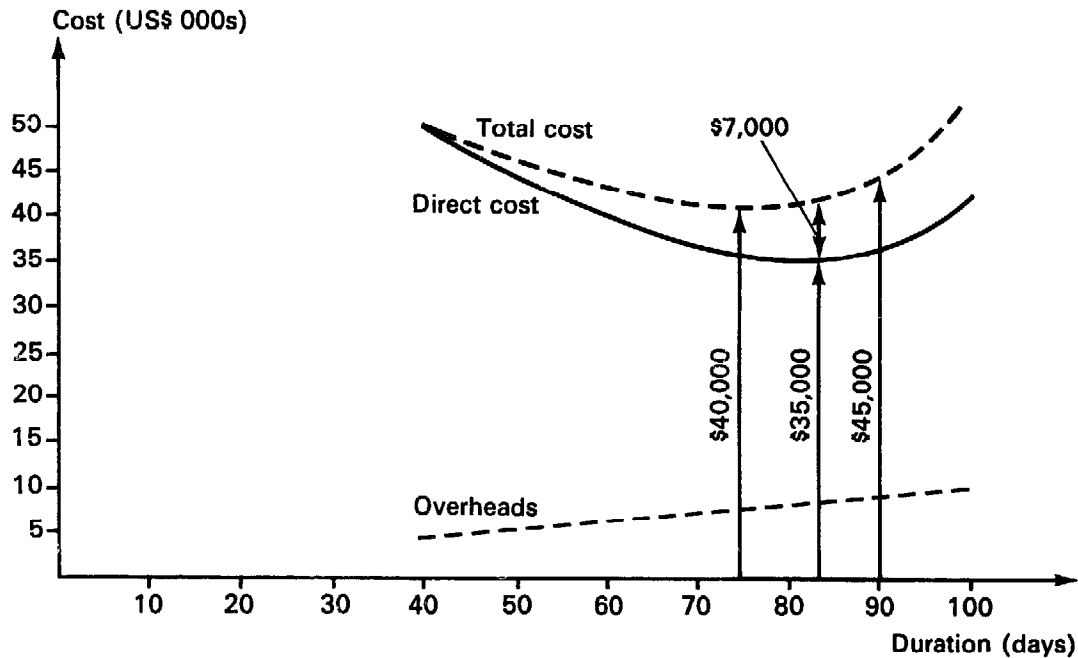
Critical path planning can, of course, be used in the normal way to assess the cost of delays or of shortening the duration of the project as a whole. Normally this involves making some assessment of the fixed overhead costs and assessing the direct cost of the project for a variety of durations. If the critical path is shortened there will be an increased cost relating to one or all of the following:

(a) the supply of materials;

(b) the number of labourers; and

(c) payment of overtime or special incentives.

The effect of delays or reducing the project duration can then be assessed graphically as shown in figure 49.

This is particularly useful in analysing whether labour-intensive methods can be used: these methods may increase the duration of a project; if this is so the effect on project cost can be seen.

In the case shown in the graph the minimum direct cost (US$35,000) is at a duration of 83 working days. However, when the indirect costs are added, the minimum total cost (US$40,000) occurs when the duration is 75 days. Thus the extra cost of paying special incentives, including overtime payments, is offset by the reduction in overhead costs. The graph also shows a direct cost implication of increasing the project duration: in this case an increase in duration of 7 days produces an over-all cost increase of US$3,000. Thus not only is there a

loss of direct benefit because the duration is extended but the direct cost is also increased.

From the foregoing discussion it is clear that critical path planning can play a valuable part in the efficient scheduling and organising of labour utilisation. Not only does it help to match supply and demand; it also reveals the implications of unforeseen delays. The network can, of course, be up-dated when necessary, and can thus provide a permanent check on the organisation and productivity of the labour force.

Critical path planning can also be used to assess activities in which labour-intensive techniques could be used. In many cases it will be a question of looking for the correct labour-equipment mix. Throughout this guide it has been stressed that the methods used must be economically viable. Some activities can be carried out best by equipment, others by labour. If labour-intensive techniques are found to increase the duration of projects it may not be economically feasible to use them; overhead costs and the loss of benefit may preclude them. Nevertheless it is still possible to use such techniques for operations that are non-critical, i.e. those that have "float" in the jargon of critical path planning. It does not matter if those operations take longer, provided that they do not use up all the float time. Thus the operations that are non-critical in the light of the critical path network could readily be earmarked for the use of labour-intensive techniques.

Time and location charts

A recent innovation in the planning of civil construction has been the use of time and location charts.[1] This technique is used to simplify the planning process and present it in a way that is easily understood by non-technical staff in the field. On a large project, network diagrams can be very complex indeed. Because the new technique illustrates the main elements of a critical path network without resorting to such diagrams, it has already been received with enthusiasm by road works contractors and engineers in the United Kingdom. It should be said that the method is really applicable to rural roads only, because in urban areas the location and provision of public utilities such as gas, water, sewerage and electricity are external factors difficult to accommodate in the technique. However, this limitation is not a great restriction when labour-intensive road construction is concerned since most of the projects to which such methods are applicable are in rural areas. The technique is illustrated in figure 50, which refers to the project already described above. The diagram is

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[1] The authors are indebted to Mr. M. I. Hussain of the International Labour Office for his detailed comments, criticism and information on this topic.

Figure 50. Time and location chart
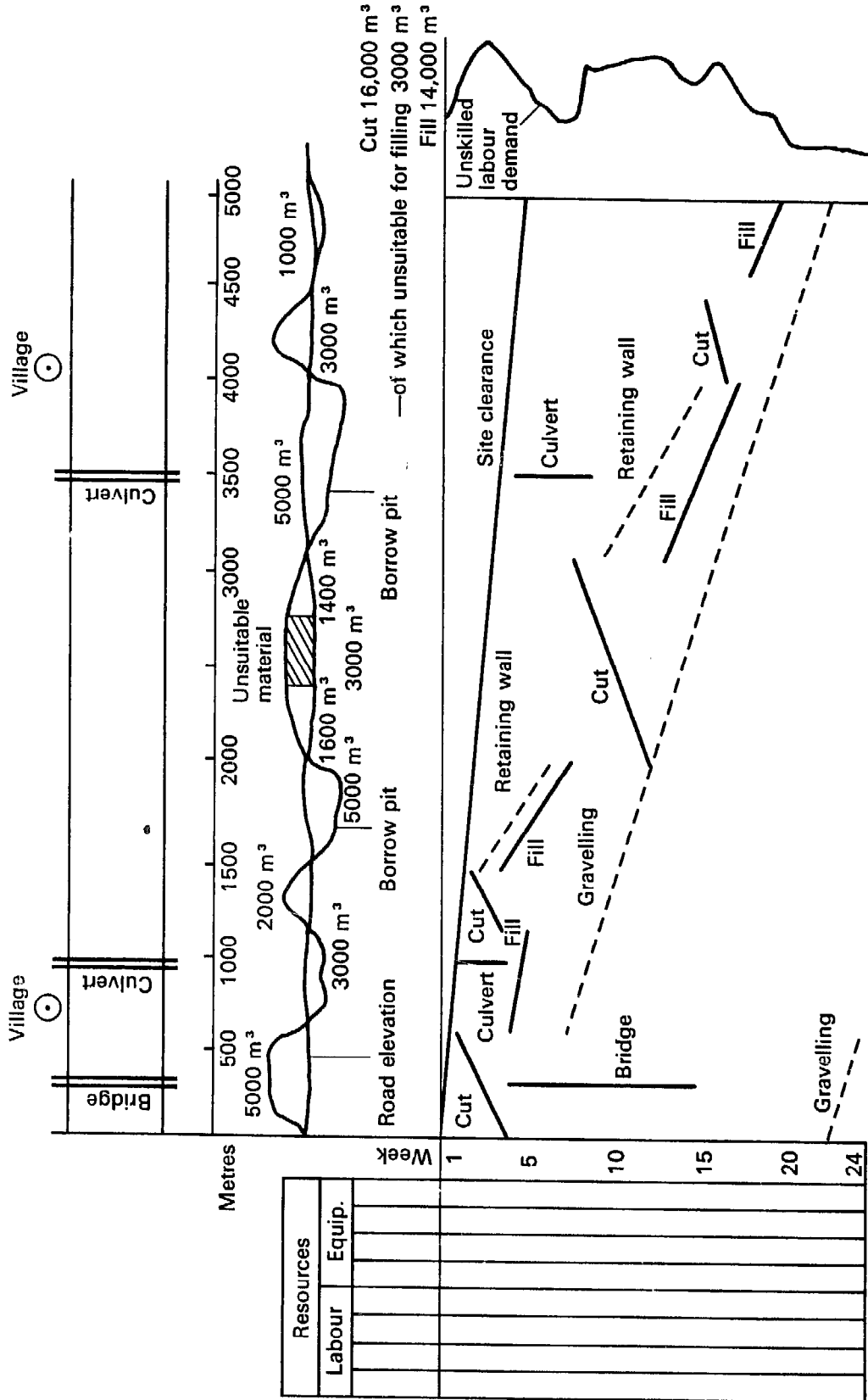
a graphical representation of the major constituents of the project. The plan of the road is drawn at the top of the diagram. In this case only a 5 km stretch is shown, but in practice the whole length of the road would be represented. The chainage points are marked, as are all the structures such as bridges, culverts and retaining walls. Naturally other major features that have an influence on the project, such as areas of unsuitable material and populated areas, can also be shown on the plan. It is useful, however, to make the plan as simple as possible. The longitudinal section of the road is then drawn under the plan. This shows immediately the areas of cut and fill, generally the most important part of any project. The volume of cut and fill can be marked on this longitudinal sector or alternatively, if a more detailed description is required, a mass-haul or block diagram can be drawn underneath the longitudinal section.

The working part of the diagram consists of a graphical representation of the project. The horizontal axis represents the length of the project and is a direct projection of the longitudinal plan. The vertical axis is on a time scale and can be in days, weeks or months depending on how much detail is required. Further, the seasons when construction activity is limited can also be shown. Each operation is then drawn on the diagram as a series of lines and each point on the line represents a point in time and location. In figure 50, for instance, site clearance is envisaged as a continuous process commencing at week 1 at chainage 0 and finishing at the end of week 5 at chainage 5,000 (metres). The cut and fill operations can now be drawn in. It should be noted that the time and location diagram is not merely a representation of the time taken for each activity but also of its location, and the drawing of the diagram incorporates the planning of the project: thus the fill operation between Ch600 and Ch1,200 cannot effectively be executed until the drainage culvert at Ch900 is completed; owing to scarcity of resources the cut operation between Ch2,000 and Ch3,100 cannot commence until week 8; the fill operations between Ch1,500 and Ch2,000 and between Ch3,100 and Ch4,000 can be carried out only in conjunction with the construction of adjacent retaining walls; the gravelling operation can be a continuous operation between Ch600 and Ch5,000 but, because of the bridge construction, the gravelling between Ch0 and Ch600 has to be delayed.

The important elements of the road construction project have now been portrayed graphically. It is now possible to tell at a glance the most important facets of the project: the precise time and location of each operation is portrayed; for any section of the road it is possible to see which operation will take place and at what point in time. The over-all duration of the project is also shown in the diagram.

The important features of the earth-moving operations can be immediately ascertained. For example, take the cut and fill operations between Ch0 and Ch1,500. Let us assume that a labour-intensive method is envisaged for ex-

cavating and hauling and that the maximum efficient haul distance for this method is 300 metres. This means that less than half of the cut from Ch0 to Ch600 can be effectively transported to the fill area (Ch600-Ch1,200). This will not satisfy the requirement for the fill area (3,000 cu. m). However, this shortfall can be made up from excavated material from the cut area Ch1,200-1,500. The remainder from this area could be taken to the next fill area, Ch1,500-Ch2,000.

The cut area between Ch2,000 and Ch3,100 provides another example. The soil in one section of this cut (Ch2,400 to 2,700) is unsuitable for fill material, and must therefore be carted to tip. The remainder could be used for the adjacent fill areas. However, the hauling distance will be too great for efficient transport of all the material to the fill areas. In this case the amount of inefficient hauling will be small, and it may be better to use the labour-intensive method rather than change the means of hauling, or to bring in material from a borrow pit, although in that case one is available at Ch3,400 (and can also be marked on the longitudinal section). It should be clear that the diagram can be used to show exactly where the excavated material will be transported to, by what means and whether the chosen means of haulage will be efficient: if most of the excavated material had to be transported more than 300 metres it would obviously be wrong to think in terms of a means of hauling for which the efficient maximum lead was only 300 metres. The diagram can therefore be used as a guide to the choice of techniques. By assessing the capability of each possible means of hauling and comparing it with the time and location diagram it is possible to tell at a glance whether the method is practicable for a particular operation.

The foregoing discussion merely points out the possibilities of the use of this method. Engineers will automatically see the relevance of a planning diagram which can be easily read and which can show pictorially the problem involved in the execution of the project.

The diagram also shows the relationship in time and location of one operation with another: thus the dependence of one operation on another is shown in the same way as in a critical path network. Figure 50 in fact shows only one starting point of the project, i.e. at chainage 0. However, it would of course be possible to start in many places along the length of the project at the same time as long as resources were available. Thus the site clearance operation, which is shown as starting at chainage 0 in week 1 and concluding at chainage 5,000 in week 5, could start in week 1 at several points along the length of the project. For ease of identification each type of operation should be drawn in different colours or patterns.

Complex operations such as the construction of a bridge are shown as a single line on the diagrams. However, a separate critical path diagram can be

drawn for each such operation so that the separate, individual operations involved can be related to each other. In the basic diagram this would be unnecessary since what is important in that context is the relationship of the bridge construction to the project as a whole.

The diagram can be used to calculate the total resources required on the project day by day or week by week. This is shown at the left hand side of the diagram. This resource scheduling process can be as detailed or as simple as is required. In this case, for the sake of simplicity, only a few different kinds of resources have been allowed for (four kinds of labour and four kinds of equipment). Taking week 5 as an example, reading across the row to calculate the number of unskilled labourers required, we find that the bridge construction requires 50 labourers and the fill operation at Ch600-Ch1,200 requires 70, as does the same operation between Ch1,500 and Ch2,000. The adjacent retaining wall requires 40, the culvert at Ch 3,500 requires 20 and the site clearance operation a further 12. This gives a total of 262 unskilled workers; similar calculations can be made for skilled workers (perhaps disaggregated into say, carpenters, masons and steel-fixers and supervisors) and the whole range of equipment and small tools. The project planner therefore has an immediate display of the resources required on a weekly basis. On labour-intensive projects the labour demand curve can be directly plotted and included as shown in figure 50, and on this can be superimposed the expected labour supply curve.

The time and location study technique is a very useful instrument of planning and execution. On labour-intensive projects it provides a firm basis for the scheduling and planning of the work of large labour forces and therefore has a direct management application. The technique has already been successfully used on large rural motorway projects. It has been particularly well received by site managers and supervisors, who can understand it easily without formal training. Because it is simple and efficient, the technique seems ideally suited to the planning of road construction projects in developing countries.

SUPERVISION

One cannot overemphasise the importance of good management in relation to labour-intensive projects. In equipment-intensive projects a manager creates the right conditions for the maximum utilisation of his plant. In labour-intensive projects a manager must create an environment conducive to high labour productivity. With regard to the management of large labour forces the main point to recognise is that the manager has to be not only a technician and an administrator but also somewhat of a behavioural scientist: he needs to have an understanding of such factors as tribal differences, the family and

village hierarchy, the attitude to work and the psychological involvement of the workers in the project. At the very least he must ensure that the rates of pay are sufficient to act as incentives; and the composition of the gangs must ensure that each member is working with his fellows and not against them.

The cost of administration and supervision may be much greater in public works and construction than in labour-intensive manufacturing. In particular, organisation and administration become more important (and hence expensive) when a large number of small labour-intensive projects call for the mobilisation and use of large numbers of workers. Although a shift from large to small projects may render the use of labour-intensive methods much more economical in terms of construction costs in the narrow sense, there are offsetting disadvantages: if a project is divided into a number of smaller projects, this increases the administrative workload, especially if the organisation of the group of projects remains highly centralised. Paradoxically enough, the limited decentralisation of authority in such cases may ultimately increase the workload for the central management, especially if decentralisation is combined with local participation in decision making. It is, however, not proven that labour-intensive programmes which require that work be taken to the workers must necessarily raise administrative and supervisory costs. The subdivision of a given amount of work into smaller amounts not spread over distant worksites may effect over-all economies in organisation, management and supervision. On the other hand a vast increase in the number of small-scale projects would make greater demands on planning, organisation and co-ordination.

Study of Chinese experience in labour mobilisation on construction schemes shows that successful organisational innovations considerably reduced the need for scarce supervisory skills. For example on the People's Victory Canal Irrigation Project (in the Yellow River Basin in Honan Province), the construction of structures was divided into large-scale, medium-scale and small-scale works, the last being undertaken mostly by peasant workers supervised by team leaders. It has been reported that "wherever possible standard sectors were set up 164 to 328 feet (50 to 100 metres) apart to serve as models for the peasant workers. This enabled the number of team leaders to be reduced." [1]

Unfortunately, there is a distinct lack of training in this sort of management in developing countries, and it will be necessary to launch special courses for this purpose. [2] It would be best if the running of such courses were regarded as being an integral part of the duties of the public works department so that the

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[1] Kanwar Sain and K. L. Rao: *Report on the recent river valley projects in China* (Government of India, 1955), p. 53.

[2] The Kenyan Government has recently initiated a training scheme for middle management personnel in connection with labour-intensive road construction.

courses might be directly related to the product of the projects on which the trainees will subsequently work.

LOGISTICS

In any labour-intensive project it will be necessary to provide extensive site facilities for the labour force. It has often been suggested that the overheads in these projects will be greater than in an equivalent capital-intensive one. In cost terms, however, the facilities in question should be seen as a part of remuneration, as an extra incentive to work: if the workers are given good working and living conditions they will respond more easily to management.

When discussing the logistics of large labour forces a distinction should be drawn between the "core" labour force, i.e. the workers who are employed throughout the duration of the project, and the casual labour. The core workers will move along with the progress of the work; they will in fact live on the job, whereas the casual workers will be taken on locally as and when demand requires. Although casual labourers should also have basic canteen and other welfare facilities, and should receive equal treatment as far as wages are concerned, there is no necessity for camps to be provided for these local recruits. However, it is desirable that they should be transported to and from their villages. This ensures that the workers will actually report for work on the site and that when they arrive they shall not be tired from walking to work. If a large proportion of the workforce is casual, this fact limits the length of the section on which work can be undertaken. The total length of road to be built would have to be broken down into sections that could be easily supplied with labour.

It may be impossible to build the road purely by locally recruited labour, and it may in fact be better to use a basic core of workers, because they will constitute a section of the labour force for which training time will have to be allowed only once during the life of the project, whereas a learning period has to be allowed for every time a new band of local workers is taken on.

The core workers will have to be housed, fed and provided with other facilities in a communal camp. Its size and sophistication will depend upon the length of time for which it is occupied and the size of the project. However, there are certain basic prerequisites. A clean and adequate water supply must be provided for drinking, cooking and washing. The provision of water for the workforce must be planned for and costed. This may be a very difficult task in some areas, and may require the provision of water bowsers to bring the water to the site, or the drilling of wells.

The provision of food is particularly important. The effect of a good diet

on the productivity of workers can be taken for granted, although it has not been possible to establish any exact correlation between the productivity and nutrition of a group of workers in developing countries. As far as large labour camps are concerned it should be possible to ensure that all the workers are adequately fed. This could be done by means of a site canteen, whether run by the site management or by a private firm brought in for the purpose. However, if the workers are recruited locally from among the unemployed and underemployed, in areas where food is scarce, two problems arise. First, to work effectively they will probably need more food than they consumed previously. Secondly, if there is already a shortage of food and they earn money with which they buy food, a rise in food prices may result. Conversely, experience has shown that care must be taken to provide only food that is not readily available in the locality; otherwise it may depress the price and the production of locally grown food. Nor must the labour employed be moved away from other productive work such as farming. If the workers on the project are brought in from outside the area a problem may also arise in that they may be able to purchase the little food that is available, thus giving rise to a shortage of food for the local people and ill-feeling on their part. In any event in any area where a big construction project is undertaken, the local price of food may be affected by the increased demand on the part of the workers and by any additional supplies brought in by the management. This possibility must be foreseen, and preventive action taken if possible.

Difficulties of the kind just described may also arise if food is provided in part payment of wages. Payment in food can ensure that the workers have a correct diet, and it can also attract workers who would not be interested in a purely money wage. However, it would not be proper to make food the only remuneration, except for self-help projects under which workers build short stretches of link or feeder roads in their free or underutilised time, to meet the specific, direct needs of the local community to which they belong by facilitating access and the marketing of produce. No such justification exists for works of general public interest, such as important components of the national road network, including main highways.[1]

Yet other problems may arise: for instance, a British military assistance team supervising the construction of rural roads in Ethiopia found that the further the roads progressed from the main roads the more difficult it became to maintain food stocks and ensure a regular supply. Because food is a precious commodity in many developing countries great care has to be taken to ensure that the food is in fact all distributed to the workers and not channelled elsewhere. This involves some strict supervision and may lead to delays.

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[1] The Protection of Wages Convention, 1949, deals with this matter of payment in kind.

There are no ready-made answers to the problem of feeding the labour force. However, in planning the work it is important to recognise that the availability of food is an important consideration: the secondary effects of using a large workforce must not be underestimated, and the construction of the road must be viewed in terms of the over-all economic development of the area.

Medical facilities must also be provided of a level that will depend among other things on the size of the labour force. In large camps it is also important to provide leisure facilities serving the requirements of recreation, entertainment, adult education and religious observance. Because such facilities engender a community spirit and aid discipline, they can often be justified on economic grounds alone.

Certain other problems arise in relation to the use of large labour camps. These relate more to the effect on the local population and environment than to the workers themselves. Whenever a large, predominantly male group of workers are brought together for hard, physical work it is inevitable that there will be discipline problems. Unless very strict precautions are taken a great deal of ill-feeling may arise among the indigenous population. This will be particularly true if the imported workers are of different ethnic origins to the local population.

It should be clear from the foregoing that on major projects involving the use of large labour forces the setting up of a work camp may be one of the major costs. This may not be such a serious problem in the case of dam construction, for example, in which the work camp is fixed for the duration of the project. However, in the case of road projects which may be 100 miles long it may not be feasible to have one fixed camp. In that case the cost of setting up work camps will be magnified, and it is therefore not recommended that labour-intensive methods should be used, initially at least, for such major projects. If long lengths of road are to be built by these methods, however, it will be necessary for the planners to seriously consider alternatives to the setting up of large camps. Three such possibilities are to set up a larger number of smaller camps; to break the road length into short stretches and use only the locally available labour; or to plan the work so that the workers responsible for the different operations will be housed at different locations. This last system implies, for example, that one section of the route will be cleared of vegetation while the major earthworks are being carried out on another. It requires very careful planning, and the practical problems involved in carrying out the different major construction operations in isolation instead of in their normal immediate sequence would be considerable. The latter two methods and the more usual method are shown in figure 51. The two non-traditional procedures give rise to problems of co-ordination between the sections, but this

Figure 51. Location of operations half-way through the construction of any given long stretch of road under different construction procedures
(Direction of progress left to right →)

Typical traditional procedure

Completed	Site Clearance (S.C.)	Unworked
	Earthworks (E)	
	Base course (B.C.)	
	Surfacing (S)	

Sectionalised construction procedure

| Completed | S.C. E B.C. S | Un-worked | S.C. E B.C. S | Un-worked | S.C. E B.C. S | Un-worked | S.C. E B.C. S | Unworked |

Procedure involving complete physical separation of operations

Completed	Surfacing	Base course	Earthworks	Site clearance	Unworked

may be preferable to the difficulty, human, physical and financial, of constituting a single large workforce housed in one camp.

RECRUITMENT

In some cases the public works department or its equivalent will have a hard core of permanently employed unskilled labour. However, where labour-intensive projects are concerned it will be unlikely that sufficient labour is available from this source, and it will therefore be necessary to recruit locally. Armed with his evaluation of the labour demand the project co-ordinator should have a clear idea of how many labourers he requires from each location, when he will require them and for how long.

In developing countries direct recruitment of workers on an individual basis may be a complex matter. On the assumption that the prospective employees are literate, which is not necessarily the case, notices can be posted to publicise the employment available. It will probably be necessary to hold meetings in each population centre to inform the people of the forthcoming project and to ascertain how many labourers would be available. Recruitment may also be carried out through authorised or licensed recruiting agents

Figure 52. Information bulletin for workers employed on a labour-intensive project

PASIG PROTERERO RIVER CONTROL PILOT PROJECT

Why " pilot project "?

To prove the work can be done as well by hand labour and bull carts at it can by bulldozer.

Why do we have to prove this?

If you prove this the Government may do most of its levee construction by hand labour.

How will this benefit me?

If the work is done by hand labour all the money is paid to you in wages.
If it is done by bulldozer you will not receive any of it.

How much work is involved?

The pilot project will last two or three months. The new levees to be built on the Pasig river could last for three years. If the pilot project succeeds there may be three more years of work.
If the pilot project fails there will be no more work.

What decides the success of the pilot project?

The pilot project will suceed if—

(1) it costs no more than doing it by bulldozer;
(2) the compaction of the earth in the levee is good;
(3) there are no labour troubles.

How can we help to ensure success?

1. Make sure your carts are fully loaded—this will keep the cost down.

2. Obey the traffic signals—we have to direct traffic so that the carabao[1] hooves and bullcart wheels compact the earth.

3. Help the engineer as much as possible. If you have some good ideas as to how the work can be improved, let him know.

[1] Water buffalo used as a draught animal.

operating under the supervision of the competent authorities. In that case, however, it is essential, and very difficult, to ensure that the remuneration of the recruiting agents is limited to any authorised fee and that they do not take a percentage of the wages paid in addition.[1]

It is very important that the persons doing the recruiting should explain exactly why the labour is being recruited. This should produce a feeling of participation. In the Philippines the ILO project staff issued a bulletin to each work group which explained why the particular work was being undertaken and how it would benefit the community. (The bulletin is reproduced in figure 52.) This helped in the subsequent recruiting of personnel, since the local farmers could see the advantages of being employed on a project that could be of lasting benefit to them.

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[1] Details of the safeguards to be taken if it is proposed to use intermediaries for recruitment will be found in the Recruiting of Indigenous Workers Convention, 1936, and the Fee-Charging Employment Agencies Convention, 1949.

METHOD OF PAYMENT

The method of payment of workers has important repercussions on productivity. Workers may be paid daily, task or piece rates. Productivity is generally increased when workers are paid on a task-work or piece-rate basis. However, financial or legal restraints may severely limit the choice of the method of payment; in particular there may be a fixed daily wage payable on government projects, so that it will be impossible to implement any form of incentive scheme. Elsewhere the law may set maximum and minimum limits to the wages that can be paid.

The task-work system is one in which a given task is set to be done in a certain time: the workers are paid according to that fixed time. The estimation of the task time is important, for if it is overestimated the operation becomes inefficient, while if it is underestimated the workers will feel exploited and unrest may result. The task time should therefore be based on a thorough-going investigation of the average time taken for each relevant operation.

The piece-rate system provides an even greater financial incentive. Payment is made according to the amount of work completed. Again the norms that are used to calculate the payment for each unit of output must be reasonable.

In either task-work or piece-rate systems the established norms should be well publicised on the site. This will ensure that all workers know exactly how they are to be paid and will not have any cause for complaint about the wages they receive.

The method of payment used will depend on the type of project and even on the type of operation being carried out. Thus, even when most of the workers are paid by the day, piece rates may be paid for certain operations of critical importance to ensure that they keep on schedule. In terms of pure wage costs it may be that piece or task work is more expensive than work paid for by the day. However, the appropriateness of the method of payment must be judged by the cost per unit or by output per unit of time. For example, a group of daily-paid workers may take ten days to construct 1 km of earth road at a wage cost of US$2,000. If a piece-rate system is introduced the wage cost may increase to US$2,500, but the length of road may be completed in six days. However, the overheads involved in large labour force participation can be appreciable. In this case let us assume that the overheads are US$150 a day. Since the daily-paid workers take four days longer to build 1 km of road, the overheads for that distance amount to US$600 more. Thus although at first sight it would appear more expensive to use a piece-rate system, when overheads are taken into account it is in fact cheaper.

The choice of method of payment therefore depends on a variety of factors.

From a technical point of view the method chosen for each major operation will be that which, on the whole, ensures maximum productivity and minimum cost.

MOTIVATION

It is clear that a whole series of factors affect the willingness of workers to work. Financial incentives, a feeling of belonging to the project, good relations with fellow workers, adequate welfare facilities are but a few. A good manager of men will understand all this and more. In particular he must recognise the need to communicate with people; he should appreciate the problems of using groups of workers with different ethnic and social backgrounds; and he must realise the need to be frank and honest in his dealings with his workers.

The crucial factors bearing on willingness to work are the financial incentive and confidence in the management. The financial incentive has already been discussed: on the basis of a detailed assessment of productivity norms it should be possible to provide workers with the correct financial reward for their work. The question of confidence in the management is more difficult: managers must instil the feeling that they have a complete grasp of the problems involved in the construction of the project, and must be able to express their understanding in terms comprehensible to ordinary workers.

CONTINUITY OF WORK

One of the main benefits of labour-intensive methods is that they give employment to a large number of otherwise unemployed or underemployed workers. Road construction is a field in which these benefits are most easily achieved. Thus, the ILO team in the Philippines showed that the construction of a gravel road by labour-intensive methods provided 12,000 man-days of employment per kilometre, whereas its construction by a capital-intensive method provided only 1,600.[1]

One of the aims of road construction by labour-intensive methods should be to provide permanent employment for the unemployed while also giving opportunities of seasonal employment to the underemployed.

Once an individual road is built, the workers employed on it will normally be laid off, and the improvement in the employment situation will therefore have been only temporary. This drawback can be avoided if the use of labour-

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[1] Deepak Lal: *Men or machines,* op. cit.

Figure 53. Labour supply and demand graph for a hypothetical series of local road projects

Thousands of workers
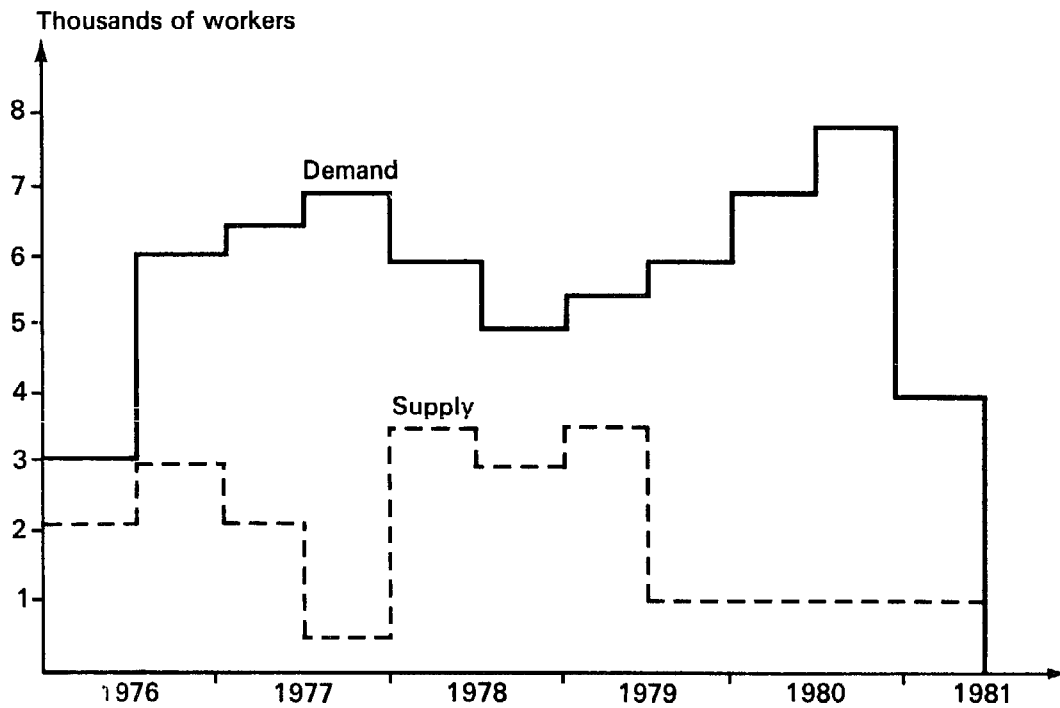
intensive methods is incorporated into a long-term plan. Once it has been decided that these methods are effective for certain types of road, project planning should then be geared towards providing continuity of employment for the workforce. The authorities must draw up a detailed plan of road construction projects for a period of five years, for example. Projects on which it is considered that labour-intensive methods could be used can then be singled out and the labour demand calculated for each one as described earlier in this chapter. The use of resources can be scheduled in relation to these projects as a group. Allowance would have to be made for the fact that each particular project could draw on a local labour supply. Demand and supply could then be equated.

The following is a simple example of how this could be done. Let it be assumed that ten roads are to be built, by labour-intensive methods, between 1976 and 1981. These roads are located in the six areas of a region. For the sake of simplicity let it be assumed that each contract takes 18 months and that the starting dates and labour required are as given in table 19. It is assumed that the peak period is always the second half of the year and that during the first and last six months of the contract the labour requirements amount to only half of the peak demand. The labour demand curve would then be as in figure 53. Let it now be assumed that a survey has shown that the potential casual labour supply is as follows:

Area	Supply
A	500
B	750
C	3,000
D	2,000
E	500
F	250

If the supply curve is then placed over the demand curve as in figure 53 it is clear that there is a serious shortfall in supply.

Table 19.   Labour demand and starting dates for a hypothetical series of road projects

Area	Road	Starting date	Number of workers required at peak of project
A	1	1976	1 000
	2	1977	3 000
	3	1977	4 000
B	4	1979	2 000
	5	1980	6 000
C	6	1978	5 000
D	7	1976	2 000
E	8	1976	3 000
F	9	1979	4 000
	10	1980	2 000

If permanent employment is given to 3,000 workers this will obviously raise the supply curve by 3,000 units (on the assumption that the permanent employment of 3,000 men does not affect the supply of casual labourers.) The situation is now much improved. However, there are still some problems. During the latter half of 1977 there will be a shortfall on projects A2 and A3. It is possible that the casual workers from areas D and E couid be induced to work on projects in area A. There is again a shortfall in supply from mid-1979 onwards, and this may mean either that extra labour has to be taken on, on a permanent basis, or that projects B5 and F10 will have to be spread over a longer period and thus require less labour.

CONDITIONS OF TENDER AND CONTRACT TERMS

11

This chapter is concerned with the fact that the choice of technique is conditioned by the contractual system: the conditions of tender and the provisions of the contracts often provide such a strong built-in bias against labour-intensive techniques that no amount of information about their advantages will induce people to use them.

RESTRICTED BIDDING AND PRELIMINARY SELECTION OF CONTRACTORS

Bidding procedures may vary from country to country and for large and small contracts. Tenders may be issued in an open market, with an invitation to any contractor to offer bids. At the other extreme a contract may be negotiated with a particular contractor: under that system of the "negotiated contract", the client deals directly with a contractor of his choice. That system is often used when a contractor has a known expertise in a particular speciality. The negotiated contract can be used to ensure that a project is carried out using particular techniques: the client can specify not only what he wants to have built but also how. Under that system, of course, the client must be convinced that the methods specified are efficient.

The system of selected tender is intermediate between open tender and individually negotiated contracts. Tender documents are drawn up and presented to a list of private contractors who are considered to be capable of undertaking the project. In many developing countries not all contractors are qualified to bid for construction projects. For instance in the Philippines a committee of the Public Works Department screens contractors on the basis of what is called a "pre-qualification test". The main purpose of this screening is to ensure that the short-listed contractors have an adequate stock of equipment, or ade-

quate funds to be able to rent whatever equipment they may need. Since only contractors who have or will have a sizeable stock of equipment are allowed to bid, the system encourages the use of capital-intensive methods. The requirement concerning availability of stocks of equipment may also give preference to big foreign contractors over the local medium-sized and small contracting firms: a big contractor is not only likely to have more and bigger equipment but also machine operators, mechanics and supervisors and his own spare parts and supply organisation, in addition to an easy access to finance, equipment and repairs abroad. To eradicate some of the biases involved in the selection of contractors for a selected tender list the minimum plant holding proviso could be waived for contractors who are known to be efficient in the use of more labour-intensive techniques. This suggestion implies a more thorough examination of the qualifications of contractors who apply to be placed on the selected list. The criterion will not be whether the contractor has enough equipment to carry out the project, but whether he is efficient in the use of his resources, be they equipment or labour.

The size of contracts may also favour the big foreign over the small local contractor, and it is desirable that, wherever possible, projects should be divided into large numbers of small lots to facilitate tendering by small and medium-sized local firms. However, there may not always be scope for splitting up large contracts into small ones: the nature of construction work may require large contractors. Secondly, while the small contractor cannot take on large contracts, a big contractor may subcontract to small contractors by splitting the total amount of work into different parts. In such a situation, the effect on employment might not be adverse unless equipment-intensive methods were used extensively even on smaller-sized works.

CONTRACT TERMS

Standard design specifications

Consulting engineers, be they local or foreign, introduce biases at an early stage of a project. It is they who undertake the pre-feasibility and feasibility studies. Once such studies are completed and a certain direction is recommended in them, there is often very little chance of varying technology at the design or construction stage. In many countries genuinely local firms of consulting engineers are few. On the other hand many nominally local engineering firms in developing countries are branches of large foreign or multinational firms whose knowledge and experience is confined to highly equipment-intensive methods. Thus a bias in favour of a high degree of mechanisation will be caused by the fact that these firms import standardised design and construction speci-

fications from the advanced countries. In many cases these standard specifications are not appropriate to the needs and local situations in the countries to which they are transplanted. Unless they are modified to suit local conditions, they remain "over-specified", and thus necessitate corresponding equipment-intensive methods. Governments can be much stricter in their selection, briefing and supervision of consultants. They should look very closely at their experience and expertise, and should ensure that the brief given to them clearly indicates the need to investigate the employment and foreign exchange aspects of any proposals that are produced. Within government agencies it would be possible to set up a small unit which would study the specifications and standards set by consultants to ensure that there is no unnecessary bias towards equipment-intensive methods. The international organisations also can be much more rigorous in their letting out of contracts to consultants for projects in developing countries.

Technology clauses

In most cases the contract documents in developing countries do not include any specifications about the equipment-labour mix to be used for any particular task. In some countries, however, as in the Philippines, guidelines issued by the public works department for provincial and district authorities do mention the need to study the feasibility of using labour-intensive methods, even though the use of such methods is not specifically provided for in the contracts.[1] In the Philippines such guidelines have been useful in encouraging consulting engineers and contractors to consider the possibility of using efficient labour-intensive methods.

A detailed evaluation of alternative labour-intensive methods needs to be made first by consulting engineers at the design stage.[2] Subsequently, specification of the alternative techniques needs to be introduced in contract documents. However, mention of alternative methods in contracts alone is not enough: it is important also to ensure proper implementation, and supervision of the use of labour-intensive methods in practice. Both governments and consulting engineers have a role to play in that respect. The former could make sure that terms of reference for feasibility studies and engineering design promote the investigation of possibilities of substitution of labour for equipment in road construction.[3]

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[1] See Deepak Lal: *Men or machines*, op. cit.
[2] See Chapter 2.
[3] Also see G. W. Irvin: *Roads and redistribution*, op. cit., Ch. 6.

Minimum employment clauses

A specific provision about the minimum amount of employment to be created by the implementation of a road project can also be included in the contract. Such a provision amounts to making the contract a "labour contract" under which a labour contractor provides a specified number of workers at some specified time and place. This implies that the management of labour will be subcontracted locally. This method has been tried out by the Kenyan Ministry of Works quite successfully.[1] However, it is important to ensure that the conclusion of a minimum employment contract does not really amount to the mere provision of unemployment relief or to an unproductive utilisation of labour. When contract specifications and documents simply specify what should be done but not how, there is a danger that contractors will overstaff by hiring extra labour without necessarily making use of it. The most objectionable aspect of this approach is that an opinion might develop that employment on a road involves no work at all.[2]

To avoid underutilisation of labour, it may in some circumstances be better to specify in contracts that either *(a)* particular labour-intensive methods shall be used, or *(b)* a minimum amount of employment shall be created. If the labour-intensive methods are explained in detail, the contractors will make use of them provided that they are given the appropriate incentives to do so. In such a situation, a minimum employment clause might not be necessary. By making use of labour-intensive methods, contractors will *ipso facto* employ more labour than they would in the absence of knowledge of such methods.

Time limits

Most contracts provide that the construction work must be completed within a certain time. Because of such deadlines, both the public authorities and the contractors themselves are inclined to prefer capital-intensive methods, on the assumption that it will take much longer to complete a given task with the alternative labour-intensive methods, not necessarily owing to any technical inferiority of these methods themselves but owing to the organisational and planning difficulties that are considered in the previous chapter: for example, when work has to be completed by a time specified in the contracts, the possibility of a bunching of operations caused by initial delays in either starting work or completing part of it may tend to favour mechanisation. However, even if gestation lags with labour-intensive methods are longer, the social cost

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[1] See ILO: *Employment, incomes and equality*, op. cit., Chapter 11 and Technical Paper No. 8.

[2] Jens Müller: *Choice of technology in underdeveloped countries*, op. cit., pp. 86-87.

of delay in completion of construction work may be compensated by the social benefits that may result from greater employment or benefits in terms of reduction of social costs of construction through the use of labour-intensive methods. Where it is clear, therefore, that labour-intensive techniques, though they may extend the duration of the work, are socially the most efficient, consideration should be given to waiving the contract duration limit and any attendant penalties. In cases in which labour-intensive techniques can be applied, the contractor himself can be requested to specify the contract period in his tender. The onus will then rest on the client to decide whether the increased duration is offset by the more efficient use of the available resources.

ATTITUDES OF ENGINEERS

12

It has been said that "... the basic trouble with engineers is that they are professionally driven by what Schumpeter once called 'the half-artistic joy in technically perfecting the productive apparatus'. Give an engineer a machine and his instinct is to improve it; give him a plant and his instinct is to automate it. From his point of view it is perfectly understandable, even laudable. The engineer's interest is in technical efficiency ... and from this point of view, machines are often more reliable than men."[1] Many aspects of the engineer's education and environment tend to reinforce such an attitude. Most engineers, whether from developed countries or from the developing ones, are educated and trained according to curricula relevant to the problems of developed countries. This often implies a very high degree of specialisation and a tendency to ignore possibilities of trying alternative approaches to problems. As Jens Müller[2] puts it, polytechnical training institutes are being replaced by mono-technical institutes, with the result that "a one-solution-to-one-problem attitude" has developed among technologists and engineers.

Until recently, little attempt has been made to introduce the subject of appropriate alternative technologies into the curriculum of institutions for the training of civil engineers. It is all very well for civil engineers from the developing countries to be trained in the intricacies of sophisticated highway design, project planning and evaluation, but to give them such training without considering the environment in which they will be working in their own countries is irresponsible. It is often the case that an engineer's training precludes a choice of technology related to his own environment; and it is therefore necessary to instil into educationalists in both the developed and the developing countries the need to adapt their courses to the needs of the participants.

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[1] James Pickett, D. J. C. Forsyth and N. S. McBain: "The choice of technology: Economic efficiency and employment in developing countries", in *World Development*, Mar. 1974, p. 51.

[2] Jens Müller: *Choice of technology in underdeveloped countries,* op. cit.

Even when engineers have received a grounding that would enable them to envisage the use of alternative techniques, their approach is often biased by considerations of professional prestige. Because the socio-economic environment from which the "best-practice" techniques are borrowed is one in which labour is scarce, such techniques are capital-intensive and labour-saving. In developing countries, on the other hand, it is capital and not labour that needs to be saved. The desirability of technical efficiency can in any event be exaggerated in the context of road construction in developing countries. For one thing, earlier chapters in this manual have shown that labour-intensive methods of road construction can also be technically efficient. Wherever they are not, requirements of technical efficiency need to be weighed against those of social and economic efficiency. High standards of design and quality, which may have to be met by the exports of developing countries in order to compete in international markets, may not be necessary for roads, since they are not tradeable goods.

The inclination of engineers to use capital-intensive methods also results from a preconceived notion that operational problems involved in managing large masses of labour are avoided if capital-intensive methods are used. While this may well be true, the problems of labour management are not insurmountable, as has been shown in Chapter 10. Nor should one ignore the very serious problems involved in using heavy equipment in developing countries. Shortages of spare parts, late deliveries, cannibalisation of equipment and lack of skilled manpower are by no means exceptional. Moreover, the cost of breakdowns and non-utilisation is often left out of account when assessing the desirability of using such equipment, as was shown in Chapter 5.

Changing the attitudes of civil engineers is partly a matter of creating the right professional environment, i.e. altering the system of incentives and rewards, both material and non-material, and partly a matter of changes in the contents and methods of training.

The current system of rewards and recognition for engineers is such that they are not likely to either develop or promote technologies and designs that are not up to the most "modern" western standards. One means of encouraging engineers to devise and implement designs and technologies more suited to local requirements is to establish a structure of financial incentives that would specially favour such innovations. However, financial incentives alone are not likely to be enough, and the prestige of engineers who promote the use of appropriate technologies needs to be fostered more directly by such means as special annual awards for innovative labour-intensive designs and seminars for the display and demonstration of such innovations, with the participation of the highest-ranking political leaders in these events to show their commitment to and support for the innovations in question.

Since unduly specialised training has at times prevented engineers and technologists from considering different solutions to a given problem, it is worth encouraging the development of training institutions where different approaches are taught. However, such institutional changes alone will not be enough. Even in institutes without the desirable variety of courses, curricula could be changed to include discussions of the concepts of "intermediate" or "appropriate" technologies, with some illustrations and exercises to show how such a concept is translated into action. At present most engineers and technologists are not easily exposed to such issues in the normal course of their training. There is a virtual absence of appropriate training material for work on appropriate technologies, and it is therefore necessary that material suitable for training in schools, technical colleges, institutes of technology and universities be developed and used as part of the curricula.

Special seminars and training courses could also be organised. In these courses, instead of the standard training material, specially designed material for demonstration of technological alternatives could be used in order to enhance their acceptability. Demonstration projects could also be set up on which political leaders could demonstrate such "intermediate" techniques as the use of wheelbarrows and steel scrapers, thus giving them social sanction.

In certain developing countries there are State-owned construction companies: Ghana, Kenya and Tanzania, for example, all have publicly financed, government-managed companies that compete with private contractors. As long as these are efficiently run they can be used as a vehicle for promoting viable alternative technologies. The demonstration effect would enhance the prestige of these methods and the reputation of the engineers involved.

ESTIMATION OF THE IDLE TIME COEFFICIENT

It was shown on p. 101 that the over-all capacity, OVC, per man-hour or equipment-hour must be adjusted for a number of remunerated idle times, including—

(a) travelling time to and from the worksite,

(b) sick leave,

(c) public holidays and annual holidays with pay,

(d) work stoppages due to bad weather, and

(e) officially agreed rest periods.

The foregoing list of renumerated idle times may be expanded or shortened depending on the laws, regulations or practices that determine the conditions under which labour is employed. It should, however, be noted that idle times included in the formulation of the idle time coefficient should not include idle times that are already taken into consideration in the formulation of the over-all time (OVT) as defined in Chapter 3. In particular, it should not include idle times such as those resulting from equipment breakdown and normal waiting between consecutive operations.

The remaining part of this appendix will show how x may be estimated. The symbol x expresses the ratio of the sum of idle periods per unit of time to the number of remunerated hours in the same unit of time, that is

$$x = \frac{\sum_{i=1}^{n} t_i}{T} \tag{58}$$

where i refers to the type of idle time period (e.g. rest period, travelling time);

t_i = duration, in hours or fractions of an hour, of idle time of type i during the adopted unit of time;

T = total number of remunerated work hours that make up the adopted unit of time (e.g. 8 hours per day, 40 hours per week); and

n = number of types of idle time.

Since many of the idle periods occur every day, it is suggested that the working day be adopted as the unit of time. Idle periods that do not occur daily must then be divided by the number of working days over which they occur. Thus, if some idle periods occur weekly, these periods must be divided by 5, 6 or whatever other number of working days make up the working week.

SUBDIVISION OF IDLE TIME

Idle time can be subdivided as follows in order to estimate t_i in equation (58).

Travelling time to or from the worksite

The estimation of travel time is required only if workers are paid for the time during which they are being transported to or from the worksite. The way to carry out such an estimation is described in Chapter 5. It may be noted that the travelling time is project-specific.

Rest periods

The term "rest periods" here covers periods of idle time of at least five minutes. The duration and number of rest periods may be governed by regulations or by custom. In cases in which they are governed by regulations, one need merely refer to the regulations in order to obtain a fairly accurate estimate of this element of idle time. If the frequency and extent of rest periods are governed by customs applying to the whole region they will also be easy to ascertain simply by interviewing a field engineer or a foreman. On the other hand if they are governed by customs applying in smaller areas, project evaluators may need to undertake field studies in order to obtain the information required.

Bad weather

Stoppages due to bad weather that affect labour costs are necessarily work stoppages during which the workers are remunerated. Remunerated idle time due to bad weather is a function of—

(a) regulations governing the remuneration of labour in the event of bad weather; and

(b) the weather at the project site at the time when the road is being built.

Project evaluators may obtain data from the local weather bureau, if any, in order to estimate the probable number and duration of work stoppages due to bad weather. Given these data and the regulations governing remuneration, it will be possible to estimate the duration of remunerated idle time due to bad weather. For example, if a road is being built in a tropical country at a time of the year where it rains daily in the afternoon for about one hour during which construction work must stop, and if workers are paid for that hour, then $t_i = 1$. The following is another, slightly more complicated example. A road is being built during the winter season in a country where, on the average, it rains for about 10 hours a week. The workers are employed for 8 hours a day 6 days a week. On the assumption that the 10 rainy hours are spread over the week without following any specific sequence, the fraction of idle time per working hour may be computed by relatively simple probability calculations: the total number of hours per week is $24 \times 7 = 168$ hours; the total number of working hours per week is $6 \times 8 = 48$ hours; the probability that it will rain during working hours is thus equal to $48 \div 168$, and the expected value of rainy hours during the working hours of the week is equal to

$$\left(\frac{48}{168} \right) 10 = 2.857 \text{ hours} = 172 \text{ minutes.}$$

The two foregoing examples are fairly simple; real cases may require more sophisticated calculations. In general, however, such calculations are warranted only in cases in which the climatological data are reliable; if this condition is not met, rough estimates of idle time due to bad weather will have to be used.

Holidays

Given tentative starting and completion dates, it will be possible to sum up the number of paid holidays that occur during the construction period. Holidays with pay falling on the usual weekly days of rest should not be included in the summation. Given a construction period of D days, and a number d of holidays, the fraction of idle time due to paid holidays is equal to $\dfrac{d}{D}$.

Sickness or injury

As long as sick or injured workers continue to receive a daily wage, their sick leave should be regarded as idle time since it affects labour costs. The main difficulty is to estimate the total number of days of absence due to sickness or injury in any given period. Project evaluators may obtain averages from interviews with contractors and foremen or from field studies. If it is found that an average of l labourers out of a total labour force of L miss work every working day by reason of sickness or injury, the fraction of idle time due to sick leave is equal to $\dfrac{l}{L}$. If information on sick leave is not available and if there is no time for field studies, project evaluators may use averages derived from over-all national studies or from studies of particular sectors of the economy.

FORMULATION OF THE IDLE TIME COEFFICIENT

A mathematical formulation of the idle time coefficient, x, may now be provided for cases in which labourers receive a wage during any of the idle time periods enumerated above. For any kinds of idle time that are unremunerated or do not occur for a given project the appropriate terms in the equations that follow would be equal to zero.

The sum of individual idle times, t, may be defined as follows:

$$t = t_t + t_r + t_w + \frac{d.T}{D} + \frac{l.T}{L} \tag{59}$$

where t_t = round trip travel time in hours,

$\quad t_r$ = daily idle time due to rest periods, in hours,

$\quad t_w$ = expected daily work stoppage due to bad weather, in hours,

$\quad D$ = total number of work days in order to complete the project,

$\quad d$ = total number of holidays occurring during the construction period that do not fall on the weekly day or days of rest,

$\quad l$ = average number of labourers who are sick out of a total number of labourers L, and

$\quad T$ = number of paid work hours per day.

The idle time coefficient x is then equal to

$$x = \frac{t}{T} \tag{60}$$

The foregoing formulation may, however, need to be modified if idle periods overlap: a rainy period may occur during a rest period or during the travel time to

the workplace; similarly, a rest period will necessarily overlap with a sick leave period. To allow for overlaps probability calculations may be made as described below.

If there is no overlap of idle periods, the sum of these periods, not including holidays and sick leave, is equal to

$$t_t + t_r + t_w = t'$$ (61)

One may consider first the case of bad weather, defined here as weather conditions necessitating that work be stopped for at least 5 minutes. The probability that bad weather will occur at any time during the idle time t' is equal to

$$\frac{t' - t_w}{T} = p.$$

The expected value of the time overlap between t_w and t' is then equal to

$$p \cdot t_w.$$

Thus once account is taken of the possible overlap between idle time due to bad weather, t_w, and idle times t_t and t_r, the adjusted sum of these idle periods is equal to

$$A = t' - p \cdot t_w.$$ (62)

The value of x may now be reformulated as follows:

$$x = \frac{t''}{T}$$ (63)

where $t'' = A + \dfrac{d \cdot T}{D} + \dfrac{l \cdot T}{L}$.

Equation (63) is not strictly correct, in the sense that it does not take into consideration an additional possible adjustment, namely that sick leave and holidays could overlap with the sum of idle times A (overlap between sick leave and holidays need not be included because sick leave records cover work days only).

In most circumstances such an adjustment would not be substantial enough to have a significant effect on the value of x, and equation (63) would therefore generally provide a sufficiently accurate basis for estimating the idle time coefficient.

The following numerical example illustrates the use of equations (60) and (63). Let it be assumed that 1 million cubic metres of earth are to be excavated and that

$$T = 8, \, t_w = 0.5, \, t_r = 0.5, \, t_t = 0.3.$$

In the interests of simplicity, let it also be assumed that there are no holidays or sick leave; then x and the estimated excavation cost C will have the values indicated in table 20, according to the assumptions made or in other words the equation used. It will be seen that adjustment for idle time periods increases excavation costs by between 15.6 and 16.3 per cent. Adjustment for overlaps does not substantially affect excavation costs, since these decrease by less than 1 per cent.

Other formulations of the idle time coefficient could be worked out in order to take into consideration additional or different idle periods, as well as various possible overlaps among them. It is up to the project evaluator to identify relevant remunerated work stoppages and integrate them into a single coefficient.

Table 20.   Effect of different formulae on the adjustment of labour costs to allow for idle time

Assumptions	Idle time coefficient (x)	Excavation cost (C) ($000s)
No idle time	0	300
Equation (60)	0.163	349
Equation (63)	0.156	347