TRANSPORTATION TECHNOLOGY SUPPORT
FOR DEVELOPING COUNTRIES

SYNTHESIS 3

Labor-Based Construction and Maintenance of Low-Volume Roads

prepared under contract AID/OTR-C-1591, project 931-1116,
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Notice

The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competence and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

Cover photo: Labor-intensive road construction in Oaxaca, Mexico

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Project Description

The development of agriculture, the distribution of food, the provision of health services, and the access to information through educational services and other forms of communication in rural regions of developing countries all heavily depend on transport facilities. Although rail and water facilities may play important roles in certain areas, a dominant and universal need is for road systems that provide an assured and yet relatively inexpensive means for the movement of people and goods. The bulk of this need is for low-volume roads that generally carry only 5 to 10 vehicles a day and that seldom carry as many as 400 vehicles a day.

The planning, design, construction, and maintenance of low-volume roads for rural regions of developing countries can be greatly enhanced with respect to economics, quality, and performance by the use of low-volume road technology that is available in many parts of the world.

In October 1977 the Transportation Research Board (TRB) began this 3-year special project under the sponsorship of the U.S. Agency for International Development (AID) to enhance rural transportation in developing countries by providing improved access to existing information on the planning, design, construction, and maintenance of low-volume roads. With advice and guidance from a project steering committee, TRB defines, produces, and transmits information products through a network of correspondents in developing countries. Broad goals for the ultimate impact of the project work are to promote effective use of existing information in the economic development of transportation infrastructure and thereby to enhance other aspects of rural development throughout the world.

In addition to the packaging and distribution of technical information, personal interactions with users are provided through field visits, conferences in the United States and abroad, and other forms of communication.

STEERING COMMITTEE

The Steering Committee is composed of experts who have knowledge of the physical and social characteristics of developing countries, knowledge of the needs of developing countries for transportation, knowledge of existing transportation technology, and experience in its use.

Major functions of the Steering Committee are to assist in the definition of users and their needs, the definition of information products that match user needs, and the identification of informational and human resources for development of the information products. Through its membership the committee provides liaison with project-related activities and provides guidance for interactions with users. In general the Steering Committee gives overview advice and direction for all aspects of the project work.

The project staff has responsibility for the preparation and transmittal of information products, the development of a correspondence network throughout the user community, and interactions with users.

INFORMATION PRODUCTS

The two major products of this project are compendiums of previously published information on relatively narrow topics and syntheses of knowledge and practice on somewhat broader subjects. Compendiums are prepared by project staff at the rate of about 6 per year; consultants are employed to prepare syntheses at the rate of 2 per year. In addition, proceedings of at least 2 international conferences on low-volume roads are prepared and transmitted to the project correspondents. In summary, this project aims to produce and distribute between 20 and 30 publications that cover much of what is known about low-volume road technology.

News about the project work is published in the bimonthly *Transportation Research News*; reprints of these articles are distributed to the project correspondents.

INTERACTIONS WITH USERS

A number of mechanisms are used to provide interactions between the project and users of the information products. Review forms are transmitted with each publication so that recipients have an opportunity to say how the products are beneficial and how they may be improved. Through visits to developing countries, the project staff acquires first-hand suggestions for the project work. Additional opportunities for interaction with users arise through international conferences in which there is project participation and through informal meetings with U.S. students who are from developing countries and who attend the annual TRB meeting.

Foreword and Acknowledgments

This publication is the third in a series of syntheses being produced by the Transportation Research Board's project on Transportation Technology Support for Developing Countries. A list of all project publications that have been completed to date appears on the inside back cover of this book.

It is planned that each synthesis be published first in the English language and that separate French and Spanish versions be published as soon thereafter as the respective translations can be completed.

The objective of the book is to provide useful and practical information for those in developing countries who have responsibility for the labor-based construction and maintenance of low-volume roads. Feedback from project correspondents will be solicited and used to assess the degree to which this objective has been attained and to influence the nature of later syntheses.

Acknowledgment is made to the International Labour Office and International Bank for Reconstruction and Development for permission to use figures that are reproduced in this publication.

Appreciation is also expressed to libraries and information services that provided reference material that was consulted in preparing the synthesis text. Special acknowledgment is made to the U.S. Department of Transportation Library Services Division and to the Library and Information Service of the U.K. Transport and Road Research Laboratory, as well as to the various libraries of the World Bank.

Finally, the Transportation Research Board acknowledges the valuable advice and direction that have been given by the project Steering Committee, and is especially grateful to G. A. Edmonds, International Labour Office, Clell G. Harral, International Bank for Reconstruction and Development, Voyce J. Mack, U.S. Department of Transportation, and Peter H. Thormann, U.S. Agency for International Development, who provided special assistance during the development of this particular synthesis.

CHAPTER 1

Introduction

TRANSPORTATION AND RURAL DEVELOPMENT

The problem of rural and urban employment has emerged as one of the most important and challenging to face developing countries today. Even countries with good rates of national growth experience high rates of unemployment and underemployment, as well as a growing gap between the rate of new entries to the labor force and the capacity of the economy to absorb them. Moreover, the unemployed and underemployed are forced to accept very low levels of income; this results in considerable disparity between the highest and lowest income groups with little in the way of offsets to income inequality. The surplus of labor, which is currently available and is expected to grow, cannot be fully utilized without an increase in the supply of capital.

In view of the relative abundance of labor and the shortage of capital in developing countries, it has been suggested that labor be substituted for capital in building and maintaining roads, thereby generating more employment and output than would otherwise be possible.

Some 85 percent of the world's poor is estimated to be living in rural areas(1). Through rural development, much of the suffering of this large number of rural poor may be alleviated. Some 70 percent of public investment expenditures in the developing world is typically directed toward civil works (2); rural roads, water supplies, irrigation works, markets, and storage facilities typify the public works needed for an improved quality of life. In contrast to major civil engineering undertakings, such as large dams or bridges, rural development projects are often characterized as small in scale, dispersed among many sites, and having relatively elementary technical requirements. Transportation, particularly roads, has been perceived as an especially important component of rural development in terms of stimulating local development in agriculture and industry, marketing agricultural commodities and expanding trade, providing access to social services, and generally serving to integrate the rural population into the overall economy. Trends in transport investment in recent years have been increasingly away from the primary road network and toward greater emphasis on rural feeder and penetration roads.

Labor-based road construction is not, however, a panacea. The effect on the overall unemployment situation in many developing countries is likely to be relatively small due to the magnitude of the employment problem in relation to the expenditures in the sector. At the same time, many activities in road construction, particularly earthmoving, are common to other civil works construction and, in turn, might become heavier users of labor; the same holds true for maintenance operations. Increased labor use by other sectors of the economy is necessary in order to create substantial employment.

POTENTIAL FOR USE OF LABOR IN ROAD CONSTRUCTION AND MAINTENANCE

Years ago, before the advent of modern civil engineering equipment, roads and other public works were built by laborers who used simple tools and animal power. Technological development and rising wage levels over time led to increased mechanization of construction techniques in the industrialized countries. Concurrently, project design, design standards, and materials have been adjusted to better suit the equipment-based techniques and to upgrade the quality and service of the final product. These capital- or equipment-based techniques and designs have often been transferred to the developing countries.

Although substituting labor for equipment may be difficult for high-standard roads, the potential for increased use of labor in lower-standard roads is most promising. However, it is important to consider labor-based methods in the early stages of project planning, so that materials and standards that are compatible with the technology can be used in the design. For example, the design of feeder roads is influenced by the method of construction. The tendency in countries where labor-based techniques are used is to do only the outline design before construction begins, leaving final design details to the site engineer.

Labor-based technology for construction and maintenance of low-volume roads are potentially most favorable in the following situations:

- Low-volume roads, among other rural public works, are needed to assist in local development; the projects are largely characterized as small in scale, geographically dispersed, and technically uncomplicated.
- There are many poor people, most of whom are underemployed or openly unemployed.
- A mechanism is desired to generate additional income for these poor people and improve the equity of income distribution.
- Capital reserves, both local currency and foreign exchange, are insufficient to buy and operate the machines needed to construct and maintain the rural improvements in their entirety.
- Personnel with the necessary experience to manage and operate the equipment are in limited supply.

Such conditions are familiar to the developing world. Characteristics of individual countries, however, are not constant over distance or time.

Established tradition or recent management experience with either labor or equipment methods are major dimensions in their introduction. Accumulating such experience is a costly process that develops over many years. The services of equipment-based foreign contractors can often be imported, but labor-based expertise is less easily imported. The introduction of labor-based methods in those countries without a recent tradition in manual methods must be planned carefully and executed gradually. Limited mixing of technologies among projects or even within a single project may be possible in order to maximize the use of labor without sacrificing regional or national development goals, or without violating technical, cost, or scheduling constraints on the construction program as a whole.

In addition to asset creation and upkeep in the form of the road itself, greater use of labor in low-volume road construction and maintenance in an efficient and effective manner brings the benefits of increasing self-reliance on the part of the country involved. The tasks involved in road construction are relatively simple and can be carried out largely by unskilled labor with little training (although skilled management is needed). The tools and techniques used in the major activities, such as earthworks, are not dissimilar from those used in agricultural activities. Moreover, the potential pay-off in terms of employment per unit of investment appears to be high. Studies of road construction in India, the Philippines, and elsewhere, for example, have found the employment generated by using labor-based techniques to be potentially some seven to eight times that of equipment-based alternatives (3, 4). Development of local contractors by using more labor-based, often indigenous, techniques, as well as locally available materials, has potentially significant implications for the development of the local construction industry, as well as certain support industries, e.g., manufacture of tools, simple equipment, and construction materials.

Construction equipment and spare parts are major import items in many developing countries. Moreover, the skilled personnel necessary for their management, operation, upkeep, and fuel are often in short supply and relatively expensive. Transporting machines to numerous geographically dispersed, often remote, projects is expensive and difficult at best. Much equipment is disproportionately large for the small-scale, low-volume road projects. The net result of such conditions is low utilization of the equipment. In conjunction with the study of the Indus superhighway in Pakistan, for example, numerous estimates of equipment utilization were obtained; an average of the available estimates suggests a figure under 1000 hours/year, compared with the standard of 2000 hours observed in industralized countries (5).

The underlying rationale for considering the use of labor-based techniques is maximizing the efficient use of available resources. It is important to consider the disadvantages of increased labor and its potential benefits. It is generally thought that use of labor means an automatic decrease in standards of construction. This may indeed be true in the case of certain activities, such as compaction and final surfacing, which labor alone may have difficulty performing comparable to the standards attainable by equipment. The objective of labor-based construction is not to blindly use it everywhere but, rather, to use it where it is appropriate and does not produce an inferior product.

Project cost and timing are two frequently raised objections to the use of more labor in road construction. For example, low productivity can lead to the extension of project time, or an increase in the number of laborers needed for its execution. Significant variations in productivity by using labor-based methods have been observed. But, although unimproved traditional methods of road construction may indeed result in low productivity, the potential for improvement through better organization and supervision, use of incentive schemes, improved tools and simple equipment, and upgraded nutrition and health seems promising. There are, of course, certain construction activities that are not critical to project completion. With proper planning these can be done by labor, even if more time is needed. Preliminary efforts in pilot projects of the World Bank and the International Labour Office (ILO) have been encouraging, but productivity improvement remains a major factor in the successful implementation of labor-based methods of construction.

Low productivity may also have an impact on the cost of the project. Labor-based methods have been found to be financially competitive with equipment-based alternatives in some low-wage countries, but such comparisons among alternatives, have largely been attempts to evaluate what might have occurred had labor-based methods been used on a project that was actually planned for and executed by equipment. Consideration of alternatives at the start and the neutralization of projects are necessary if alternatives are to be equitably compared. It may also be necessary to extend the comparison beyond construction costs to maintenance and user costs, if two somewhat different projects are to be compared in view of their respective appropriateness for use of labor or equipment. It may be that the market price of labor, equipment, and other resources does not adequately reflect the opportunity cost of these items. The implication is that comparisons ought to be done by using shadow prices (see Chapter 3). Given the chance, nevertheless, labor-based methods must be able to compete if they are to be used because the budget for road construction is necessarily limited.

A third objection to the use of labor-based methods of road construction pertains to the management burden of large numbers of laborers. The output of a single piece of equipment may be equivalent to that of 200 laborers. These laborers, in turn, must be mobilized, supervised, and provided with the necessary amenities. The overhead costs can be expected to be high, although they are difficult to anticipate. This is an area still relatively new, unexplored, and just now being touched on as labor-based programs and projects begin to be implemented. Similar problems, of course, often exist where equipment is used. Mobilization of machines and provision of repair facilities, for example, can be an expensive as well as a difficult proposition when projects are remote and dispersed. This can also result in significant delays in project start-up and execution and is typically a very serious problem for highway maintenance.

Finally, certain institutional forces and contractual rigidities within the construction industry itself and the sector providing the roads tend to militate against the use of more labor. Design methods, specifications, conditions of contracts, and methods of tendering, for example, have evolved with the mechanization of road construction and have been transferred to developing countries by expatriate consultants, contractors, and others. Methods of selecting contractors, for example, are often based on the amount of equipment they have, not on their ability to manage men. Biases inherent in the requirements of sponsoring aid agencies have also been a contributing factor, perhaps more so in the past than recently. Particularly important is the education of the technical leadership in most developing countries. Engineers educated in Western-oriented schools stressing state-of-the-art technology tend to be conditioned to using heavy equipment.

Predictable productivities, costs, and performance associated with machinery as opposed to the risks usually associated with labor make the use of equipment particularly attractive.

These various constraints on the use of labor-based methods for low-volume road construction and maintenance are each discussed in the following sections of this synthesis. Any labor-based program that is to be successful must first show how the basic technical, financial, and economic problems can be solved; then it must demonstrate how the institutional and social environment of road projects might be made more conducive to the effective use of labor. Road construction is typically financed and supervised by the government, which, therefore, can be instrumental in ensuring that available resources are used in the most effective manner possible. Through economic incentives (e.g., taxes, tariffs, and subsidies), regulatory measures (e.g., import quotas, visa restrictions, and minimum employment requirements), contract award procedures (e.g., contractor selection on the basis of national economic profitability rather than minimum cost), the government can do much to promote the use of labor-based techniques where appropriate.

SYNTHESIS 3: PURPOSE AND SCOPE

In response to the conditions facing many developing countries in the late 1960s, the World Bank, the International Labour Office, and other similar organizations began to consider the fuller utilization of available resources, such as labor, and the conservation of resources in scarce supply, such as capital, when building rural infrastructure facilities. Knowledge of how to apply unskilled labor effectively in public works construction was limited in all but a few countries. No systematic studies had yet been done on the advantages and disadvantages and the comparative costs and results of using large groups of workers to build projects previously constructed by machines. Extensive research programs were therefore initiated to identify potential alternative technologies. Studies in India, Indonesia, Iran, Thailand, and the Philippines demonstrated the technical and often socioeconomic feasibility of various labor-based technologies under local conditions. The financial feasibility of the alternative technologies appeared less clear-cut. Some studies found that the labor-based methods under consideration were competitive with equipment-based options, but other studies did not. The general consensus was that an effort should be made to increase the role of labor for road construction by effectively using more labor-based technologies and improving labor productivity in labor-abundant, capital-scarce countries.

These findings led to further studies and pilot projects throughout the world, including, for example, Kenya, Honduras, Nepal, Pakistan, Chad, Lesotho, Republic of Haiti, Benin, and the Dominican Republic. Mexico and Colombia initiated earlier labor-based, rural road programs. Many of the findings and recommendations of the case studies of the late 1960s have been tested and refined, and the process continues to the present. Within the last year or two a number of manuals have been (or are being) produced as a final research product of these studies. Some of these are

1. ILO *Guide to Tools and Equipment for Labour-Based Road Construction* (6), which will serve as a catalogue of tools and simple equipment potentially suitable for use with labor;
2. ILO *Manual on the Planning of Labour-Intensive Road Construction* (7), which largely focuses on the evaluation of alternative technologies in a project context;
3. World Bank and ILO *Labor-Based Construction Methods: A Planning and Management Handbook* (2), which will concentrate on implementation of labor-based technologies both in program and site terms, particularly the details of site planning and management; and
4. ILO *Guidelines for the Organization of Special Labour-Intensive Works Programmes* **(8)** and the U.S. Agency for International Development (AID) *Creating Rural Employment: A Manual for Organizing Rural Works Programs* (9), which focus largely on concerns of program level implementation and integration into economic development.

Given these five manuals and the extensive background publications on the subject, largely produced in the course of the last 10 years, a summary or state-of-the-art document is clearly needed. It is the purpose of this synthesis to fulfill this need. Drawing on the work completed to date and in progress, the synthesis presents an overview of the meaning, concerns, and use of labor-based technologies in low-volume road construction and maintenance in the context of development. The major topics of discussion include

- identification of alternative technologies;
- evaluation of alternatives under varying conditions in technical, financial, and socioeconomic terms; and
- implementation at the national (program) and local (project) levels.

Alternative technologies include the full spectrum from all-labor- to all-equipment-based options. Speaking of labor- versus equipment-based technology is too great a simplification because construction methods throughout the world span a wide range of combinations of human, animal, and mechanical resources used. Attention throughout this synthesis is focused on labor-based alternatives because knowledge about equipment-based approaches is more widespread. The appropriate mix of men, animals, and machines in any particular case is a function of technical, financial, economic, institutional, and social considerations. Also, this synthesis assumes that proposals for the greater use of labor must be cost-effective and not simply make-work propositions.

Synthesis 3 is written mainly for policymakers in the transportation ministry, planners of road programs, and chief engineers in the road authority. Policymakers and planners more broadly concerned with the financial and economic affairs of the nation and site engineers may also find this synthesis helpful. A primary objective is to identify the various factors to be considered when selecting among various technologies and to structure a framework by which this might be done even if the factors are not fully quantifiable. The synthesis is intended to be an unbiased overview of the situation, and a complementary document to the implementation manuals noted above.

Chapter 2 begins the investigation of alternative construction and maintenance technologies for low-volume road construction by presenting the spectrum of available alternatives. The discussion is illustrative and demonstrates the range of options and their potential use. The topics of productivity and organizational, as well as technological, alternatives for maintenance are also discussed. Chapter 3 then proposes a framework for the evaluation of the alternatives in the context of their use in road projects. A three-tiered assessment is outlined: technical, financial, and socioeconomic feasibility of alternative means of construction and maintenance. Data for such an evaluation will be generated in the course of implementation. Chapter 4 discusses the use of labor-based technologies. Beginning with the national-level policy, or the program concerns and requirements that may arise, the chapter then proceeds to the more detailed local level planning and project-related activities that are affected by the increased use of labor.

CHAPTER 2

Alternative technologies

A wide variety of factors enters into the process of identification, selection, and utilization of alternative combinations of resources or technologies for construction and maintenance of low-volume roads. First and foremost are resource availability and potential for development and use. The availability of unskilled and skilled labor, animals, simple tools and equipment, heavy equipment, and materials pertains to the time and location at which the resources are to be used; this includes concerns as to the available numbers, requisite skills necessary to use these resources, and managerial capabilities to organize their use.

Given availability, the next issue to be raised is the feasibility of using these alternatives. This is subject to considerations of project design and other technical constraints such as product quality and timing. Moreover, productivity and cost of these alternative combinations under various conditions of use are of concern from both a financial and economic point of view. (Resources can be priced at market or prevailing cost — a financial consideration — or at "opportunity" cost to eliminate market price distortions — an economic consideration.) Finally, the benefits one might expect with the use of these alternative technologies might include creation of infrastructure assets, unemployment relief, improved income distribution, and reduced foreign exchange expenditures.

Given feasibility, issues in implementing these alternative combinations of resources come to the fore, namely the commitment of policymakers, administrators, and engineers to the idea; financial arrangements and incentives at various levels; contracting and procurement procedures; contractor and tool development; and administrative and operational issues in planning, financing, executing, and monitoring the program and projects involved.

Chapter 2 begins the process of investigating alternative construction and maintenance technologies by presenting the spectrum of available alternatives; the topics of evaluation and implementation are left to Chapters 3 and 4. The discussion is intended to be illustrative and not inclusive of all possible resource combinations. The objective is to demonstrate the range of alternatives and their potential use. For a more complete list of alternatives and more details on those that are discussed here, the reader is referred to forthcoming publications of the World Bank and International Labour Office (2,6).

In this chapter, attention is focused on construction because it has been the primary focus of efforts to date in the field. It is felt that the development of labor-based maintenance techniques will be similar to the development of labor-based construction techniques because many of the tools and operations will be similar. Information is more generally available for equipment-based alternatives so the labor-based end of the spectrum receives more attention in this discussion. The topic of construction productivity — what it means, why it is important, and how to measure and improve it — is also briefly discussed below. Maintenance, organizational, and technological alternatives are discussed later in this chapter.

ROAD CONSTRUCTION ALTERNATIVES

The spectrum of technologies available for low-volume road construction ranges from labor-based to equipment-based alternatives. Nearly all projects use a mix of labor and equipment, although the relative proportions can differ substantially. Some projects may be basically labor-based but may need to use equipment to achieve a specified quality in the end-product of certain activities such as compaction. Even the methods at the extremes require a certain amount of the complementary resource; for example, labor-based approaches use equipment in the form of hand tools, and equipment-based approaches use labor in the form of operators. Work animals may also be very useful and cost-effective in combination with labor and simple equipment such as carts and rollers. Table 1 gives an indication of the range of construction methods potentially appropriate for use in low-volume road projects in India. The suitability of the alternatives is a function of the particular conditions of the project and region.

Mechanization of road construction over the past 50 to 100 years has been considerable in the industrialized countries. These techniques have been transferred to developing countries, and information about them is readily available in manufacturer's catalogues and textbooks. Developments in the design and manufacture of hand tools, the adaptation and modification of agricultural and mining equipment for use in

Table 1. Spectrum of road construction methods potentially appropriate for use in India (**10**).

Activity/Task		Labor-Based Methods	Intermediate Methods	Equipment-Based Methods
Excavation of soils and rock	soft soil	Hoe[1]		Dozer; Tracked excavator; Wheeled loader; Scraper with or without pusher
	firm soil	Hoe[1]		Dozer; Tracked excavator; Wheeled loader; Scraper with or without pusher
	hard soil	Pick		Dozer; Tracked excavator; Wheeled loader
	soft rock	Pick; Crowbar		Dozer-ripper; Tracked excavator
	medium rock	Crowbar		Dozer-ripper
	hard rock	Hand-drilling and blasting	Hand-drilling and blasting	Compressed air drill blasting
Loading, hauling and unloading	0-50m	Hoe into headbasket; Hoe, wheelbarrow	Hoe, animals[2], panniers; Power winch wheelbarrow or rail wagon up slope of bank	Dozer; Wheeled loader alone
	50-100 m	Hoe into headbasket; Hoe, wheelbarrow	Hoe, animals[2], panniers; Power winch wheelbarrow or rail wagon up slope of bank; Manually operated rail system	
	100-200 m	Hoe, wheelbarrow	Manually operated rail system	Scraper with or without pusher
	200-500 m	Hoe, animals,[3] carts	Hoe & head basket or shovel into tractor/trailer, unload by tipping or hoe or shovel; Hoe & head-basket or shovel into flatbed truck, unload by hoe or shovel	Scraper with or without pusher; Wheeled loader or tracked excavator into dump truck
	500-1000 m	Hoe, animals,[3] carts	Hoe & head basket or shovel into tractor/trailer, unload by tipping or hoe or shovel; Hoe & head-basket or shovel into flatbed truck, unload by hoe or shovel	Scraper with or without pusher; Wheeled loader or tracked excavator into dump truck
	1000-2000 m		Hoe & head basket or shovel into tractor/trailer, unload by tipping or hoe or shovel; Hoe & head-basket or shovel into flatbed truck, unload by hoe or shovel	Wheeled loader or tracked excavator into dump truck
	2000-5000 m		Hoe & head basket or shovel into tractor/trailer, unload by tipping or hoe or shovel; Hoe & head-basket or shovel into flatbed truck, unload by hoe or shovel	
	over 5000 m			
Excavation, loading, hauling and unloading in earthworks in side-long cut in hill roads, mixed soil and soft rock, maximum haul 50 m		Excavate by hoe, pick or crowbar, haul by headbasket	Excavate by hoe, pick or crowbar, haul by wheelbarrow	Dozer
Spreading soils and aggregates		Hoe or rake		Grader or Dozer
Loading hauling and unloading stone materials in quarry, haul distance 0-200 m		Carry by hand Load by hoe or rake into headpan	Collect by headpan into (a) Wheelbarrow (b) Manually operated chute (c) Manually operated aerial ropeway (d) Manually operated rail system	Dozer and wheeled loader alone Dozer, wheeled loader and dumper Dozer, wheeled loader and dump truck Mechanical conveyor
Production of stone aggregates (i.e., breaking or crushing)		Hammer	Mobile crusher, loaded by hand, stone prebroken to 100-150 mm	Crushing plant with integral screens and conveyor, loaded by wheeled loader
Loading, hauling and unloading aggregates from quarry to road site, haul distance 1 km upwards			Load by rake and headpan, or by rake or shovel from loading platform or chute into (a) Tractor/trailer, unload by rake or tip (b) Flatbed truck, unload by rake	Wheeled or tracked loader into dump truck
Heating and mixing bitumen macadam		Heat chippings and bitumen over open wood fire, mix by shovel or rake	Heat bitumen in tar boiler, heat chippings and mix with bitumen in small or medium-sized mechanical mixer	Integrated hot mix plant

Table 1. (Continued)

Activity/Task	Labor-Based Methods	Intermediate Methods	Equipment-Based Methods
Hauling and laying bitumen macadam surface	Haul by stretcher, lay by rake	Haul by wheelbarrow, lay by hand-propelled screed board with or without rails	Dump truck and paver
Compaction of earthworks and sub-grade		Hand-propelled mechanical rollers of various types for small quantities Animal-towed sheepsfoot roller for large quantity	Self-propelled roller Tractor-towed sheepsfoot roller
Compaction of base and surfacing materials			Self-propelled roller Tractor-mounted ('Khamini' type) roller

[1]The word 'hoe' is used to describe the back-acting tool used all over India for digging in soft soil and for loading, variously named 'powrah', 'mamti', etc. For non-cohesive soils, a shovel may be more suitable than the hoe.
[2]I.e., mule, donkey or camel.
[3]I.e., mule, camel or bullock.
[4]This method is untested in India.

construction, and the use of pedal and simple motor-powered equipment over this same period have been limited. Only in the last 10 to 15 years has there been an expression of renewed interest in greater use of labor in construction activities, and only more recently have efforts been directed toward improving the efficiency of these alternative approaches under suitable conditions. ILO and World Bank have been instrumental in some of the early studies, along with certain developing countries (Mexico, Kenya, Honduras, Haiti, Colombia, India, and the Philippines), that have cooperated in these efforts and, in some cases, have developed their own labor-based programs.

In beginning to look at the spectrum of technologies available for road construction, it is useful to divide the construction procedure into various stages: site preparation; earthwork; subbase, base, and surfacing, using earth, stabilized earth, gravel, and surface treatments among other materials; minor structures; and major structures. Each stage, in turn, consists of several activities, with some commonality among stages. Earthwork, for example, consists of excavate, load, haul, unload, return, spread, compact, and finish. Similarly, tasks can be defined as groups of possibly interdependent activities, such as earthwork activities and excavate through spread. The resources used include unskilled and skilled labor, engine and animal-powered equipment, animals, simple tools, and construction materials. Table 2 classifies a wide range of construction hardware in terms of its particular capabilities in road construction operations.

Various environmental conditions, such as climate, soil/rock type, and haul distance and condition, and various institutional conditions, such as management and organization, physical condition and skill of workers, availability and quality of maintenance, and repair facilities, may have an important impact on resource productivities and the subsequent costs of various alternatives. Table 3 organizes a list of typical parameters as specific (those applying to certain activities/tasks) and general (those applying more or less equally to all activities/tasks).

Construction Technologies: Their Identification and Use

Site Preparation

Site preparation, the first stage in road construction, consists of brush, tree, and stump removal from the roadway, and disposal of debris; it may also include removal of topsoil, or this may be included in earthwork. The environmental condition of primary concern is the amount of vegetation, which might range from grass and scrub to dense forest. The tools and techniques vary accordingly.

Table 4 shows the resource requirements and productivities of two basic technologies for clearing different levels of vegetation. The capital- or equipment-based approach calls for a tractor with a blade and various other attachments in light to medium vegetation. In heavier vegetation, some tree-cutting equipment in addition to a dozer with a ripper attachment may be necessary.

Agricultural implements, such as long-bladed knives, hoes, and picks, are useful for labor-based techniques in light and medium vegetation. Productivity depends on the organization of the labor force. Table 5 is a detailed example of the overall process followed to determine the organization of a manual clearing operation on a road project in Kenya. Dense vegetation requires some use of intermediate tools, such as small power saws and other mechanical tools. Although stripping of topsoil might be considered earthwork, loosening and clearing the top layer is often considered site preparation. Agricultural plows drawn by animals or small tractors are sometimes useful for the loosening operation. The materials are then removed by hand or small scrapers. Figure 1 shows a plow drawn by a water buffalo used in the Philippines.

Excavation and Loading

Earthwork constitutes a major portion of low-volume road construction. Excavation and loading constitute the first part of earthwork and may be treated as one or two operations.

Table 2. Hardware capabilities (**11**).

Class and Sub-Class		Item	E	EL	EM	ES	S	L	U	H	HU	HUS	T	EMS	SC	LHU	LHUS	ELHU	HMUS	C*	C
Excavation tools: pointed and narrow bladed	Vertical cutting action	Crowbar	•																		
		Grafting Tool	•																		
		Pick	•																		
		Mallock	•																		
		Pneumatic Tools	•																		
	Horizontal cutting action	Animal Plough	•																		
		Winched Plough	•																		
		Towed or self-propelled Tipper, Rooter or Scarifier	•																		
Excavation, loading and spreading tools: toothed, forked and bladed		Spades, Shovels and Forks	•	•	•	•	•	•	•	•				•							
		Hoes and Rakes	•	•	•	•	•	•	•	•				•							
		Chute									•										
		Sledge									•										
Manual Haulage, Animal Haulage		Sach									•										
		Panniers									•										
		Stretcher									•										
		Double Basket Yoke or shoulder Pole (one man)									•										
		Shoulder Pole (two men)									•										
		Head Basket or Headpan						•			•	•									
Wheeled haulage	Non-tipping	Hand Cart								•											
		Animal Cart								•											
		Tractor Trailer								•											
		Flat Truck								•											
	Tipping	Wheelbarrow									•										
		Bottom Dumping Cart									•										
		Rear Tipping Cart									•										
		Dumper									•										
		Tractor Tipping Trailer									•										
		Rail system with Tipping or Dumping Wagons									•										
		Ropeway or Cableway with Tipping Buckets									•										
		Tipping Truck, Dump Truck									•	•									
Scrapers, blade excavators		Animal-drawn Scraper														•	•	•	•		
		Winched Scraper														•	•	•	•		
		Towed or self-propelled, pushed or self-loading Scraper														•	•	•	•	•	
		Grader			•	•	•							•							
		Animal Dozer			•	•	•							•							
		Dozer track-laying and wheeled			•	•	•							•	•					•	
Bucket excavators, power shovels, conveyors and equipment incorporating conveyors		Excavators, Shovels, Grabs, Draglines, etc.		•				•								•		•		•	
		Endless chain bucket trencher with Elevator		•																	
		Elevating Grader		•				•													
		Bucket wheel Excavator		•				•													
		Elevator (bucket conveyor)						•													
		Mobile Conveyor						•			•										
		Belt Conveyor, Warm Conveyor									•										
Transfer systems		Shaduf											•								
		Chinese level transfer Basket											•								
		Ropeway with Containers											•								
		Carousel											•								
		Rail system with Containers											•								
Compaction equipment		Tampers																			•
		Animal-towed Rollers																			•
		Towed Rollers																			•
		Self-propelled Rollers																			•
		Power Rammers																			•
		Plate Compactors																			•

Activity or Task Capability

KEY:

E = Excavate
L = Load
H = Haul
U = Unload
S = Spread
T = Transfer
C = Compact
C* = Incidental Compaction
Hence, for example,
HUS = Haul, Unload, Spread.

Table 3. Set of environmental and institutional conditions potentially affecting the productivity of both men and machines (**2**).

Specific Parameters, applicable only to specific activities/tasks:

Soil/Rock	Excavation	SPECIFIC PARAMETERS
Loading height	Loading	
Haul distance Haul route rise/fall Haul route condition	Haulage	
Layer thickness Rate of spread	Spreading	
Reduction factor Rock hardness	Breaking/ Crushing	
In-situ density Loose density Compacted density	Earthworking Adjustment	

General Parameters, applicable to many or all activities/tasks:

Payment method	Incentive	INCENTIVE PARAMETER
Condition of tools Supervision Job Organization Labor relations On-site training Type of contract	Labor Management	MANAGEMENT PARAMETERS
Supervision Job Organization Labor relations On-site training Type of contract Equipment condition Maintenance level Spares availability	Equipment Management	
Air temperature Relative humidity Rainfall	Climatic	SITE PARAMETERS
Altitude Terrain Type of work Traffic interference	Site Environment	
Health and nutrition Traditional skill Local customs	Human Environment	

The materials may be from cuts for the road itself or from borrow; these may be going to an embankment or to spoil. The type and volume of material to be handled, as well as local custom and conditions, dictate the particulars of the method to be used.

Limiting the discussion for the moment to manual methods, Table 6 serves as a guide to the selection of general categories of tools for specified conditions. Labor-based methods of excavation and loading tend to be rather tradition-bound. This is an area of work familiar to most rural poor, and the tools used are largely basic farm implements,

Table 4. Sample of alternative site-clearing methods under different vegetation conditions (**8**).

Task[1]	Technology	Inputs	Resource days required
Task A	Labor-based	Laborers, handtools	16
Task B	Labor-based	Laborers, handtools	45
Task A	Capital-based	Dozer Operator	1/2 1/2
Task B	Capital-based	Dozer, operator, laborers handtools	1 1 4

[1]Task A: Light clearing—thick bushes and scrub but no trees above 4 in. in diameter (one acre).

[2]Task B: Medium clearing — dense undergrowth with a few trees up to 10 in. in diameter (one acre).

each of which has certain country-specific characteristics. The range of productivities achieved by using labor-based methods is very broad. Soil type and load height are two parameters affecting resource productivity in these activities, as shown in Figure 2. A loading height of some 1.5 m seems to be the limit for effective loading by hand (**7**). In hard soils, excavation and loading often have to be executed as two separate operations. A variety of other factors, somewhat more institutional in nature, may also influence the competitiveness of labor-based methods:

- Usage of tools familiar to the laborers and of as few different types as possible — provided that they are suitable to the materials being handled and methods being used—is important. The variation in tools used for particular operations among countries appears to have little effect on the productivity achievable given all other conditions constant.
- Quality, durability, and maintenance of the tools can significantly affect productivity. The cost of high-quality, simple tools is very small relative to the cost of labor (as low as 3-4 percent of wages); similarly, the cost of employing a carpenter to fix tool handles and a blacksmith to sharpen hand tools may be repaid many times by increased productivity.
- Organization of the site and the laborers on the site, along with balance between workers and tools and among tasks (e.g., excavate, load, haul, and unload) are critical to the efficiency of the operation. For example, it is better and easier for labor to excavate from vertical faces rather than to work on large horizontal areas; this helps (a) to prevent excessive drying, (b) to maintain a clear excavation face, to keep the materials haulage area uncluttered, and (c) to possibly allow for direct loading by gravity.

Given proper attention to such conditions, labor-based methods of excavation and loading may be reasonably competitive with machine-based methods in countries where

Table 5. Description of inputs and organization of manual methods of site preparation in road construction in Kenya (**12**).

1. Bush Cutting

This operation consists of cutting the existing bush within the 8-meter right-of-way of the proposed feeder roads. Tools required for this operation are pangas and one file. The general system used has not varied from one road to another; a crew of laborers is spread along both sides of the proposed road, each man being placed X meters from the next. One laborer clears the distance from the starting point to the point where the next nearest man to him has started. He then rotates ahead to the front of the crew to begin clearing a new section. This rotation continues until the entire length of the proposed road is cleared. Within this general system several variations have been tried. The objective has been to determine

- the optimal distance which one headman can effectively supervise and, given this,
- the distance between laborers which will assure maximum cost effectiveness.

That is, too great a total distance cannot be supervised well, and it has been found that laborers placed too close together tend to engage in excessive conversation, thus slowing the work. The range of optimal spacing of labor depends on the degree of supervision required in the operation.

2. Stump Removal

This operation entails removing the stumps of the bush cut in operation 1. Tools required include mattocks, axes, and shovels. The optional system is the same as bush cutting.

3. Grass and Topsoil Removal

Tools used for the removal of grass and topsoil are jembes, fork jembes, and shovels. Initial difficulty was encountered when grass tended to grow back rapidly after this operation was completed. The technique used at that time was to loosen the topsoil to a depth of approximately 4 inches and shake out the grass and roots. Several modifications to this approach were tried, and the following was settled upon: dig and throw out 4 inches of topsoil; then loosen approximately 9 additional inches of soil; let dry and remove any remaining grass or other unsuitable material. To date this approach has proven to be the most effective.

The general system used in this work is again, the same as in 1 and 2 above. However, the optimal crew and distance between laborers differs. Laborers are placed at each side of the road. One laborer is responsible for removing grass and topsoil from his edge to the center of the road (i.e., 4 meters). This operation requires more careful supervision than the previous operations described.

4. Stone Removal

One of the most difficult and in some ways most interesting problems confronted has been the removal of the large stones found in Vihiga and Hamisi Divisions. Tools required for this operation include crowbars, shovels, jembes, and fork jembes. Stones within 12 inches of the top of the proposed roadway must be removed. Several methods to accomplish this have been used:

- Small stones (1 cubic meter and less)—dig the stone out and roll it from the roadway.
- Stones larger than 1 cubic meter — if the stone is 90+% above the surface of the road a first attempt is made to dig it out and roll it from the road. If this is not possible because it is too large or more than 10% buried, the following alternative approaches are used:
  - dig a hole to one side of the stone sufficiently large so that the stone can be buried;
  - after digging the hole attempt to manually push the stone into the hole;
  - in those cases where stones have been too large to be pushed manually the following alternatives have been tried:
    - tying a rope around the stone and pulling it with the use of a truck. This has had only a limited success.
    - using a hydraulic jack. Sufficient earth is removed from the side of the stone opposite the hole so that a jack can be wedged behind the stone. It is then slowly jacked (with the help of laborers to direct the roll of the stone) until it falls into the hole. This approach has proven to be the most successful.
    - cracking stones with fire. Wood is placed on top of the stone and burned. When the stone becomes sufficiently hot, either a sledge hammer alone is used to crack it or is first doused with cold water and then hammered. This method is used generally on very large stones of which a foot or less is exposed above the ground.

The incidence of rocks, of course, varies greatly from place to place. In order to determine the labor input needed and the cost per kilometer of stone removal for any particular segment of road, an assessment of the extent of the rock outcrops must first be carried out.

5. Tree Removal

Tools used for this operation include axes, mattocks, jembes, shovels, and ½-inch rope. Thus far two methods have been tested:

- cutting the tree down and only then removing the stump by digging around its base and cutting its roots; and
- tying a rope near the top of the tree, digging around its stump, cutting its roots, and pulling the tree over. This method involves essentially only one operation and is the most cost effective.

As in the case of stones discussed above, the number of trees per kilometer varies greatly.

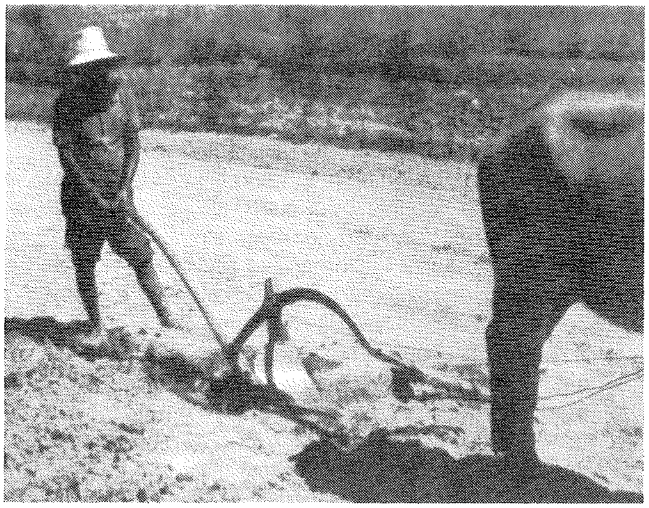


Figure 1. Water buffalo-drawn plow used for loosening soil in road construction in the Philippines (**4**).

labor is abundant, wages low (e.g., US$0.5-1.0/day in 1976 dollars), and equipment scarce (**11**).

The development of tools specifically for use in excavation and loading in road construction in developing countries has received relatively little attention to date. Any efforts to introduce new techniques must proceed slowly, recognizing the need for training time for labor and the possible need for tool modification. Spades and shovels, for example, are commonly used throughout Europe and North America; however, introducing them in some developing countries may require modification for use without shoes. Much can also be done with tools already commonly used in these countries to make them suitable for use in road construction — for example, adapting cutting edges, shape and height of sides, and size.

On a somewhat more mechanized level, animal and tractor-drawn agricultural plows and scrapers might be used. Plows are primarily useful in loosening materials, particularly where excavating labor is in short supply. Scrapers may be used for excavation and transport, but are basically restricted

Table 6. Guide to tool selection among manual methods of excavation and loading (**2**).

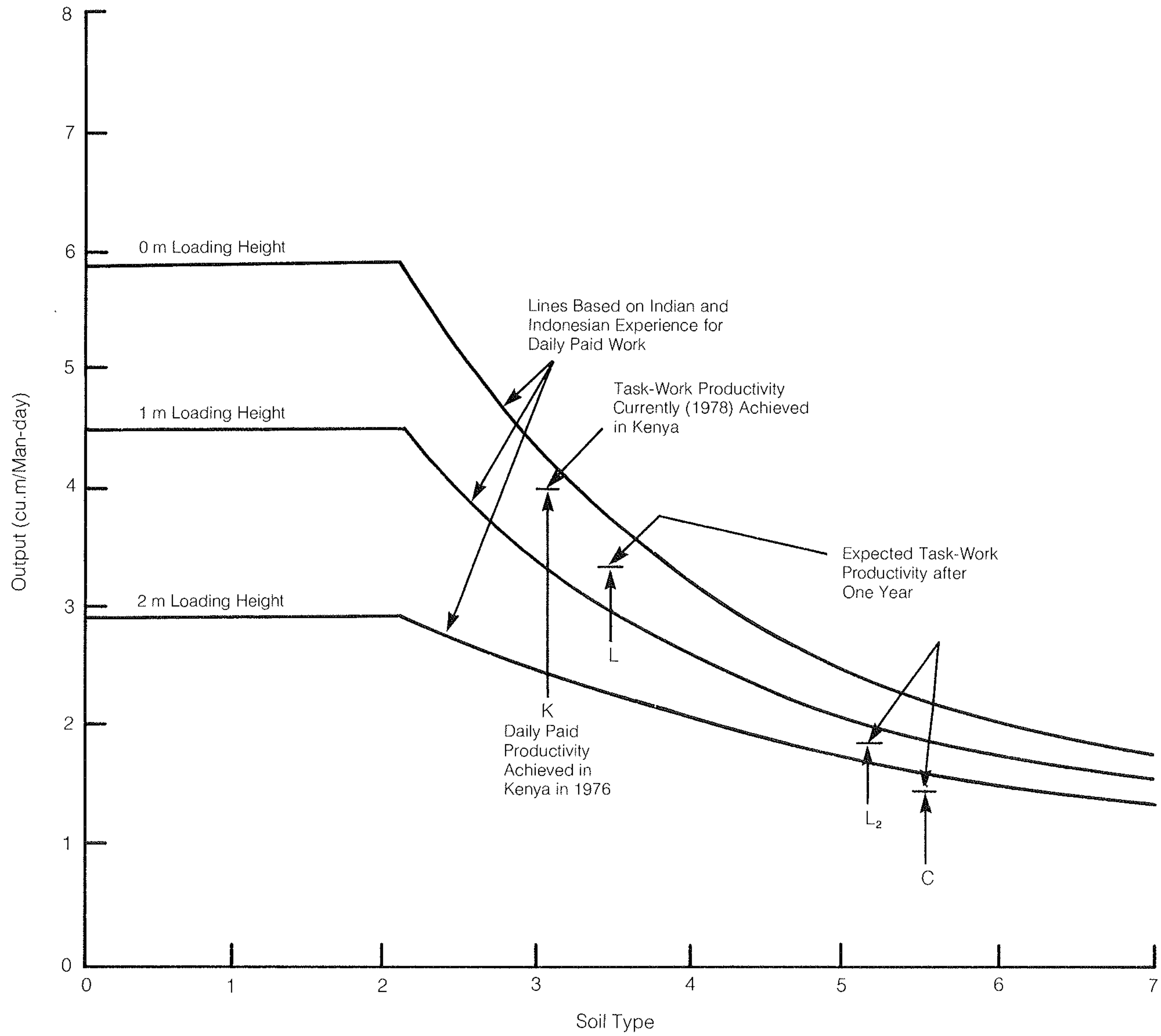
Soil Type	Cohesive						Non-Cohesive						Cemented Soils, Soft Rock	Boulder Deposits
Tool Type or Combination of Tools	Fine Grained			Mixed			Fine-Medium Grained			Coarse Grained				
	Soft-Firm	Firm-Stiff	Hard	Soft-Firm	Firm-Stiff	Hard	Loose	Com-pact	Dense	Loose	Com-pact	Dense		
Crowbar, grafting tool		E	E		E	E		E	E		E	E	E	eE
Pick		E	eE		E	eE		E	eE		eE	eE	eE	
Hoe	eEL	eEL	eEL	eEL	eL	L	eEL	eEL	eL	eE	eE	e		
Rake				L	L					L	L	L		
Shovel	EL	L	L	EL	L	L	EL	L	L	E			L	
Spade	eL	e	e	e			eL	e		e				
Fork				EL	EL	L				L	L	L		

Notes: e = Excavating small quantities, trimming to line and level, and so forth;
E = Bulk excavation;
L = Loading.

This table is based on limited field experience, and is intended to suggest optimum usage for particular tools. Thus, for example, the hole is not shown for loading coarse-grained non-cohesive soil, but probably could be used for this activity with some difficulty. Suitable forks or rakes, as indicated, would be better if available.

Excavation Activity:
a) Round mouths/pointed ends for non-uniform soils.
b) Square mouths/chisel ends for uniform fine soils.
c) Wide blades for weak soils, narrow blades for tough soils.
d) Square mouth/flat blade for trimming to line and level.

Loading Activity:
a) Hoes best at loading height below 1m approximately.
b) Shovels best at loading height 1-1.5m approximately.
c) Long-handled shovels best at loading height above 1.5m approximately.
d) Large blades are more suitable for light materials.
e) Small blades are more suitable for heavy materials.
f) Hand loading is generally required for boulder deposits and may be used to advantage after bulk excavation in strongly cohesive materials.



Note: Productivities at beginning of their respective programs:

K: loading height of 0.2m — Kenya
L: loading height of 0.2m — Lesotho
L_2: loading height of 2.0m — Lesotho
C: loading height of 0.5m — Chad

Soil types:

	cohesive soil	non-cohesive soil	rock
0	very soft	—	—
1	—	very loose	—
2	soft	—	—
3	firm	loose	—
4	stiff	compact	—
5	very stiff	dense	—
6	hard	very dense	—
7	—	—	soft

Man-day defined to be 8 hours of available time.

Figure 2. Productivity figures for manual methods of excavation/loading under various soil conditions and lift heights (**13**).

to soft soil or previously loosened/excavated materials and relatively short hauls.

Figure 3 shows three scrapers that have been used in the Philippines:

1. A traditional bamboo scraper made by weaving bamboo through the prongs of a harrow traditionally used in the rice fields (the modification takes approximately 0.5 man-hour);
2. An oil-drum scraper made from a section of a 44-gal drum and some suitable welded attachments; and
3. A factory-made scraper, costing approximately US$100 each in the early 1970s to produce by the dozen, and appearing to be robust and productive (it is very similar to the drag scraper used in North America early in this century; replaceable runners and cutting edge could considerably extend its life).

Turning to machine-based methods of excavation and loading, the two activities that are frequently treated as one and, as in the case of the scrapers above, of haulage may also be included in the process. Crawler and wheeled bulldozers can excavate most materials, with the assistance of a ripper in harder soils, and can transport them a short distance. Towed and motor scrapers can be similarly used, requiring a pusher for excavation in firmer ground; these can also be used for longer hauls (up to 3 km for motor scrapers). Excavation/loading alone is done by face shovels and backhoes, draglines, and front-end loaders, listed in order of declining capability for excavating in harder materials. Finally, bucket-wheel excavators can be used in all materials (except rock), but they require haulage equipment able to keep pace with their continuous output. Explicit comparisons among labor and equipment-based alternatives are reserved for the section on hauling.

Excavation in rock calls for special tools and techniques, whether carried out by labor or machines. Some of the excavation options are mentioned here, with further discussion left to the section on materials production. Labor-based methods of rock excavation include (a) use of crowbars and wedges in cracks and planes of weakness; (b) heating by fire followed by rapid cooling by water to cause shattering; (c) wooden wedges, placed dry and then saturated to cause splitting; and (d) use of chisel-ended bars for drilling of shot holes.

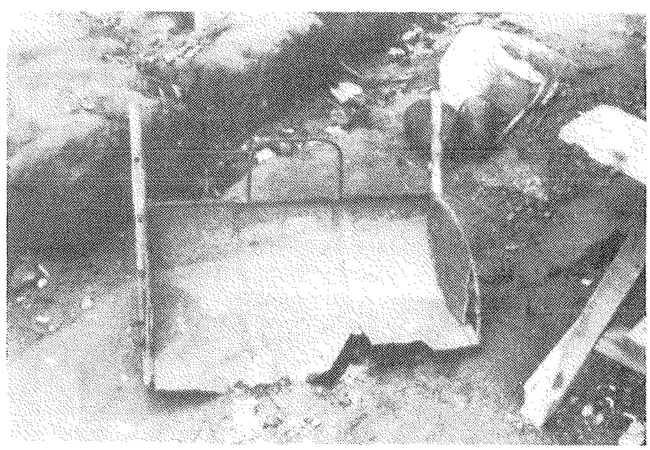
Equipment-based alternatives include use of (a) heavy machines for ripping the rock; (b) hand-held or machine-mounted, pneumatic, diesel, or electric-powered breakers; and (c) rock drills.

Hauling and Unloading

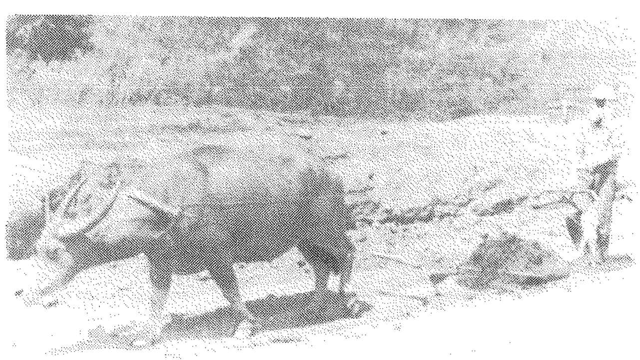
Hauling the materials either to an embankment or to spoil is the step following excavation. Depending upon the method used, hauling alone, hauling and unloading, or the fuller spectrum of excavate through spread may be done by the same vehicle(s). Careful matching of transport capacity and volume of materials being excavated is critical to minimizing idle time and maximizing productivity. The length and condition (such as roughness and slope) of the haul route, among other parameters, further influence the efficiency and thus appropriateness of various haul techniques. The length of haul may range from a few meters when excavating from cut to fill in embankment construction, to several kilometers when hauling selected fill or surfacing materials to the site. The potential impact of route conditions on different types of wheeled vehi-

Figure 3. Three types of scrapers.

Traditional Bamboo Scraper



Oil-Drum Scraper



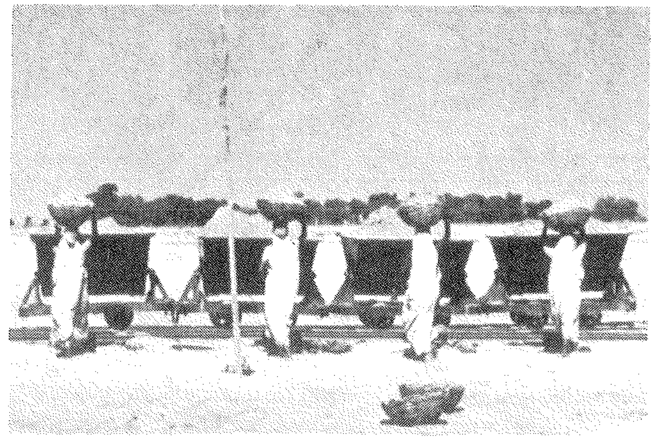
Factory-Made Scraper

cles and vehicle speeds is indicated in Table 7; route condition affects the productivity of walking less than wheeled haulage.

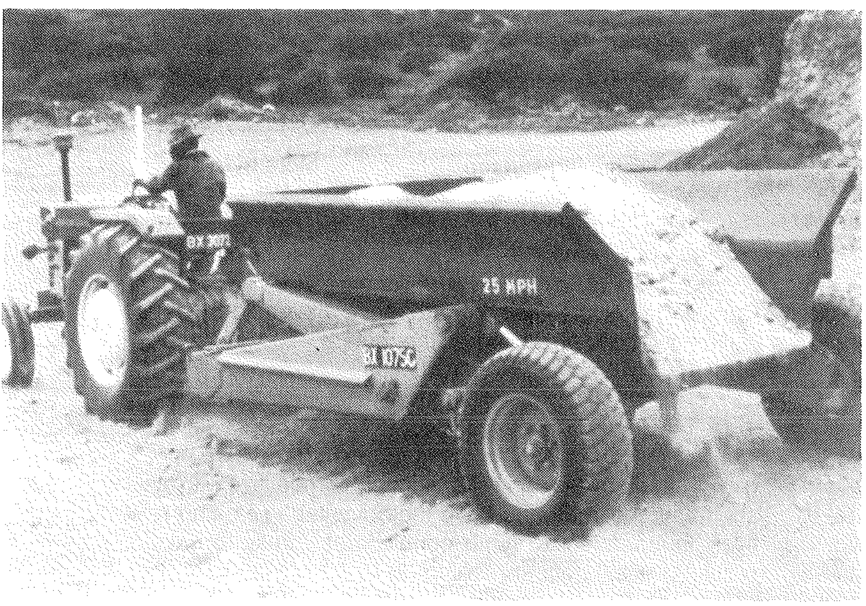
The spectrum of technologies available for haulage in road construction is broad. Some of the more labor-based alternatives are given in Table 8 with their relative appropriateness as to haul distance and other conditions. Figure 4 illustrates several of these alternatives. Figures 5 through 7 provide

Figure 4. Alternative modes of haulage in low-volume road construction (7).

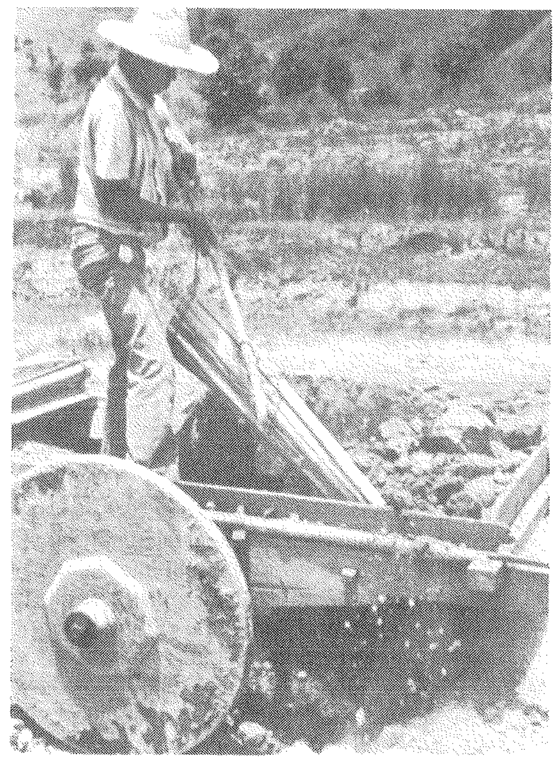
Carrying excavated materials on 2-man stretchers (Philippines)



Loading tipping trucks on rails from headbaskets (India)



Tractor/trailer combination of small tractor, towed chassis, and hauling container which can be hand-loaded (Southern Africa)



Modified animal-drawn cart: this one has wooden wheels but its bottom consists of bamboo mats which are simply lifted to unload (Philippines)

Modified animal-drawn cart: this one has rubber tires and built-up sides but has to be unloaded by hand (Philippines)

Table 7. Range of possible haul route conditions (**2**).

Description of Haul Route	Type of Surface	Effect on Haulage of Non-Rubber-Tired Carts or Barrows	Effect on Haulage of Pneumatic-Tired Vehicles or Barrows	Average Speed for Vehicle (Truck) Haulage[1] (km/h)
Very poor	Earth, muddy, no maintenance/ loose sand or gravel	Virtually impossible	Very difficult	Less than 10
Poor	Poorly maintained earth (dry clay loam)	Very difficult	Fairly difficult	10-20
Average	Normal site earth road or path	Fairly difficult	Slight difficulty	20-30
Good	Hard and smooth-compacted earth, well maintained	No difficulty		30-40
Excellent	Concrete/asphalt/ well maintained gravel/ well laid barrow run	Excellent free-running surface		More than 40

[1]Vehicle haulage speeds indicated are not necessarily those of the haulage vehicle itself, but are those attainable by a fully loaded, carefully driven, well maintained truck (e.g., 5-ton) in the traffic conditions prevailing on the route.

some exemplary quantitative details about these various haulage modes; the first two figures give unit cost and resource requirement data for excavation/hauling in the Philippines, while the third provides cost information for the task excavate-through-spread in India and Indonesia. Differences between Figures 5 and 7 in terms of the apparent appropriateness of various technologies are a function of differences in the particular techniques, and thus the achievable productivities, as well as differences in resource costs (labor is relatively lower cost in India) and other local conditions.

Manual methods of haulage include both carried and wheeled varieties. Headbaskets, shoulder yokes, head/shoulder pans, sacks, and stretchers can be used effectively only for the shortest of hauls. Each method has particular circumstances to which it is most suited such as magnitude of load, bulkiness, steepness, distance, and so forth. In practice, local custom is the most important factor for choosing a particular method. Headbaskets, for example, are most common in Asian countries. They are most useful for hauls under 30 m or so, but they can be used in longer hauls by employing a chain of haulers. Headbaskets are also useful in intermediate hauls as indicated in Figure 4. Properly organized, headbaskets can be reasonably competitive with other short-haul methods and have the advantage of being relatively independent of route condition and easy to unload, requiring little further spreading (2).

The use of wheelbarrows or handcarts in labor-based road construction can considerably improve productivity for hauls from 25 to 125 m. A wide variety of hand-carts and wheelbarrows exists (hand-carts have two wheels, wheelbarrows have one). Some are lightweight with pneumatic tires, others are heavy-weight with solid tires; some have wheels in front of the container, others have them underneath it; some have trapezoidal section bodies, others have triangular section bodies. These particulars of design appear to be more a function of tradition than of applicability to particular work. Design and maintenance of wheelbarrows, condition and slope of the haul route, and organization of the labor force are important to efficient use. Their design and use have been the subject of several studies by the World Bank, International Labour Office, and others. For example, a scooter-tired wheelbarrow with a ball-bearing axle was found to be the most efficient design in the World Bank studies, costing approximately US$40 (1976) and having a working life of 2000

Table 8. Alternative haulage methods toward the labor-using end of the spectrum (**2**).

Haulage Method	Recommended Haul Distance (m)	Comments
Headbaskets	5-30	A traditional method. Good results can be obtained with little supervision. Route condition and steepness not critical.
Sacks		Inefficient, particularly loading, but useful for long-distance haulage in hilly terrain and for fine granular materials.
Yokes	5-30	As headbaskets but wider route needed. Zero loading height.
2-man stretchers		Inefficient, but useful for hot materials.
Handcarts		Needs good haul route.
Wheelbarrows	25-125	Very competitive if well organized. Haul route condition and steepness critical — this can be improved by using planks for barrow runs.
Donkeys	50-125	Reasonably independent of haul route condition and steepness. Gang balance fairly critical for good results.
Ponies	50-125	
Mules	50-125	
Camels	100-400	Low loading height.
Elephants		
Scrapers		
Bullock carts	100-600	Require average or better route conditions.
Camel carts	100-600	
Mule carts	100-600	
Tractor/trailer	250-5000	Good organization critical for economical results.
Truck (Flat Bed)	500+	Cost dependent on roads, distance, condition and type of truck, etc.
Truck (Tipping)	500+	
Manual ropeway	10-40	For short steep slopes. Competitive in specific situations.
Manual rail systems	100-300	Good potential where large volumes must be moved along one route (e.g., quarries). Results depend on individual situation and system used.
Chute	5-30	Applicable to downhill haulage only.
Sled + chute	5-100	

hours (**11**). Other studies have included variations in wheel and bearing types and sizes, body and frame materials and shapes, use as a means of improving route conditions, and assistance, as with winches, in steep grades.

Animals may also be used for transport in road construction either by carrying materials on their backs in panniers or by pulling carts or scrapers. Substitution of animal power for human power allows heavier loads and longer haul distances; donkeys and ponies, for example, can carry 100 to 200 kg in panniers for 50 to 125 m or more, while laborers can carry 15 to 35 kg in headbaskets for 5 to 30 m (**2**). The age and condition of the animal and the design and condition of the simple equipment are important factors in the efficiency of the operation; so, too, is the animal's need for rest and watering (e.g., water buffaloes need an hour of watering during the work day). Although animal-drawn carts are the most com-

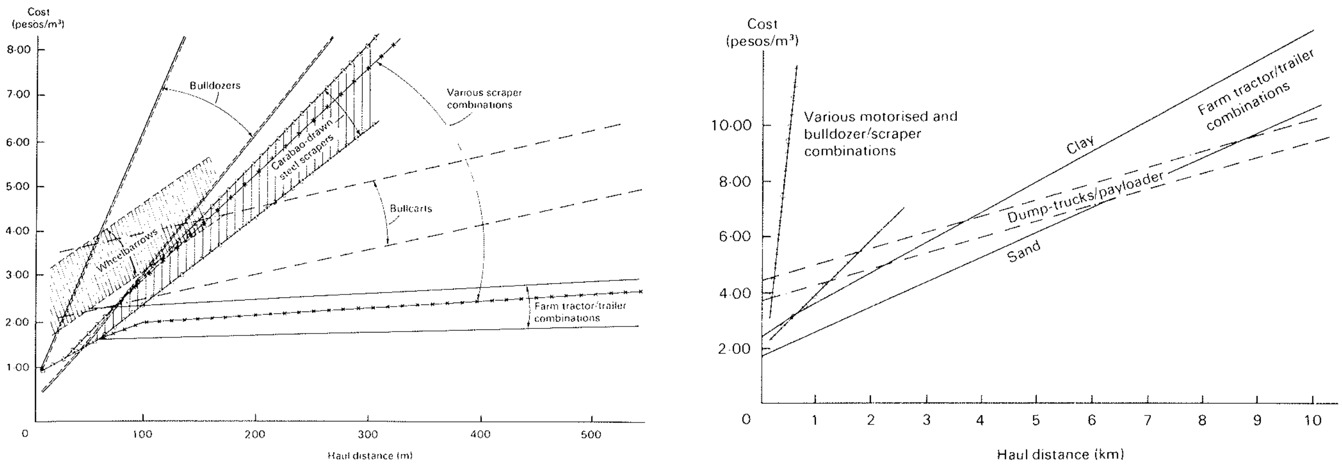


Figure 5. Unit costs for alternative methods of excavating and hauling fill materials in the Philippines (4).

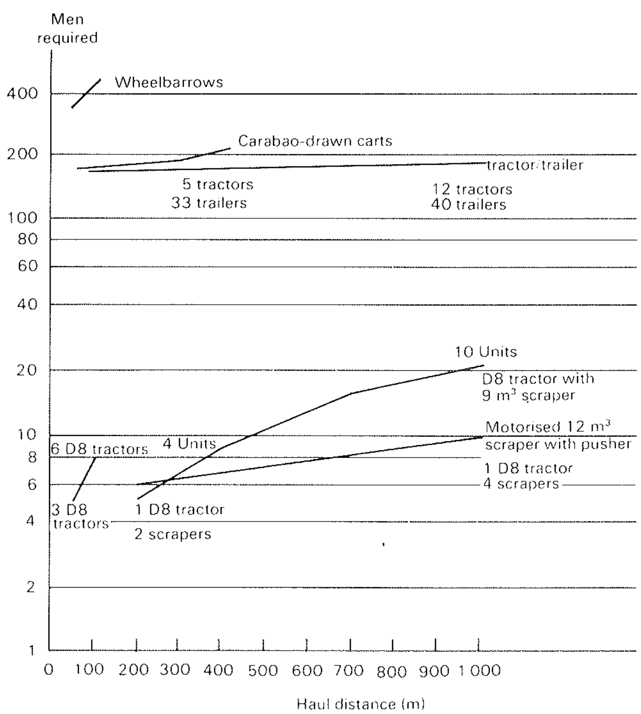


Figure 6. Labor force required for different methods of excavating and hauling 1000 m³ of fill material per 8-h day in the Philippines (4).

mon mode of transport in many developing countries, they are less frequently used in road construction than are animals with panniers. This is probably because better haul route conditions and lesser grades are necessary for carts, and they are more difficult to load/unload. Carts also represent a larger capital investment. Some of these constraints may be alleviated (as shown in Figure 4) through specific modification for use in road construction of the traditional, wooden-bodied, large, solid-wheeled carts. Camel carts have proven to be very cost-effective in India.

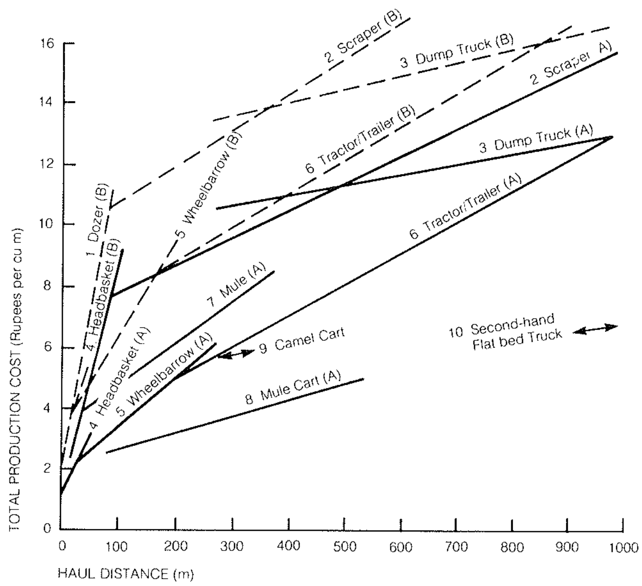
Manual and animal methods of haul lost their competitiveness in hauls over 500 to 600 m (**2**). Tractor/trailer combinations, flat trucks, and, less commonly, tipper or dump trucks seem to be the currently available technology for these longer hauls. Experience with the tractor/trailer alternative is limited; its particular advantage is that one tractor and several detachable trailers can be used. The most expensive item of equipment, the tractor, can thus be more fully utilized in conjunction with manual loading and unloading. Furthermore, other attachments such as plows, rippers, scrapers, graders, and rollers might be used with the tractor, although this flexibility may be limited if the generally lower horsepower agriculture tractors are used. Figure 8 shows the production rates that might be achieved along with the trailer and labor requirements for one tractor; the numbers alone suggest the importance of good organization for this method of haulage. Experience with tractor/trailer combinations in Kenya further suggests that durability in the design and construction of the equipment, particularly the trailers, is critical, and that smaller tractors (e.g., 45 hp) might be substituted for the larger ones (e.g., 75 hp) that were specified (**14**).

These methods of haulage represent a significant jump from the animal-drawn devices. Single-axle tractors (10-12 hp) and modified versions of three-wheeled, motorcycle-based, cargo carriers (8-12 hp) have been suggested as a more intermediate mode of haulage for use with labor in civil construction (**14**). Although promising, these remain to be tested under the rather arduous conditions of rural road construction, and efforts must be made to adapt them to such usage.

Having progressed to the equipment-based end of the spectrum of haulage methods, it should suffice to simply mention the alternatives. For short hauls up to some 100 m, the bulldozer may be used; for longer hauls up to some 300 m, the towed scraper; for hauls up to some 3 km, the motor scraper; and for even longer hauls, tipping trucks (**2**). All except the truck are self-loading, perhaps with some assistance, and all are self-unloading.

Another group of haulage methods might be collectively termed transfer systems. Among these are trucks on rails, ropeways and cableways, belt conveyors, and chutes and sleds. Each of these has the potential for moving materials rather efficiently through the use of some low-friction system such as wheels on rails, wheels on cable, or a pivoting/rotating boom; any needed power may be provided by manual, animal, or mechanical means. Each system entails the use of a fixed or semi-permanent installation, which, in addition to the setting up/dismantling of the installation, adds

Figure 7. Unit costs for alternative methods of excavate/load/haul/unload/spread in India and Indonesia (**10**).



Note: Methods

1. D7 dozer for all activities.
2. Cat 621 motor scraper, D8 pusher, 12 G grader.
3. Cat 769B (35-ton) dump truck, 988-wheeled loader, excavation by D8 dozer, spreading by 12 G grader.
4. Headbasket, handtools, labor.
5. Wheelbarrow, handtools, labor.
6. 35-hp tractor and 3-ton tipping trailers, manual excavation, loading, spreading.
7. Mule with panniers, handtools, labor.
8. Mule cart, handtools, labor.
9. Camel cart, handtools, labor (observations limited to one site).
10. Second-hand truck (5 tons), handtools, labor (observations limited to one site).

Notations:
A — piecework payment with good supervision.
B — daily-paid work with poor supervision.

Conditions are average (firm) soil and relatively flat terrain.

Costs include overhead and supervision. 1976 prices assuming piecework earnings to be RS 9 daily and daily-paid wage to be RS 4.5.

several steps to the haulage process itself; i.e., haul from the excavation to the transfer device, haul using the transfer device, and haul to the point of final deposit. Under a rather narrowly defined set of conditions, therefore, each transfer system is potentially an economic haul mode. Use of the small tipping trucks on rails shown in Figure 4, for example, yielded three-fold increases in labor productivity in an Indian project compared with other manual methods used previously; the main difficulties encountered were the setting up and moving of the track and its tendency to obstruct the site (2). Small manually operated cable ropeways have also been used effectively on a limited scale in India for hauling materials in small bags up from river beds; chutes and sleds have been experimented with for downslope haulage (2). Although further consideration of these transfer systems for direct use in road construction activities appears warranted, their main applicability probably remains in quarry and materials production operations where large quantities of materials are usually moved over a fixed route.

Spreading

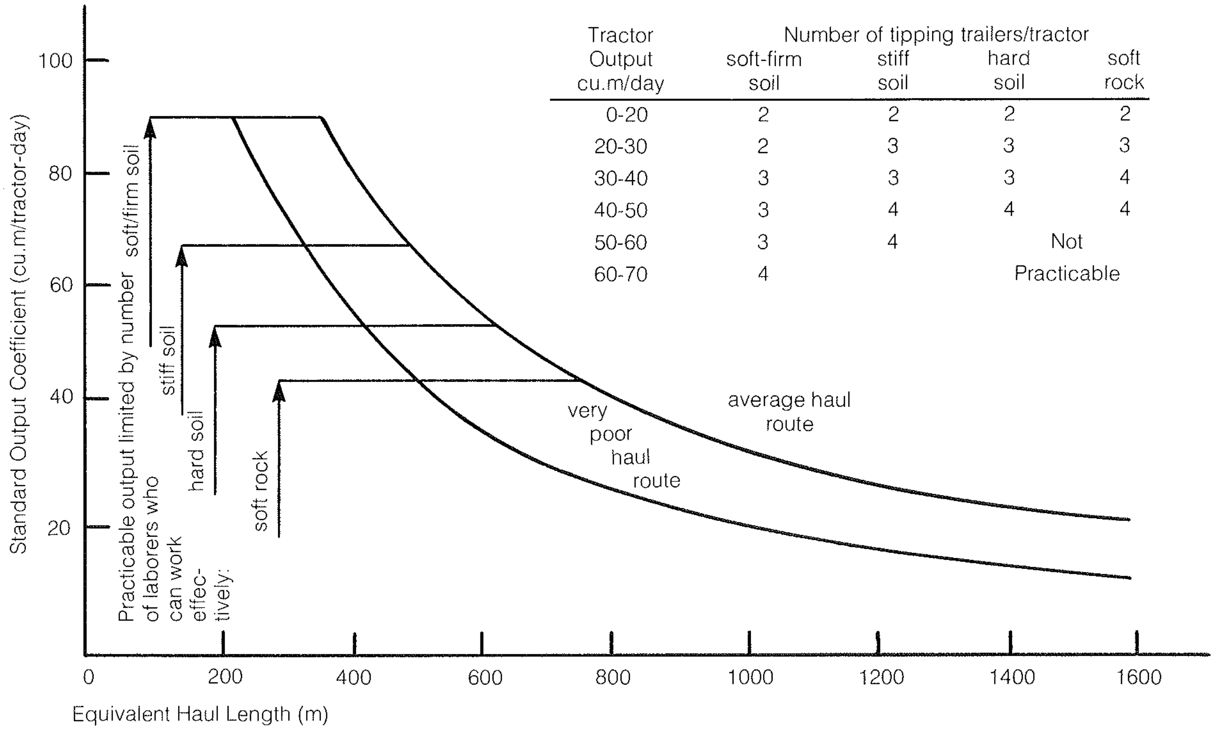
Spreading is frequently a rather minor activity in road construction. Nevertheless, once materials have been unloaded, they must be spread before compaction. Uniform spreading is particularly important in the final layers of the embankment and in road surfacing if compaction is to produce good riding qualities. The spreading activity pertains both to earthwork for the road embankment and to the subbase, base, and surfacing materials for the road. The appropriateness of various technologies and their relative efficiencies are sensitive not only to the nature of the materials being spread but also the thickness of the layers; Figure 9 demonstrates this for the case of manual spreading.

The standard tools used for manual spreading of earthwork include many of those used for excavation, namely, hoes, rakes, forks, shovels, and spades; even picks and heavier tools may be employed for breaking up lumps in the materials. Table 9 indicates that the level of effort expended in spreading is in part a function of the method of haul. Generally, the smaller the haul container, the less the need for spreading; larger haul containers such as carts, trailers, and trucks, however, can assist the spreading activity by continuing to move while unloading. As for more intermediate methods of road construction, spreading may be effectively accomplished in the unloading of animal or tractor-drawn scrapers with only a minimum of manual assistance. Animal-towed blade graders were used in North America early in this century; simple drags towed by animals, tractors, or even trucks might also be used. (Figure 10). Equipment-based alternatives include scrapers, graders, and angledozers, for which details on spreading are difficult to separate from other earthwork activities. Table 10 compares the resource requirements of the extremes in technology for grading formation.

Materials most likely to be used in the surfacing activities of low-volume road construction include granular materials (gravels, crushed rock, and laterites), stabilizing materials (lime and cement), and liquids (bitumen and water). Because granular materials are frequently stockpiled alongside the road, a small amount of additional hauling as well as the spreading may be necessary. Alternatively, with proper planning, granular materials may be brought to the site only when needed and distributed by the transport vehicle with only a minimal need for spreading. In either case, the same basic tools and equipment used for earthwork spreading may be appropriate. Additional intermediate to equipment-based options include spreader boxes and gas spreaders, which are particularly suited to finer materials like screenings for water-bound macadam and chippings for surface-treated roads. Table 11 shows some of the productivities achieved in India

Figure 8. Productivity for excavate/load/haul/unload/spread task in earthworks by using a tractor/tipping trailer(s) combination (**2**).

(a) Tractor Productivity



(b) Trailer Requirements for One Tractor

Tractor Output cu.m/day	Number of tipping trailers/tractor: soft-firm soil	stiff soil	hard soil	soft rock
0-20	2	2	2	2
20-30	2	3	3	3
30-40	3	3	3	4
40-50	3	4	4	4
50-60	3	4	Not Practicable	
60-70	4			

(c) Labor Requirements for One Tractor

Tractor Output cu.m/day	Labor Requirements for One Tractor with Tipping Trailer(s): soft soil	firm soil	stiff soil	hard soil	soft rock
15	10(3-5-2)	11(4-5-2)	14(7-5-2)	16(9-5-2)	17(10-5-2)
20	14(4-7-3)	15(5-7-3)	19(9-7-3)	21(11-7-3)	23(13-7-3)
30	19(5-10-4)	22(8-10-4)	28(14-10-4)	31(17-10-4)	34(20-10-4)
40	26(7-13-6)	30(11-13-6)	38(19-13-6)	42(23-13-6)	45(26-13-6)
50	33(9-17-7)	37(13-17-7)	47(23-17-7)	52(28-17-7)	57(33-17-7)
60	38(10-20-8)	44(16-20-8)	56(28-20-8)		
70	45(12-23-10)	51(18-22-10)		Not Practicable (More than 10 excavators or 10 loaders per trailer)	
80	52(14-27-11)	59(21-27-11)			
90	58(16-30-12)	66(24-30-12)			

Key: Total No. of Laborers (No. of Excavators - No. of Loaders - No. of Spreaders)

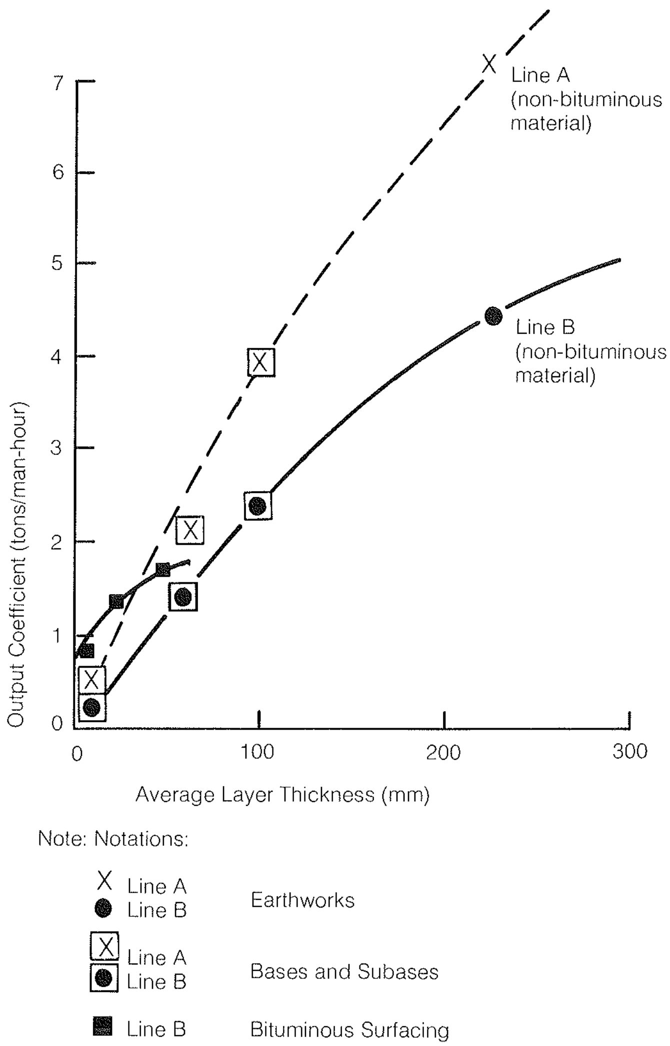
Method of working: Excavators (maximum number 10 per trailer) excavate and a separate gang of loaders (also maximum 10 per trailer) load each trailer (height 1.4m). Tractor hauls 2, 3 or 4 trailers, one being hauled while the other(s) is/are being loaded. A small gang spreads the material once it is tipped from the hydraulic tipping trailer. Data are presented in terms of one 35 hp tractor with a gang of 3-ton tipping trailers and laborers, the numbers being calculated to suit the conditions.

and Indonesia by using traditional methods of spreading with shovels, rakes, and hoes. Stabilizing materials such as cement, lime, and bitumen require mixing as well as spreading on the road. The mixing can be done by animal- or tractor-drawn plows. A full spectrum of alternatives exists for distributing liquids like bitumen and water. Bitumen, for example, might be spread by using cans, ladles, and rakes; hand-operated sprayers connected to hand- or animal-towed drums on wheels; or truck-mounted bitumen distributors. Experience in India and Indonesia shows the output rate of truck-mounted distributors to be as much as ten times the labor-based option (**11**). The animal-drawn waterbowser shown in Figure 11 has been found to be quite effective in the Philippines.

Compaction

Compaction of earthwork and surfacing materials in road construction serves to improve their stability and to smooth the riding surface. Effective compaction requires substantial

Figure 9. Manual spreading of various materials to different thicknesses (**11**).



Line A - piecework payment with good supervision

Line B - daily-paid work with poor supervision

Spreading may also include a small amount of haulage. Data are based mainly on results from India. Measure of time is in working time man-hours.

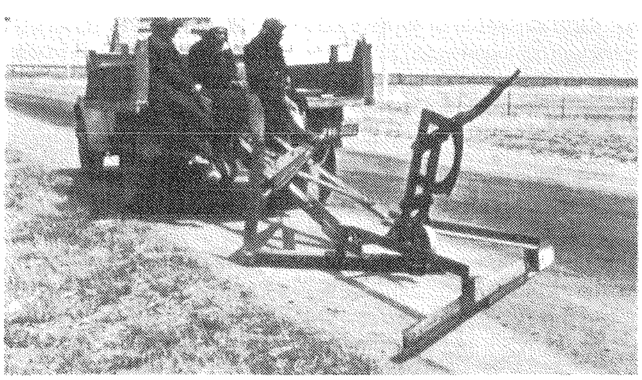


Figure 10. Drag used for shaping road surface in East Africa — adaptation of agricultural hoe by using scrap metal (**7**).

Table 9. Productivity data for manual spreading in earthworks in India and Indonesia (**2**).

Haulage Mode	Spreading Input Coefficient (man-hour/cm³)	
	Line A	Line B
Headbasket	0.17	0.33
Wheel-barrows, Animals	0.25	0.50
Animal carts, Trailers, Trucks	0.33	0.67

Note: Spreading means distribute deposited loose soil in a uniform layer 200-400 mm loose thickness, breaking up any large lumps and removing organic matter.

Line A, Line B refer to conditions for associated haulage—spreading itself may be daily paid. Line A conditions correspond to good supervision and piecework payment; Line B to poor supervision and daily-paid work.

Output is measured in-situ in the borrow area; input is measured in terms of working time.

Table 10. Grading formation using extremes of technology (**8**).

Technology	Inputs	Resource hours required
Labor-based	Laborers Hand tools	160
Capital-based	Motorgrader	2
	Operator	2

Note: Task is grading formation to required levels and camber, after completion of bulk excavation and fill (1000 yd²).

inputs of energy, depending upon the type of material and thickness of the layer. There is a significant difference between the energy that can be supplied by currently available road compaction equipment and by manual and animal means. To attain the same degree of compaction, therefore, thinner layers and a greater number of passes must be used for manual methods, with resulting low productivities. There is clear evidence that compaction is one area of low-volume road construction where labor-based alternatives have trouble competing, both in terms of productivity and quality.

Before the days of massive compaction equipment, when the speed of construction was slower, soil was left to consolidate by itself or under the weight of traffic. In the case of very minor roads, this may still be the most cost-effective approach. Some relaxation in the standards of compaction for low-volume roads may alternatively be possible, potentially

Table 11. Productivity data for manual spreading in roadworks in India and Indonesia (**10**).

Type of Material	Compacted Layer Thickness or Rate of Spread	Spreading Input Coefficient (man-hour/Unit) Line A	Line B	Unit
Bases and Subbases				
Gravel subbase	100 mm	0.25	0.4	ton
Crushed rock base and subbase	100 mm	0.25	0.4	ton
	60 mm	0.45	0.7	ton
Laterite, murum, etc., for waterbound macadam	8 mm	2.5	4.0	ton
Surfacing				
Sand/bitumen seal coat	1.5 mm	na	1.8	ton
	4 mm	na	1.3	ton
Chippings for surface dressing	20 kg/m²	na	0.6	ton
Liquids				
Bitumen	0.3-0.8 L/m²	na	.015	liter
Water	—	na	.003	liter

Note: Spreading does not include associated loading and hauling from stockpiles or elsewhere.

Line A conditions correspond to good supervision and piecework payment; Line B to poor supervision and daily-paid work. Where Line A conditions have not been observed, it is suggested that the input coefficients may be taken as one-half those given for Line B conditions.

Input is measured in terms of working time.

Cost: US$30 to produce in 1972 in the Philippines.
Rate of Spread: 2L/m².
Productivity: 1006 m²/h for 50-m haul
272 m²/h for 1000-m haul

Figure 11. Animal-drawn waterbowser used in the Philippines (**7**).

increasing the feasibility of using more manual alternatives of compaction. Because of its long-term effect on the durability and quality of the roadway and surface, compaction may influence the longer-term costs of the road in maintenance and user costs. Studies in India, for example, suggest that hand-laid pavements typically have substantially higher surface roughness and thus increased vehicle operating costs. This may be a function of quality control as well as technology mix (**11**). An additional trade-off exists with the design of the pavement by using more or different materials to offset the reduced compaction. Results of the World Bank's studies on the subject, however, suggest that resource inputs are similar across the various qualities of compaction, and, therefore, if compaction is to be done at all, it should be done to intermediate or high-quality standards (**11**).

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The full spectrum of potentially available compaction methods is given in Table 12 along with their relative suitability for cohesive or non-cohesive materials. The equipment-based alternatives are largely self-propelled or towed by heavy equipment and are designed specifically for compaction. The standard item of compaction equipment found in countries like India and Pakistan, where road construction is traditionally done largely by labor, is the 10-ton, self-propelled, smooth-wheel roller, which may be used with reasonable success for essentially all compaction efforts (**5, 11**). One difficulty is that the compaction equipment is frequently

Table 12. Classification of compaction methods (**11**).

<table>
<tr><th rowspan="2"></th><th colspan="2">Engine-Powered</th><th colspan="2">Muscle-Powered</th></tr>
<tr><th>Cohesive Materials</th><th>Non-cohesive Materials</th><th>Cohesive Materials</th><th>Non-cohesive Materials</th></tr>
<tr><td rowspan="6">Equipment-Based</td><td>Heavy tractor-towed sheepsfoot roller</td><td>Heavy tractor-towed vibrating smooth roller</td><td colspan="2" rowspan="6"></td></tr>
<tr><td>Heavy tractor-towed rubber-tired roller</td><td>Heavy tractor-towed grid roller</td></tr>
<tr><td>Heavy tractor-towed grid roller</td><td>Self-propelled vibrating smooth roller</td></tr>
<tr><td>Self-propelled rubber-tired roller</td><td>Self-propelled vibrating plate compactor</td></tr>
<tr><td colspan="2">Weight released from crane</td></tr>
<tr><td colspan="2">Self-propelled smooth roller</td></tr>
<tr><td rowspan="6">Semi-Equipment Based</td><td>Agricultural tractor-towed sheepsfoot roller</td><td></td><td>Animal-towed sheepsfoot roller</td><td></td></tr>
<tr><td colspan="2">Agricultural tractor-powered smooth roller (piggy-back)</td><td colspan="2"></td></tr>
<tr><td colspan="2">Agricultural tractor-towed smooth roller</td><td colspan="2">Animal-towed smooth roller</td></tr>
<tr><td colspan="2">Agricultural tractor-towed tired cart</td><td colspan="2">Animal-towed tired cart</td></tr>
<tr><td colspan="2">Hand-held mechanical rammer</td><td colspan="2"></td></tr>
<tr><td colspan="2">Hand-held mechanical plate or roller</td><td colspan="2"></td></tr>
<tr><td rowspan="3">Labor-Based</td><td colspan="2" rowspan="3"></td><td colspan="2">Weight released from tripod</td></tr>
<tr><td colspan="2">Animal or human feet</td></tr>
<tr><td colspan="2">Hand rammer (or punner)</td></tr>
</table>

too large for the scale of an otherwise manually-run job, leading to underutilization of the equipment. It is not uncommon to find compaction equipment being used for only 20 percent of the time for which it is available.

Among the more intermediate alternatives are animal- and tractor-drawn compaction equipment. The most commonly seen of these is the animal-drawn, rubber-tired cart, although use of rollers towed or powered by tractors is becoming increasingly common. In the early part of this century, horse-drawn rollers were still being used in North America, although they were rapidly being replaced by powered rollers. Figure 12 shows some methods that were tried with varying degrees of success in Indonesia. All in all, relatively little is known about these intermediate alternatives, but the tractor-towed or powered option presently seems to hold the most promise for success, particularly when compaction standards are slightly lowered. The usefulness of labor-based alternatives and even the hand-held mechanical alternatives is primarily restricted to areas where other equipment cannot operate, such as around pipes and next to structures.

Materials Production

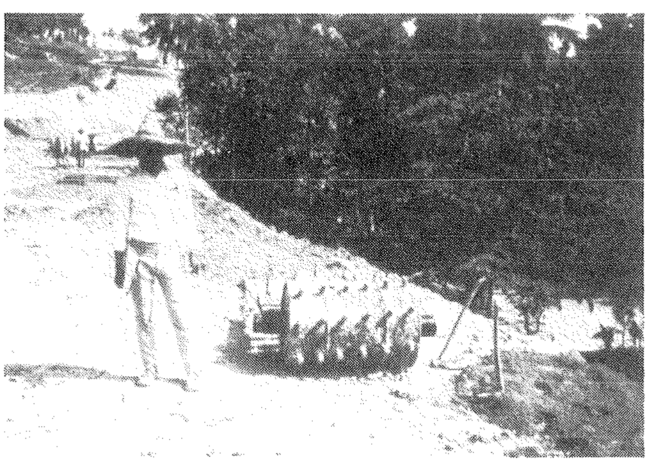
Stone, in its natural state, crushed, or broken, is extensively used in road construction and often accounts for a significant portion of construction costs. Suitable aggregate may be naturally available near the site, but more often it is necessary to break and crush quarried rock and/or boulders to obtain aggregate of appropriate size, shape, and strength. Production of suitable aggregates is thus frequently a major activity in low-volume road construction. Alternative means of excavating rock are mentioned above in the discussion about excavation and loading; the discussion here focuses on the breaking and crushing operation. The final size of the aggregate desired, the amount of reduction from the original size this represents, and the hardness of the rock all influence the productivity that might be achieved using various breaking and crushing methods, and hence their relative appropriateness. Table 13 presents a cost comparison of alternative means of aggregate production in India and Indonesia.

Labor-based methods of producing aggregate entail the use of two hammers: sledge hammers of some 3-5 kg for

Figure 12. Experimental compaction methods tried in Indonesia (**11**).

Bullock-drawn smooth-wheel roller: concrete shell at ends of oil drum to support axle, ballasted with water and weights on draw-bar with counterbalance behind roller.

Hand-held mechanical rammer: vibratory plate at foot of column supporting power unit and steering handles.



Bullock-drawn sheepsfoot roller: concrete shell inside oil drum holding tines and axle rigidly, ballasted with water.

Table 13. Comparative costs of alternative methods of aggregate production in India and Indonesia (**10**).

Method	Total Production Cost (Rupees/ton)			
	50-mm output (200-mm input)		10-mm output (100-mm input)	
	Line A	Line B	Line A	Line B
50-60 ton/h crushing plant loaded by traxcavator	15.4	20.4	23.0	30.4
6-8 ton/h mobile crusher loaded by hand	12.5	16.6	18.7	24.8
Handbreaking	7.6	13.5	21.8	33.8

Note: Total production costs include supervision and other overheads.

Line A conditions correspond to good supervision and piecework (daily earnings: Rs9); Line B to poor supervision and daily-paid work (daily wage: Rs4.5).

1976 market prices are used.

two-handed use, and knapping hammers of some 0.5 to 1 kg for one-handed use. Table 14 describes a manual breaking operation observed in Pakistan in some detail. This is a task requiring considerable practice and skill to be effective. The size, shape, and construction of the hammer as well as the steel used in the head may have an important effect on the achievable output. For example, in one of the World Bank's demonstration projects in India, the use of a 0.9 kg hammer yielded 50 percent more output than did the use of a hammer twice the weight (**11**). Available evidence suggests that even in low-wage areas manual stone breaking becomes uneconomical when the desired aggregate size is below 15-25 mm (2).

Equipment-based alternatives include a wide variety of types and sizes of mechanical crushers: the impact breaker, hammermill, roll crusher, and jaw crusher, which may be

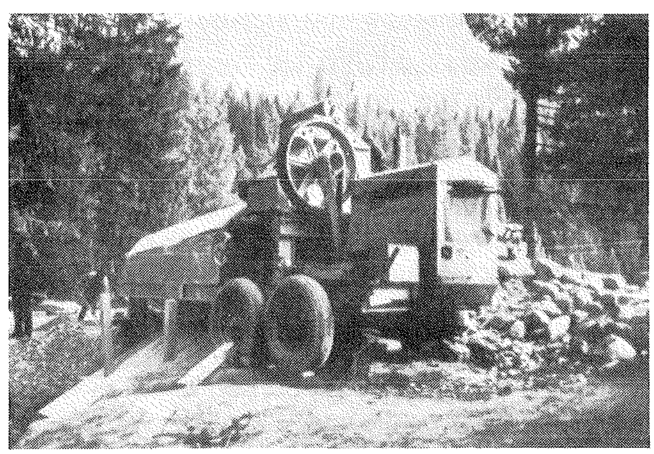
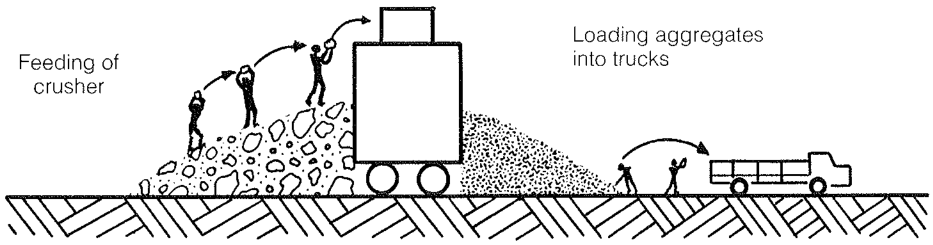
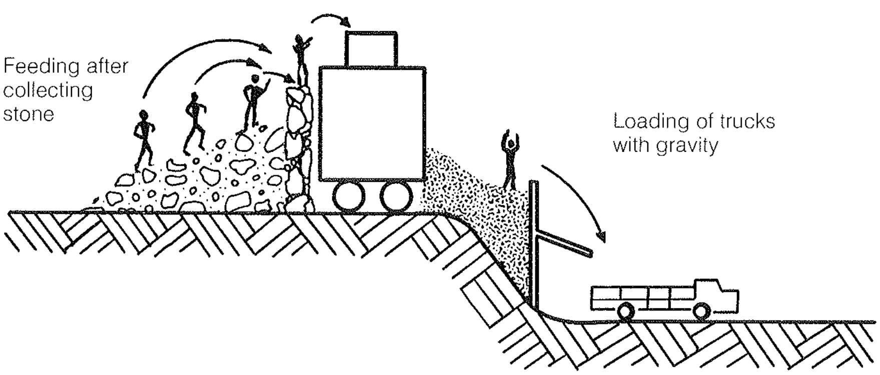


Figure 13. Simple mobile crusher (6-8 tons/h) with integrated screening equipment (**11**).

Figure 14. Reorganization of crusher installation in demonstration project in India (**11**).



Existing Set-Up



Note: Improved set-up and costs reduced 20 percent.

Table 14. Manual rock breaking operation as observed in Pakistan (**5**).

More common now in Pakistan is the use of graded materials from 2 to ¾ inches as a road base. The material could be produced by a stone crusher, but more often this type of equipment would not be available, and instead hand-crushed stone materials constitute the main source of supply.

The breaking of the rock at the quarry site is mostly a manual operation executed by workers using crowbars and pickaxes. For harder rocks, blasting would be required; skilled workers using hand drills and hammers would be employed to prepare for the blasting. Drilling could also be done by compressed air rock drills but this is only common at larger works. Some workers are always engaged in breaking larger blocks to suitable sizes by use of sledge hammers.

The hand-crushed stone is produced by professional stone crushers who move around taking jobs wherever available. This does not apply only to road work but to any type of construction work. The stone breaker is indispensible for many jobs, and unless a counterpart, experienced worker is available, the contractor would rather suspend the work than try to use inexperienced labor in this activity.

The stone breaker breaks larger stones and rock by hand to suitable sizes. Formerly, this was done at the quarry site but mishandling of the broken materials in removal and transport forced the engineers to demand that this work be executed at the road site. The worker normally receives block stones up to 25x25 cm sizes, which he breaks into smaller pieces using a 6-lb sledge hammer. He then continues to crush these into the final sizes required using a smaller hammer of approximately 1½ lb weight. To guide the worker in his job, he receives a sample of the final grading required to which he then tries to adhere. The work is checked by taking samples in the normal manner.

mobile as well as fixed installations, and the gyratory and disc crushers, which are usually permanently installed. Unlike the stone produced by manual methods, stone from a crusher is variable in size and must be sorted, generally by screens attached to the crusher, unless crusher-run or densely graded material is required. The design issue of gap versus densely graded materials also comes into play here. The smaller, mobile crushers (Figure 13) can be effectively used on labor-based road projects, particularly for producing the smaller size aggregate. Labor can still be employed in pre-breaking the materials and loading them into the crusher. As indicated in Figure 14, the layout of the crusher installation and good organization of the work force are important to an efficient operation.

Structures

In addition to the road itself, culverts, retaining walls, and bridges may be included in low-volume road projects. Structures by their very nature tend to be heavy users of labor even in largely equipment-based operations. As in the roadway itself, the design and the materials to be used exert considerable influence on the relative appropriateness of various methods of construction. Moreover, structures are potentially large users of typically scarce, often imported, materials such as cement and steel. Therefore, looking for means to increase the use of local materials in structures may be equally as important as looking for means to increase the use of labor; fortunately, these two objectives tend to be complementary ones.

Tables 15 through 17 show a range of design options for culverts, retaining walls, and bridges, each with an indication

Table 15. Culvert design options and their potential for equipment and labor-based construction (15).

Element	Potential for	
	Equipment	Labor
Pipe:		
precast pipes	Good (machine made)	Good (hand-made size limited)
corrugaged metal	Poor	Fair
Arch:		
masonry	Not practicable	Good
brick	Not practicable	Good
concrete	Fair	Good (high formwork content)
Box (r.c.)	Fair	Fair/Good (high formwork & reinforced content)
Wall-and-Slab	Poor	Good (masonry/blockwork walls & r.c. slab or filler joists)
Inlet/outlet work		
masonry	Not practicable	Good
concrete	Fair	Good

Table 16. Retaining wall design options and their potential for equipment and labor-based construction (15).

Type	Potential for . . .	
	Equipment	Labor
Mass concrete (with "plums")	Fair	Good
Masonry/brick face, concrete infill	Poor/Fair	Good
Masonry/brick	Not practicable	[illegible]
Reinforced concrete	Fair	[illegible]
Timber crib	Not practicable	Good
PCC crib	Fair	Fair
Wire gabions	Fair	Good
Sheet piles	Good	Poor

Table 17. Bridge design options (up to 30/40m total length in two or more spans) and their potential for equipment and labor-based construction (15).

Element	Potential for . . .	
	Equipment	Labor
Foundations:		
open excavation	Good	Good
cofferdam	Good	Fair (limited by use of sheet piles)
caisson (well-type)	Fair	Good (needs simple lifting gear)
piles: driven	Good	Poor (severe limitation on size of piles)
bored	Good	Poor
Abutment and piers:		
mass concrete	Good	Good
reinforced concrete	Fair	Good
masonry, brick (solid or skin) or blockwork	Not practicable	Good
Decks:		
RC slab/slab and beams	Fair	Good
RC slab and steel beams	Fair	Good
steel beam and timber deck or filler arches	Poor	Good
steel trusses and timber deck	Fair	Good (may need crane for larger spans and sections)
timber trusses and deck	Fair	Good

as to its potential for using labor and equipment in construction. Drainage for simple earth and gravel roads is often as important as the actual configuration of the road itself. Ample provision for the water to get away in the form of scour checks, drainage ditches, and run-outs may, for example, allow for relaxation of gradient standards; provision of appropriate drainage structures may prolong the life of the road. Findings of a study in Nepal report that concrete pipes made by hand in steel molds may need to be 50 percent thicker than spun pipes for equivalent strength (16). Where large stones, rubble, or locally made bricks are available, their use in culvert construction seems desirable. For retaining walls, a wide variety of alternatives to the more standard concrete construction presents itself; dry rubble walling may be a particularly appropriate option. Bridges on low-volume roads might most appropriately be limited to largely timber or masonry. A first question to ask with regard to bridge structures, however, is whether or not the bridge is really necessary. In many developing countries a river that a bridge crosses may be dry 10 or even 11 months of the year. Alternatives to a bridge in such situations include a buried drift (ford) built with its top surface at river bed level, or a built-up drift (causeway) built with culverts underneath.

Differences in the performance of these alternatives may certainly be expected and will be reflected in maintenance costs as well as in initial construction costs. Moreover, the appropriateness of various maintenance methods may also be affected.

RESOURCE PRODUCTIVITY: ITS MEASUREMENT AND IMPROVEMENT

Productivity Assessment

In order to more explicitly and quantitatively compare these alternatives in low-volume road construction technology in time and cost terms (Chapter 3) and to begin to use them, productivity data and output norms are needed

- to assess the probable cost of the work for budgetary provision (estimation);
- to evaluate the resource requirements and time for construction (planning);
- to appraise the physical and financial progress, establish piece rates, and other incentive schemes (control); and
- to ascertain the appropriateness of the methods selected in view of site experience (evaluation).

Productivity is defined as the ratio of output to input under a specified set of institutional and environmental conditions. Output is the quantity of work done and may be measured in cubic meters, tons, liters, or square meters. Input includes materials input, measured in quantity terms of cubic meters, tons, or liters, and the resource time spent in doing the work, measured in man-days or hours, animal-days or hours, or equipment-days or hours. Resource time may be defined in terms of a number of levels, ranging from including all possible delays (general, site, and technique-related) to including no delays at all (optimal or idealized time). Productivity may be expressed at the activity, task, or stage level. Specification of the parameters defining site conditions, however, becomes more difficult as the number of diverse activities at one site increases. The range of institutional and environmental conditions to which productivity is potentially sensitive was given previously in Table 3.

The sensitivity of productivity to various parameters, particularly those specific to activities or tasks, is demonstrated in various figures and tables throughout the above discussion of alternative construction technologies. Transfering data among projects and regions in a single country is difficult at best; transferring data among several countries may be impossible. The most reliable productivity data are naturally those recorded on the same site or similar sites within the same construction program. Because no country uses the full spectrum of technologies, it is necessary to rely upon data from elsewhere when considering alternatives. Manuals being published by the World Bank and International Labour Office (2,6), equipment manufacturer's catalogues, contractor's estimating handbooks, and departmental production norms are probably the most accessible sources of information available on alternative road construction technologies; they must be used with caution, however, and only as a preliminary guide until local experience can be gained.

Countries with a long tradition of labor-based construction techniques may exhibit higher productivities than a country just beginning such efforts. Figure 15 illustrates the trajectory that productivity might be expected to follow in developing a labor-based program; the spread reflects the overall quality of management and incentive schemes.

As for means of collecting productivity data on a local scale, some sort of common framework is needed if the results are to be at all comparable. This does not mean that the information itself needs to be collected in a uniform way, but rather that certain basic types of information need to be assembled in each case. The World Bank and the International Labour Office produced a manual (18) for the collection of data at the very detailed level necessary for research purposes. This was applied in certain of their field research studies. Each has since developed shorter, more simplified versions for management purposes that are described in their respective manuals (2, 7). Table 18 outlines the basic data requirements suggested by the World Bank where task-wise productivity studies are required.

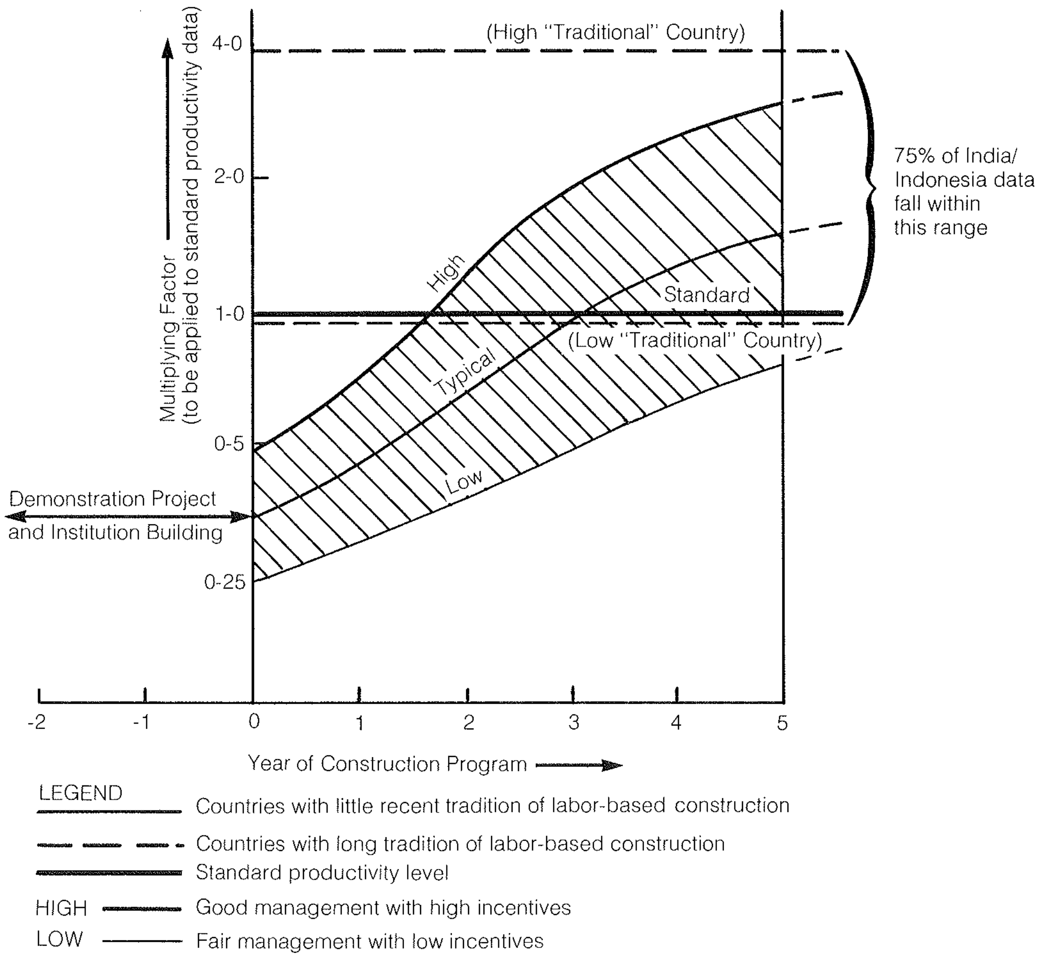
Means for Improvement

Evidence gathered to date from the field studies and demonstration projects of the World Bank, International Labour Office, and others suggests that there is considerable scope for improving labor productivity in some of the more labor-based applications, thereby enhancing labor's ability to compete with the more equipment-based alternatives. Three key areas for improvement include

1. management, organization, and supervision;
2. tools, simple mechanical aids, and the skills necessary to use them; and
3. general physical and social well-being of the workers.

A wide variety of factors pertaining to both labor and equipment falls under the heading of management, including supervision, job organization, labor relations, incentive systems, training, condition of tools and equipment, maintenance level, spares availability, and type of contract. The need for effective project organization and management exists regardless of the technology used in its execution, but the explicit requirements differ somewhat in the case of labor-based construction. For example, the output of a single piece of equipment is generally equivalent to the output of several hundred laborers working in small gangs. One or two

Figure 15. Projected trajectory of productivity in the course of development of a labor-based construction program (**2**).



Note: To achieve figures in the higher part of the range would require good management from the outset, allied to favorable environmental conditions with well-fed, healthy labor. The converse of such conditions would indicate productivities at the low end of the range. High incentives would also be required to achieve maximum productivities. This would imply gradual introduction of taskwork during the first two years of the program, followed by selective piecework probably during the second and third years. The zero on the time scale represents the start of a main production program, following a demonstration project, in a country where the labor has little previous experience of labor-based construction methods.

skilled laborers may be required to operate the item of equipment, while a dozen or more supervisors may be needed to watch over the work of the laborers. Moreover, a task or series of activities that may be done with one machine operation may require several gangs of laborers working on different activities, requiring careful coordination and balancing of resources and work. One bulldozer, for example, may carry out the earthworks task excavate-through-spread in one operation; but a labor force of 200 or 300 men with hand tools and wheelbarrows might carry it out as three operations: excavate-load, haul-unload-return, and spread. Adjustments in overall site layout and organization may also be appropriate. The Chinese have found working at a number of different points along the project at the same time to be particularly effective. A good example of the importance of supervisory quality and site organization to labor productivity and unit costs is shown in Figure 16, based on data from India and Indonesia.

Management systems that provide incentives for efficiency are one of the most effective means for motivating labor. Three basic systems exist for labor payment in low-volume road construction: (a) daily-paid (muster roll), whereby workers are paid a fixed sum each day in return for working a fixed number of hours; (b) taskwork, whereby workers are paid a fixed daily wage in return for a fixed quantity of work; and (c) piecework, whereby workers are paid an agreed upon sum per unit of output, the daily output being left to the discretion of the worker.

The daily-paid and taskwork systems are favored when local workers are used because the cash flow can be determined in advance. Piecework payments provide the greatest incentive to labor, and are frequently used in countries such as India that have a large migrant population of skilled road laborers who travel from job site to job site. The task-work system of payment normally introduces higher productivity rates than the daily-paid system when local labor is involved because it allows the worker more free time to tend his crops or to spend with his family. However, the taskwork system does not offer such motivation to the migrant laborer who has nothing to do with the spare time gained by completing his assigned work rapidly.

Table 18. Data requirements of the World Bank's "Basic System of Productivity Measurement" (**2**).

The bulk of productivity data required for the Basic System of Measurement can be extracted from records normally kept on site for logistical control purposes such as muster rolls, staff timesheets, vehicle log books, and stock control records. The format chosen for analyzing productivity and production control data should enable information for the site engineer and monthly reports to headquarters to be easily extracted.

Basis of Measurement. All productivity measurements should refer to a single task or operation. This is so even if activity level observations are being taken. In such cases all the activities comprising the task should be observed, and then aggregated to the task level at the analysis stage.

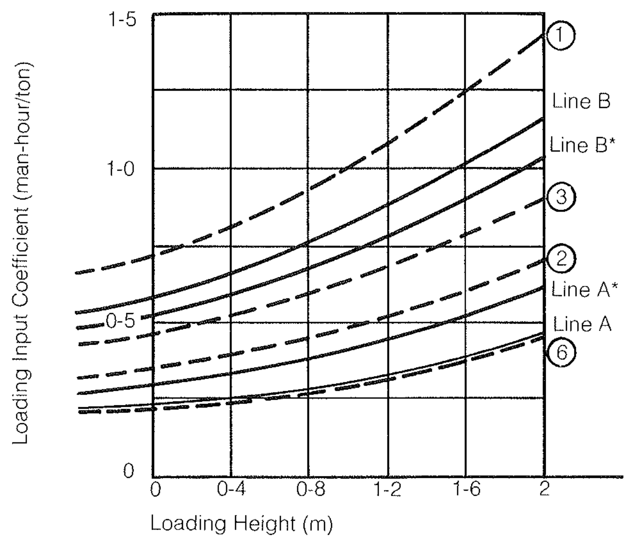
Input Measurement. The following items of information must be obtained: (a) a description of all types of resources employed (e.g., casual labor; animals; skilled labor — artisans, drivers, mechanics; tools and simple equipment; capital equipment; and materials); (b) the number of each resource type, except tools and simple equipment; (c) a note of payment method; (d) normal site hours (hence total time); (e) where taskwork is in operation, the actual hours spent on site; (f) lost time for each resource or gang of resources, preferably measured, otherwise reasonably accurately estimated (hence available time, by subtraction) (tools and simple equipment may be ignored); and (g) working time for capital equipment, where this can be easily obtained from the engine clock.

Output Measurement. The following information is required: (a) a complete description of the task; (b) the measured quantity of output with the unit (e.g., cu.m. or ton) and basis of measurement (e.g., in-situ or compacted) (estimated output should be avoided whenever possible); (c) a reference to the resources, or gang of labor, which produce the output; (d) the time period during which they produce it, if this is not clear from the input data (beginning and end date and number of working days); (e) where task work is in operation, a note of the 'piece' rate paid for the task.

Output is usually measured directly at the end of a week's or month's work. Where this is not possible, container loads such as water tanker loads can be counted. Where loads vary between trips, sample measurements of weight or volume can be taken. In this case a density conversion usually has to be made (e.g., from loose volume to in-situ volume or from tons to cu.m). The relevant densities should be measured.

Parameter Recording. It is sufficient to take a few spot readings or even to make estimates. All relevant parameters should be noted, but it is particularly important that (a) the haul distance and (b) the excavation parameter (soil/rock hardness) be recorded wherever haulage and/or excavation takes place. Wherever task work or piecework is in operation, important parameters will automatically be required for payment purposes.

Figure 16. Loading productivity as influenced by different supervision levels, payment methods, and loading heights (**10**).



Note: Observed data—

1. daily-paid work with poor/fair supervision
2. daily-paid work with good/very good supervision
3. piecework payment with poor/fair supervision
4. piecework payment with good/very good supervision

Range conditions—

Line A piecework payment with good supervision
Line A* piecework payment under average conditions
Line B daily-paid work with poor supervision
Line B* daily-paid work under average conditions

Man-hours is in terms of working time.

Figures like those in Table 19, which have been developed on the basis of experience in several countries, clearly demonstrate the beneficial influence wage incentive schemes can have on labor productivity. The development and administration of incentive systems, however, require careful planning. Job analyses must be carried out and a schedule of productivity norms established; the payment basis must be fully understood and felt to be fair by the labor force; wage payments must be made regularly and promptly; and there must

Table 19. Effect of payment method on the multiplying factor for "standard" productivity data (**2**).

Payment Method	Range of Factors by Which the "Standard" Value Should Be Multiplied: In countries with little recent experience of using labor-based methods	In countries with a long tradition of using labor-based methods
Daily-paid work	0.25-0.75	0.5-1.5
Taskwork	0.5 -1.5	1.0-2.5
Piecework	1.0 -3.0	2.0-4.0

be flexibility so rates can be revised to reflect changing site conditions.

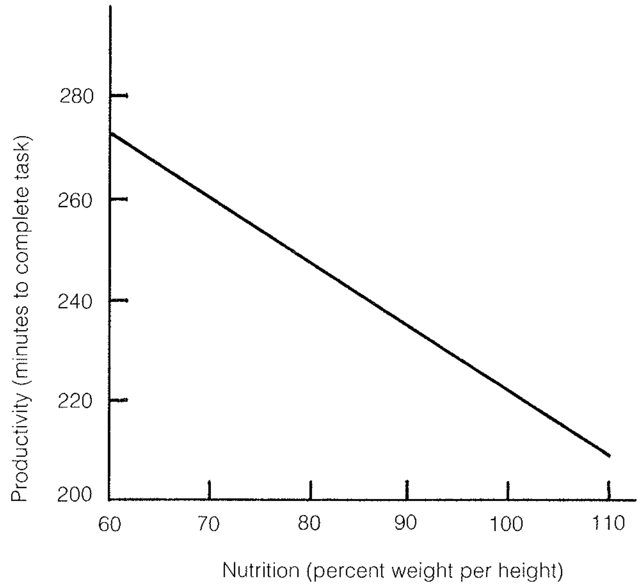
The availability of proper tools and simple equipment, their quality, durability, and maintenance, and the workers' knowledge and skill in their use are critical elements to the labor productivity. The improvement and adaptation of existing tools and techniques and the development of suitable new ones are a second important approach to productivity improvement. A wheelbarrow designed with ball bearings can be 50 percent more productive than the standard wheelbarrows usually available in developing countries; similarly, a specially designed hammer can significantly increase the rate of aggregate production by manual methods (**11**). In the Philippines bullock-drawn carts traditionally used in agriculture were modified to allow bottom discharge (**4**) (Figure 4); and a "Chinese scraper" was used as a model for factory production of a steel version, which proved to be both efficient and relatively inexpensive to produce (Figure 3).

Efforts to date in developing intermediate technologies seem to have come from the labor-based end of the spectrum of alternatives, with the intention of substituting capital for labor in small increments. The net result is an overall increase in labor productivity sufficient to offset the increase in capital cost. While substantial improvements in labor productivity have been achieved by proper selection and adaptation of conventional hardware, the more innovative devices have often proved to be less successful. It may be that the available hardware approaches the practical range of intermediate technologies and that prospects for any new intermediate technologies are limited (**13**).

A forthcoming publication of the International Labour Office (**6**) discusses the proper design, manufacture, maintenance, and use of a range of tools and simple equipment potentially suitable for use with labor; handtools, animal-drawn equipment, tractor-powered implements, and small motorized devices are to be included. This promises to be a most valuable resource for countries considering using or already using labor-based road construction techniques. The publication may also serve to further encourage and make more feasible local manufacture of good quality tools and simple equipment. Such local industrial development can be an important accompaniment to the successful implementation of labor-based construction.

Improving the health, nutrition, and social welfare of the workers is a third major means of increasing productivity. Nutritional deficiencies, parasitic infestations, and associated ill health, as are common in developing countries, reduce work output, at least in those who do sustained and prolonged physical activity as a major portion of their work. In a study of the Sharvathi Valley Project in India, for example, Malabari workers were found to have an average daily output 80 percent greater than that of non-Malabari workers. Malabaris on the average consume better than 1.5 times the caloric and protein intake of the other workers (**19**). Figure 17 shows a very consistent and significant relationship between undernutrition and low productivity during road construction in Kenya. In the case of iron deficiency anemia in Indonesia, largely caused by hookworm infestation and poor dietary intake of iron, productivity of anemic laborers was found to be some 20 percent less than that of non-anemic ones; a simple 8-week treatment for the anemia with elemental iron was found to result in productivity increases of 15 to 25 percent as compared to the control group (**20**).

Figure 17. Relation between undernutrition and low productivity in road construction in Kenya (**11**).



Note: The regression was based on data from various tasks associated with road construction (220 subjects were included in the study). The incentive was that those finishing the task early could go home early; as most men were small farmers, the extra time was valuable.

In situations where workers are undernourished, provision of food at work to the laborers and perhaps payment in food rather than money would appear to be beneficial from a strictly economic point of view, quite aside from its humanitarian aspects. Such a practice would be expected to reduce the level of undernutrition, improve health, prevent weight loss, and increase worker productivity and satisfaction. Similarly, providing iron tablets or iron-rich foods and treating common parasitic diseases such as hookworm and schistosomiasis would be expected to improve health, reduce the prevalence of anemia, reduce absenteeism, and increase productivity and well-being of the workers. These are only temporary measures, however; in the long run, public health and educational measures in the community, among other rural development efforts, are needed to control these diseases and improve nutrition.

Further discussion of these issues pertaining to improvement in labor productivity is left to Chapter 4 as topics of concern in the implementation of labor-based road construction.

ROAD MAINTENANCE ALTERNATIVES

The importance of proper road maintenance is not fully realized in some developing countries. In these countries, maintenance tends to be given relatively low priority in the distribution of available resources, financial and otherwise. In times of budgetary and resource shortfalls, it is typically the maintenance program that is cut back. Even within maintenance programs themselves, emphasis tends to be focused on the major roads. Upkeep of the secondary and feeder roads, however, is vital to the development of the rural areas.

A well organized and properly administered maintenance program can lead to reduced construction costs, reduced vehicle operating costs, and deferral of major reconstruction costs, thereby releasing funds for other projects.

Maintenance operations are of three basic types:

- Routine Maintenance—those operations that should be carried out several times a year in order to uphold the services of the road and to defer the need for resurfacing and major repairs; for example, ditch and culvert cleaning, pothole and rut repair, and patching.
- Periodic Maintenance—those operations that need to be carried out only a few times in the life of the road. The objective is to restore the facility more or less to its original standard, perhaps by regraveling. These activities are actually capital improvements rather than maintenance operations, but they are often termed periodic or recurrent maintenance because they are often undertaken by maintenance personnel.
- Emergency Repair—those operations that need to be undertaken after the partial or total collapse of a facility, usually as a result of natural disasters; for example, replacement of a bridge washed out in a flood and reconstruction of a road swept away by a landslide.

Organizing for Maintenance

It is during the planning and design stages of a road construction program that a maintenance program should be established, and funds and resources allocated for it. Moreover, it is then that the trade-offs between design and construction and maintenance, as discussed in Chapter 3, can be taken into consideration. The idea is becoming more common as lending agencies and governments grow increasingly aware of the need to place greater emphasis on road maintenance in order to safeguard their initial investment in construction. Planning for maintenance is particularly important in the case of low-volume road projects, which are as a rule designed and constructed to fairly low standards, and may therefore require relatively more maintenance for the volume of traffic carried than would higher-standard facilities.

Maintenance operations by their very nature tend to be rather large users of labor, even in industrialized countries. The organization of maintenance works tends to make them suitable to the use of either labor or equipment. For example, maintenance operations might be organized using one or more of the following systems (21):

- Lengthman System—A lengthman carries out all routine maintenance operations over a fixed length of road using only hand tools. A large group of lengthmen is assigned to one supervisor who can usually provide a supplementary mobile gang to handle larger tasks. Minimal mechanization and good workmanship are the main advantages of the system; but such a system is necessarily limited to use for low traffic volumes, although it can be extremely cost-effective in this situation.
- Patrol Gang System—Three or more men and a motor truck form the basic unit, which might handle routine maintenance of 60 to 150 km of road, carrying some 500 to 3000 vehicles per day. One field supervisor might direct ten patrols and allocate the tasks they cannot handle to a few small mobile gangs. A high level of performance in terms of inspection, fault detection, and repair is generally achieved. Providing a small wheeled tractor to the patrol substantially improves its output; other than this, the system is somewhat inflexible, and productivity is hard to improve.
- Area System—All maintenance resources for an area are concentrated in one center. Each area is some 130 to 290 km of road, and the labor strength is approximately 10 men. Inspection consists of noting the most urgent and serious faults. Crews are made up daily to handle the different maintenance tasks. This system is best suited to a close network of roads within a relatively limited area; there is some delay in fault repair, and a somewhat lower level of service for minor repairs than previous systems.
- Cyclic System—Once maintenance can be scheduled, it can be carried out by organizing units to cover each section at the required interval. These units might be assigned to specific tasks over a broad section or all tasks over a small section. A high degree of mechanization and specialization is possible. This system is most applicable to rather high-standard roads with known traffic volumes where maintenance needs are more predictable.

Although this particular description is based on experience in Australia, these various systems and combinations thereof have been observed throughout the world. Egypt, for example, practices a mix of the lengthman and area systems for routine maintenance operations. The individuals along the road primarily serve to observe its condition and report it to the area office, doing only minor shoulder maintenance themselves. Many British colonies practiced some of the more decentralized labor-based systems as recently as the 1950s. Kenya's Rural Access Roads Program has been so successful in using a lengthman approach to maintenance that the methods are now being extended to minor gazetted roads.

Increasing centralization, propensity toward mechanization, and rising design standards characterize the progression of these systems of organization and their appropriateness in use. Routine maintenance of roads carrying low traffic volumes is very dispersed, requiring small but continuous inputs of resources over a rather large number of separate points. The lengthman or patrol gang system is probably most appropriate, with occasional back-up by supplementary gangs assembled locally or brought from an area office by the supervisor-inspector. The lengthman system can be particularly cost-effective where population densities are high so that workers living adjacent to the road obviate the need for expensive transport, and a single supervisor and vehicle may handle inspection and wage payment for a 500-km network. Although these points apply equally regardless of whether construction was done by labor or equipment, it can be expected that local participation might be easier to obtain in the former case, and an ex-road worker might perform better, with less effort and training, as a lengthman. The lengthman system is inherently labor-based and the patrol gang is necessarily somewhat more mechanized, although the full extent of mechanization is limited. The supplementary gang can be fully labor- to fully equipment-based in its operations depending on the maintenance tasks themselves and how mechanizable they are.

Maintenance Operations and Technologies

Routine maintenance operations on low-volume roads include roadside, drainage facilities, surface and shoulder, and structures maintenance. The level of effort required for each is a function of environmental conditions, design and construction of the road, and traffic patterns. Many of the alternative tools and techniques proposed for use in pertinent road construction activities may also be suitable for use in maintenance operations. The subject of maintenance of low-volume roads is just beginning to receive the attention it deserves.

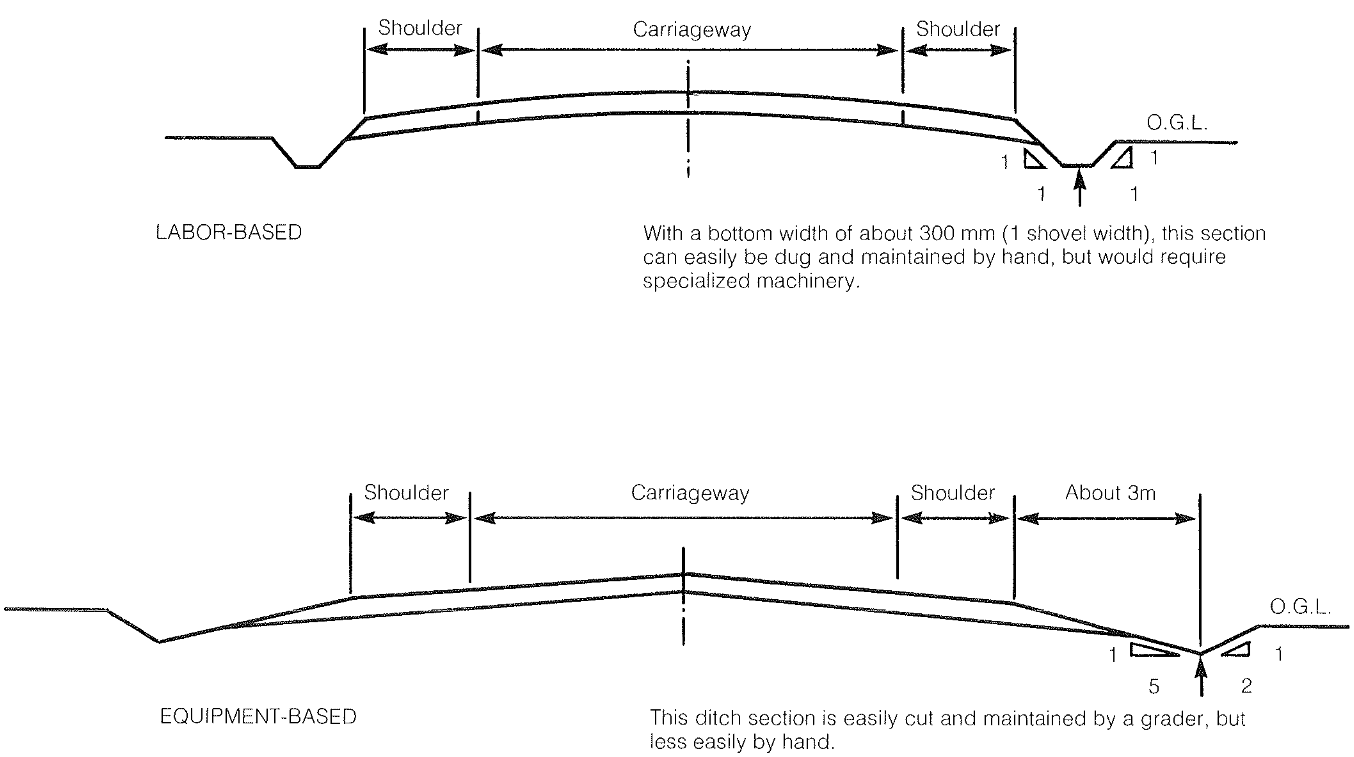
The primary activity in roadside maintenance is brush and vegetation control in order to keep shoulders and right-of-way clear. Environmental conditions such as rainfall, soil, and plant types have a major influence on the frequency and scope of this operation. For example, in Ethiopia, brushing by using labor and hand tools in dry weather zones amounts to 0.4 man-day per kilometer per year, while in high-rainfall areas it is as much as 2.9 man-days (**22**). Labor-based roadside maintenance requires labor and hand tools such as a scythe or slasher for grass cutting and a bushknife and/or axe for brush clearing. This activity can be effectively handled by a lengthman as long as the section size is compatible with the vegetation expected. Alternatively, mowers of various sizes and configurations might be used, from small hand-mowers to large 5- to 15-foot tractor-mower combinations and mowers. Steep slopes, as well as trees, rocks, and other impediments in the area to be mowed, are common in low-volume road projects, however, and can seriously limit a mower's effectiveness.

Maintenance of drainage facilities, which should be the first priority under any maintenance alternative, entails cleaning and keeping open side ditches and culverts. Excess water is an enemy of roads, and keeping it flowing and away from the roadway is important to road performance and life. Rainfall, terrain, and design and scope of the drainage system determine the magnitude of work necessary to keep it functional. Labor-based methods require hand tools such as hoes, shovels, and culvert cleaning shovels and wheelbarrows for transporting the excavated materials, some of which may be used in repairing the road surface. At the equipment-based end of the spectrum a motor grader, gradall, back hoe, and/or front-end loader, can be used in conjunction with one or more trucks to haul the excess material. Labor is still largely used for cleaning culverts, although it could be assisted by high-pressure pumps and sewer rod cleaners. A typical drainage maintenance crew, without such assistance, might include 1 motor grader, 4 trucks, and 25 workers.

In a ditching operation, a grader cleans the whole ditch and reshapes it, and can at the same time maintain the shoulders; labor cleans and reshapes the ditch selectively where needed. Use of the grader presupposes a certain width of road and is difficult in very hilly or mountainous terrain. Finally, as indicated in Figure 18, the shape of the ditch makes it more or less suitable for maintenance by labor or equipment. Decentralizing the process, as with the lengthman system, could be expected to make the labor-based approach more competitive. A major advantage of this system as well is the timeliness with which potentially damaging blockages in the drainage system might be observed and corrected.

Surface and shoulder maintenance activities might be broadly grouped as those pertaining to unpaved and to paved roads. A smooth surface and good camber, which allow water to run quickly off the surface into the side drains for dispersal, characterize a well-built road. The primary objective of maintenance is preservation of these characteris-

Figure 18. Typical cross section for low-volume roads assuming some 200 vehicles per day (**13**).



tics. Traffic, both volume and type, is a major contributor to the deterioration of the surface; overall design and environmental conditions are other factors affecting the rate at which this occurs. In the case of low-volume, unpaved roads, e.g., earth, gravel, and crushed rock, the primary maintenance activities include (a) repair, fill, and compact potholes and ruts; (b) replace materials moved by traffic from the roadway to the shoulders and slopes; and (c) keep surface, shoulders, and slopes smooth. A particularly difficult problem in the case of earth and gravel roads is removal of corrugations.

Fully labor-based maintenance of low-volume roads might require a hoe and shovel for repairing the surface and replacing materials thrown off the roadway onto the shoulders and slopes, a pick-axe for excavating soil and gravel for repairs, a rammer for compaction of repaired potholes and ruts, a wheelbarrow for hauling materials, and a rake and broom for smoothing the surface and shoulders. In cases where the wear is heavy, it may be necessary to periodically supplement the roadside materials with additional gravel or broken stone. Under the lengthman system, the supervisor might supply this in the form of small piles along the road; otherwise, a small supply of materials might be brought with the laborers to do the work. Routine maintenance of unpaved roads by labor alone is most suited to areas where traffic volumes are low and inspection and reparation are regular. The lengthman system has proven to be very effective for gravel roads built under the Rural Access Roads Program in Kenya. Each lengthman, a former road worker, is responsible for 0.5-2.0 km of road. (The current average length per contractor [lengthman] is 1.6 km.) He is paid the equivalent of 12 days a month for this and tools and materials are supplied at no charge. It is presently intended to supplement this routine maintenance with regraveling every eight years or so (**23**), although regraveling may not be required so often where traffic is low, except in hilly high-rainfall terrain.

At the opposite end of the spectrum, trucks, motor graders, and laborers with hand tools might be used for routine maintenance of unpaved roads. In extremely dry climates, a water truck is sometimes added to achieve the proper moisture content for blading-grading, followed by a roller to compact the surface before it dries. This is extremely expensive, however, and is to be avoided where it is possible to do heavier bladings during the rainy season. The basic differences between the use of labor and equipment in surface and shoulder maintenance are similar to those pertaining to the ditch cleaning operation, namely selective but frequent repair and reshaping versus more intermittent grading and reshaping of the entire surface. At a somewhat more intermediate level, truck, tractor, or animal-towed brooms (Figure 19), drags (Figure 10), blade graders (as used early this century in North America), and waterbowsers (Figure 11) might be used in conjunction with labor and hand tools for routine maintenance of unpaved roads.

Bituminous surface treatments are the highest pavement standard usually used for low-volume roads, with a single or double surface treatment being most common. Routine maintenance of these surfaces entails sealing cracks and patching areas in need of repair. Maintenance of the gravel and earth shoulders and slopes follows that of unpaved roads except the scale is considerably reduced and labor more frequently used. As observed above, maintenance of shoulders and ditches is frequently handled as one operation where equipment is used. Cold repairs of cracks, breaks, and holes in the road surface can be made by laborers using standard hand tools such as shovels, hoes, rakes, cans, ladles, and rammers, bitumen emulsion not requiring heating, and fine aggregate or chippings. As in the case of unpaved roads, repairs of minor defects in the surface on a continuous basis can go a long way toward keeping the road surface in good condition, and can be done entirely by laborers with hand tools.

Figure 19. Towed brooms used for maintenance of unpaved roads in East Africa (**7**).

As long as the repairs are relatively minor, more equipment-based approaches might simply include the use of a truck for transporting the labor, hand tools, and premix, and for compacting the repairs; a small roller may also be part of the crew. The use of hot bitumen will require the addition of a kettle or other heating device.

Repairs to structures, namely culverts, retaining walls, and bridges, tend to be largely labor-based operations. The exact nature of the activities and materials required are a function of the particular type of structure. Conscientious maintenance of lower-standard structures, as of lower-standard roads, is critical to their performance and life.

In summary, it has been the intention of Chapter 2 to give an overview of the full spectrum of technologies available for construction and maintenance of low-volume roads. Attention has been deliberately focused on construction and on the labor-based end of the spectrum of technologies. There is generally less known about these alternatives, and this is where knowledge has been sought in recent years. Having discussed the available options and their potential use, it is appropriate at this point to structure a framework within which one might begin to compare potentially interesting alternatives.

CHAPTER 3

Framework for Evaluation

It is clear from the preceding chapter of this synthesis that a broad range of alternative technologies exists that might be used in low-volume road construction and maintenance. In planning the introduction of new alternatives, various levels of consideration arise, including the conditions of the country and its road construction program, the types of road projects generally encountered, and specific low-volume road projects and technologies. Within each, certain technical, financial, economic, and social issues are of concern at varying levels of detail. It is the purpose of this chapter of the synthesis to set up a framework within which the broad level policymakers in the transportation ministry, planners of road programs, and chief engineers in the road authority might begin to look at these relevant issues and some of the means availalbe for their further analysis.

A three-tiered assessment is suggested:

1. Technical feasibility is the alternative technically practicable to use under the given conditions;
2. Financial feasibility is the alternative that is cost-effective when the resources are priced at their prevailing, or market, costs; and
3. Socioeconomic feasibility is the alternative that involves the least cost, where the resources are valued at their shadow prices—which may simply reflect the true relative scarcity of the resources or may go further to reflect certain developmental objectives as well.

In this chapter, as in the earlier chapter of this synthesis, the focus is on alternative technologies. The evaluation and assessment of program and project alternatives are discussed only to the extent necessary to accomplish a fair appraisal of the technological alternatives. Project evaluation is a vast and growing subject about which many books have been written. Some standard references are OECD's *Manual of Industrial Project Analysis in Developing Countries* by I.M.D. Little and J.A. Mirrlees (**24**), UNIDO's *Guidelines for Project Evaluation* (**25**), Little and Mirrlees' *Project Appraisal and Planning for Developing Countries* (**26**), and Squire and van der Tak's *Economic Analysis of Projects* (**27**). The subject here is dealt with in the context of technology choice in road construction and maintenance.

TECHNICAL FEASIBILITY

The literal definition of feasible is "capable of being done or carried out;" a second definition is "capable of being used or dealt with successfully: suitable." This synthesis uses the second definiton.

All evidence points to the technical feasibility of a range of technologies for use in low-volume road construction and maintenance, subject to certain qualifications. These qualifications can be broadly grouped as

1. Product quality and design,
2. Project type and timing, and
3. Availability of resources.

Product Quality and Design

Historical evidence, like the first German autobahns, and present-day works, like Mexico's Labor Roads Program and Kenya's Rural Access Roads Program, suggest that labor-based methods can produce roads of satisfactory quality. Most major tasks of road construction can be carried out using labor-based methods with results equal in quality to equipment-based methods. IBRD's initial study, in fact, reported that it is technically feasible to substitute labor for equipment in all but 10 to 20 percent of total direct costs in high-quality roads, and all but 2 to 15 percent in intermediate-quality ones (**28**).

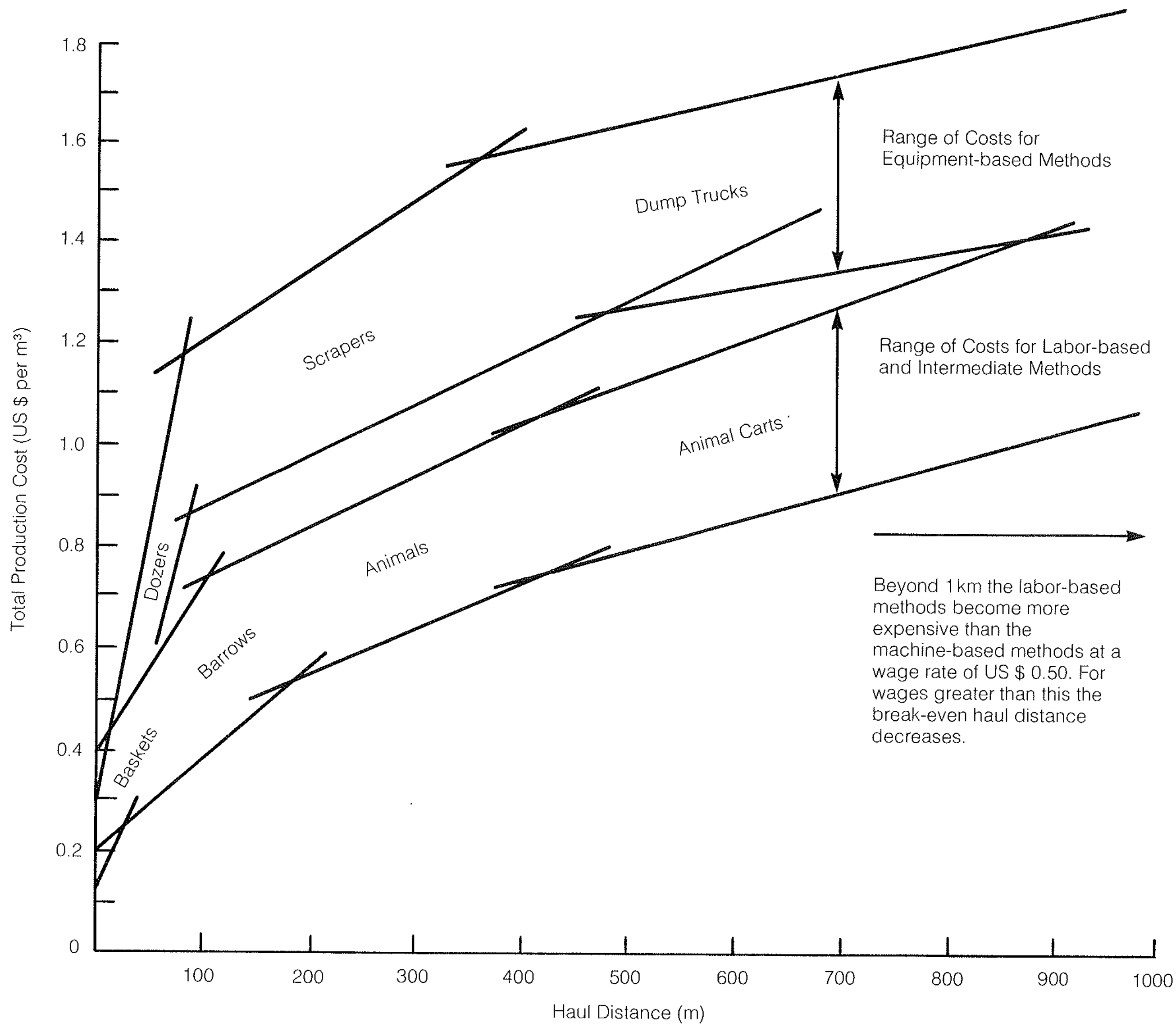
There are certain tasks for which the use of labor-based methods is either very difficult or produces an inferior product. These include haulage of materials over long distances, compaction of materials, production of certain aggregate gradings, mixing, piling, and surfacing of major roads. Materials transport is an example, illustrated by Figure 20. There are also certain activities that can actually be done better technically by labor or that can benefit from the adaptability of labor-based methods. Selection of materials for excavations, use of small quarries, and frequent changes in design are some examples. Figure 21 demonstrates this point of design flexibility over a 17-km stretch of road in India.

Any combination of technologies may in theory be specified for the various tasks, but in actual practice the use of a particular technology for one task may dictate the use of the same or similar technologies for some or all other tasks of the project. For example, hauling is one element in the overall operation of excavate, load, haul, unload, and spread. Use of a dump truck for hauling and unloading dictates use of a mechanical means of loading because manual loading would involve expensive standing time and an increased number of trucks to achieve a given output. Using a tractor-trailer combination with more than one trailer, on the other hand, would involve only the trailer's standing during manual loading while the more expensive element, the tractor, would be fully utilized in hauling trailers back and forth.

The design of the project may significantly influence the suitability of the construction work to the use of more or less labor because some tasks cannot be done well by labor without generating high costs; others may benefit from the adaptability associated with the greater use of labor; and mixing of technologies faces certain constraints.

Four examples are presented below to illustrate the interaction between design and construction methods. The first two examples illustrate a degree of rigidity whereby one aspect constrains the other. The first example is tailoring the design to fit the construction method; i.e., a design that favors the effective use of machinery is developed for equipment-based construction. The second example represents the opposite, fixing the design while leaving open the choice of construction method. More often than not, this puts the labor-based methods at a disadvantage because modern designs tend to

Figure 20. Total production cost to haul distance relations for the earthworks task in borrow to fill (**13**).



Note: Task is embankment construction in firm soil on flat terrain (excluding compaction).

Findings are based on Indian conditions, productivities, costs, etc.

Total production cost includes overheads and supervision.

Assumed unskilled labor daily wage is U.S. $0.5.

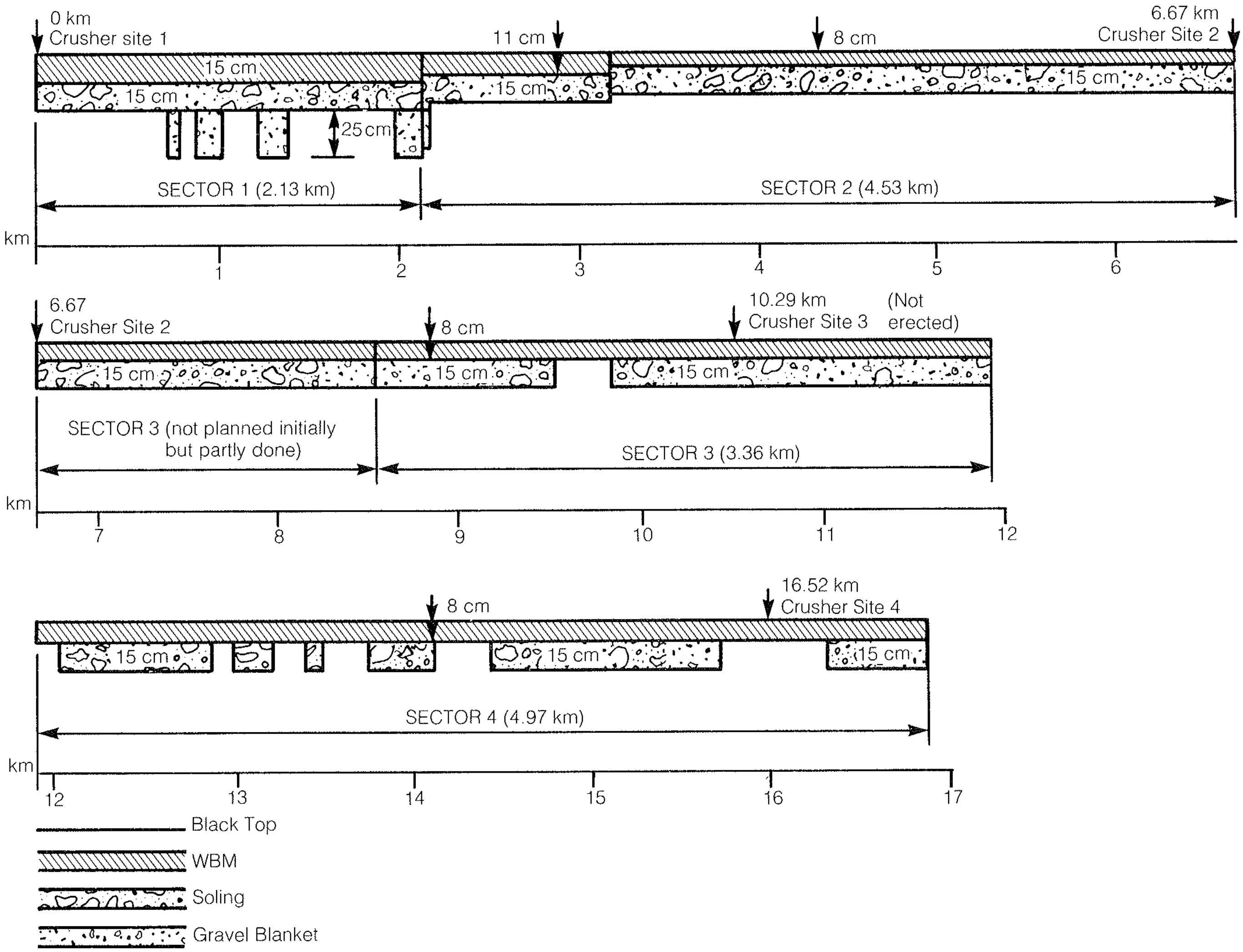
Results for animals are approximate due to variability in true costs of ownership, upkeep, etc.

1976 prices are used.

have an inherent bias toward use of equipment; nevertheless, methods using more labor are often still able to compete in low-standard gravel and earth roads.

The next two examples represent more flexible scenarios given an interest in considering alternative techniques of construction. In the third example the geometric alignment of the road is held constant while the pavement design is allowed to vary with the techniques of construction, although the structural strength and durability of the alternative pavements must be the same. The net result is that construction cost remains the overriding criterion for selection among the alternative designs. Differences in maintenance and operating costs might, with some reservation, be assumed negligible. It should be noted that studies in India suggest hand-laid surfaces have higher surface roughness and thus higher vehicle operating costs, although it may be possible to overcome this through improved quality control and design adjustment (11). Table 20 shows some of the options available for pavement materials with their respective appropriateness for construction by labor and equipment. With a fixed road alignment, the volumes of bulk earthwork excavation and filling in the embankments are to some extent fixed. Nevertheless, the site engineer can make the project more or less suitable to use of labor through controlling haul distances by size and location of borrow and spoil areas, considering hardness of soil to be excavated, selective use of gravel excavated for bases and subbases, and variation in pavement thickness along the route to minimize overdesign.

Figure 21. Pavement design for First Indian Road Demonstration Project (**13**).



The fourth example represents complete flexibility in design and construction, with the geometric alignment and pavement design varying along with the method of construction. The roads produced in this example may not be equal in quality because they can be constructed by different methods to different specifications. There may therefore be differences in maintenance and operating costs as well as in construction cost. For example, variation in alignment may affect the length of the road, design speed, safety, and areas served. Design for labor-based construction would tend to follow the contours of the land, minimizing earthworks and haul distances, and paying more attention to drainage details. It is possible that the overall routing may be altered and thus economic benefits accruing to the project may not be the same for alternative geometric designs. Considerations of total costs, i.e., construction, maintenance, and user costs, is thus necessary when comparing alternatives in this fourth example. One final dimension to the flexibility is trading savings today in construction cost for expenditures in the future in maintenance and user costs.

Considerations in Design Specification

Assuming that the most appropriate project route has been identified, road-induced benefits will not be significantly affected by the remaining choices of design specification and construction technology. Design thus includes the pavement and geometric specification of the rural road wherein small changes in overall alignment may be considered to meet cost or technology constraints. The pavement design may vary either in terms of the materials used or in terms of the structural properties of strength and durability. The geometric elements of vertical and horizontal alignment may also be varied and will affect design speed, road safety, and road length.

Several points should be made about the interaction of pavement design and technology choice. First, it is possible to produce pavements of equivalent strength and durability using different combinations and quantities of materials. The use of certain materials, however, is often more suited to one construction technology than to another. Second, certain ac-

Table 20. Pavement design options for low-volume roads and their potential for equipment and labor-based construction (**15**).

Element	Potential for Equipment	Potential for Labor
Sub-base:		
in-situ soil	Good	Good
imported	Good	Good
Base:		
in-situ soil	Good (compaction)	Good
gravel (naturally occurring)	Good	Good
gravel (mechanically stabilized)	Good	Poor
stone (crusher run)	Good	Not practicable
stone (macadam)	Fair	Good
stone (pitched)	Not practicable	Good
stone (Telford wedged)	Not practicable	Fair
brick (crushed)	Fair	Good
brick (paved)	Not practicable	Good
stabilised (cement)	Good	Poor
stablised (lime)	Good	Fair/Good
concrete (plain)	Good	Good
concrete (reinforced)	Good	Fair
bituminous pre-mix	Good	Fair
penetration macadam	Good	Good
Surfacing:		
bitumen macadam	Good	Fair
asphaltic concrete	Good	Not practicable

Note: Consideration of compaction, a relatively minor element, is excluded in the above; it almost invariably has to be carried out by equipment. Haul distances may also dictate the use of equipment.

tivities are particularly inappropriate for labor-based methods. The use of labor-based technologies tends to be more feasible for lower standard roads. Third, certain materials may be omitted from consideration when equipment is used, although these same materials might be used effectively in labor-based operations, and vice-versa. Fourth, the possibility of trade-offs between subgrade strength and pavement thickness should be considered, with pavement design possibly varying along the route. This condition may enhance the use of labor, which can accommodate such variations with greater flexibility.

The overall route location may be fixed, but the more detailed aspects of the alignment, such as the geometric design, should be kept locally variable. There are various alignment operations, for example, that are not well suited to labor-based techniques; these include long-haul earthwork operations, rock excavation, dense vegetation site clearance, large embankments and their attendant structures, and large structures themselves. Judicious modifications in the alignment can often keep these operations to a minimum. Aligning the road in close proximity to suitable sources of material, for example, enhances the feasibility of labor-based technologies. If such modifications result in extending the road length, this would have to be taken into consideration.

The specification of design speed, in particular, affects geometric alignment in that it limits vertical and horizontal curvature. It may be more economical, for example, to lower design speeds on certain roads, or portions of roads, to allow the alignment to follow the land contours, thus reducing the necessary earthwork. In addition to producing a longer road, vehicle depreciation and travel time costs may be increased, raising future transport costs. Further, lowering the design speed may preclude the upgrading of the road to higher standards as traffic demand grows over time. The possible reduction in design speed in relation to labor-based methods must clearly be evaluated in terms of total project cost, present and future.

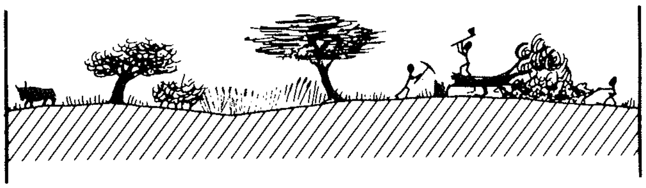
Development of Design Alternatives

The elements of pavement and geometric design can be broadly characterized as a range of designs that have [illegible] lent future consequences in terms of vehicle opera[illegible] road maintenance costs, or a range of designs that [illegible] have equivalent future consequences. The former is generally comprised of pavement designs yielding equivalent strength and durability, with equivalent geometric alignments. The latter is comprised of designs in which the pavement or geometric specifications, or both, are varied, such that road construction costs and quality are not identical. External constraints may naturally limit the range of feasible designs within one or both of these alternatives; the most appropriate design would be the one that is the most efficient.

Pavement design alternatives can be discussed in terms of three broad categories of surfaces: earth, gravel, and paved. Earth roads range from mere penetration tracks to engineered roads with a surface of local material; anticipated traffic volumes are typically less than 50 vehicles/day. Such roads are the most suitable for labor-based construction methods for a number of reasons. First, their emphasis on short-haul earthwork parallels the strengths of labor-based methods. Second, equipment-based contractors are often reluctant to construct such roads because of their usually short length, inaccessibility, and limited return on capital. Third, these roads are often for rural access and are of direct and obvious benefit to the local population. This facilitates enlisting local support in road construction and subsequent maintenance of what is often locally perceived as "our" road. Proper construction, as illustrated in Figure 22, is important. The major design consideration is probably the provision and maintenance of adequate drainage. Although these roads are usually not intended to provide all-weather access, effective drainage can greatly reduce the length of time they are closed during and after the rainy season.

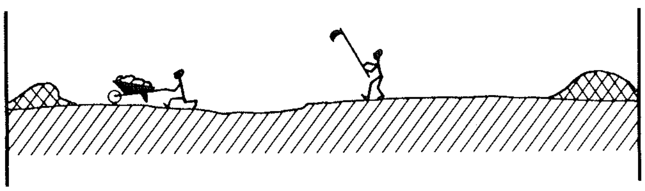
Gravel roads are suitable for daily traffic volumes of up to 200-300 vehicles. The structural design depends upon the

Figure 22. How to make a simple earth road (7).



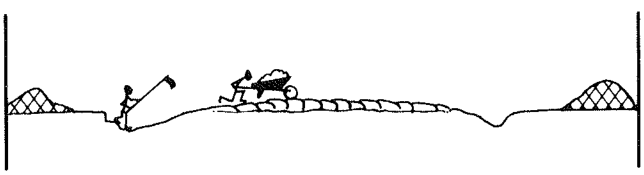
1

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



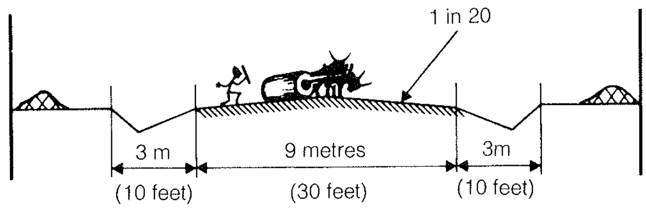
2

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



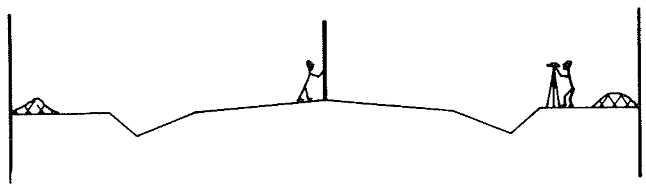
3

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



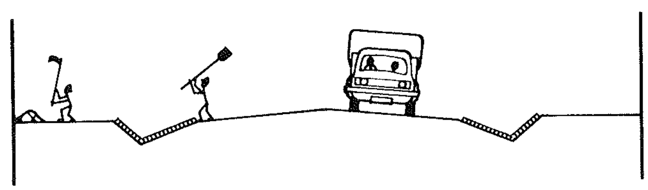
4

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.

Perhaps the most important requirements for earth roads from the engineer's point of view are proper drainage and adequate maintenance: 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.

traffic level and composition and the quality of subgrade support. The quality of gravel roads is largely determined by the materials used in construction. Where labor-based methods are used exclusively, therefore, it may be necessary to design with greater depths of local materials to achieve the desired product quality. Alternatively, trucks or other transport may be used to bring materials from farther away to the site, while labor continues to be used in the other operations.

As for paved roads, there are many design methods in use throughout the world, ranging from empirical to theoretical; the empirical California bearing ratio (CBR) method is probably the most widely used approach. Given the traffic volume and the quality of subgrade support, the objective is to select the most suitable materials and thicknesses for each pavement layer such that the stress distributed to each layer is commensurate with its load-carrying capacity.

As has already been emphasized, the feasibility of labor-based methods requires that design specifications be oriented toward materials that are suitable for labor-based technologies. Materials often not considered for use in equipment-based methods may be readily available and of adequate quality to produce the required pavement strength and durability. Materials such as wood or stone sets, pozzolan bricks, and masonry or asphalt blocks, may equally possess the desired structural properties.

A final point that should be emphasized when considering the design of equivalent pavements is that the variability of the subgrade along the route can have important implications for the efficiency of various construction technologies. Because the major structural element (i.e., pavement thickness) required to produce a given level of performance is dependent upon the quality of subgrade support, it follows that if there is a wide variability in subgrade conditions, there should be a corresponding variability in pavement design in order to provide a pavement of equal structural quality throughout the route. Such flexibility in design is not conducive to equipment-based methods, which are better suited to constant cross-sectional designs for considerable road lengths;

economy is not justified. Even in India and Bangladesh there are labor shortages during certain seasons of the year; regional variations are often dampened by seasonal migrations. The willingness of labor to work in road construction can depend on earnings compared to alternative forms of employment; "wealth" such as land holdings of the individuals; additional work-related costs (food and transport); and willingness to forego leisure time. In some cultures attitudes toward manual labor in road construction may be negative, because such activities may be perceived to be inconsistent with human dignity or even a form of enslavement. Seasonal fluctuations in demand for labor and other projects in the area, including maintenance of existing facilities, may affect labor availability. Health and nutritional conditions also play a role in labor availability and effectiveness. A more detailed evaluation of labor availability problems is presented in Chapter 4.

Aside from labor, the availability of appropriate tools and simple equipment and materials is important. These items may be locally produced or imported. The existence of managerial and supervisory capabilities and potential for developing them are still other indicators of appropriateness. Lack of experience in managing large labor forces can be a major constraint on adopting labor-based techniques regardless of the situation concerning other resources. Nevertheless the need for road construction and a concurrent lack of equipment and capital for investment in equipment may suggest the use of labor-based means.

The foregoing points primarily serve as indicators of the potential for using more or less labor in the construction and maintenance of various road projects. In assessing the financial and socioeconomic feasibility one can begin to be somewhat more quantitative and rigorous.

FINANCIAL FEASIBILITY

An assessment of the financial feasibility of alternative means of construction and maintenance of low-volume roads can range from a broad country or sector and program or project screening of possible suitability of labor-based techniques to a detailed analysis of the relative cost-effectiveness of alternative approaches. The first is a relatively qualitative assessment that may be based on break-even wage rates. The second encompasses construction, maintenance, and user costs as well as other quantifiable project benefits and costs, all at market prices.

Screening Process

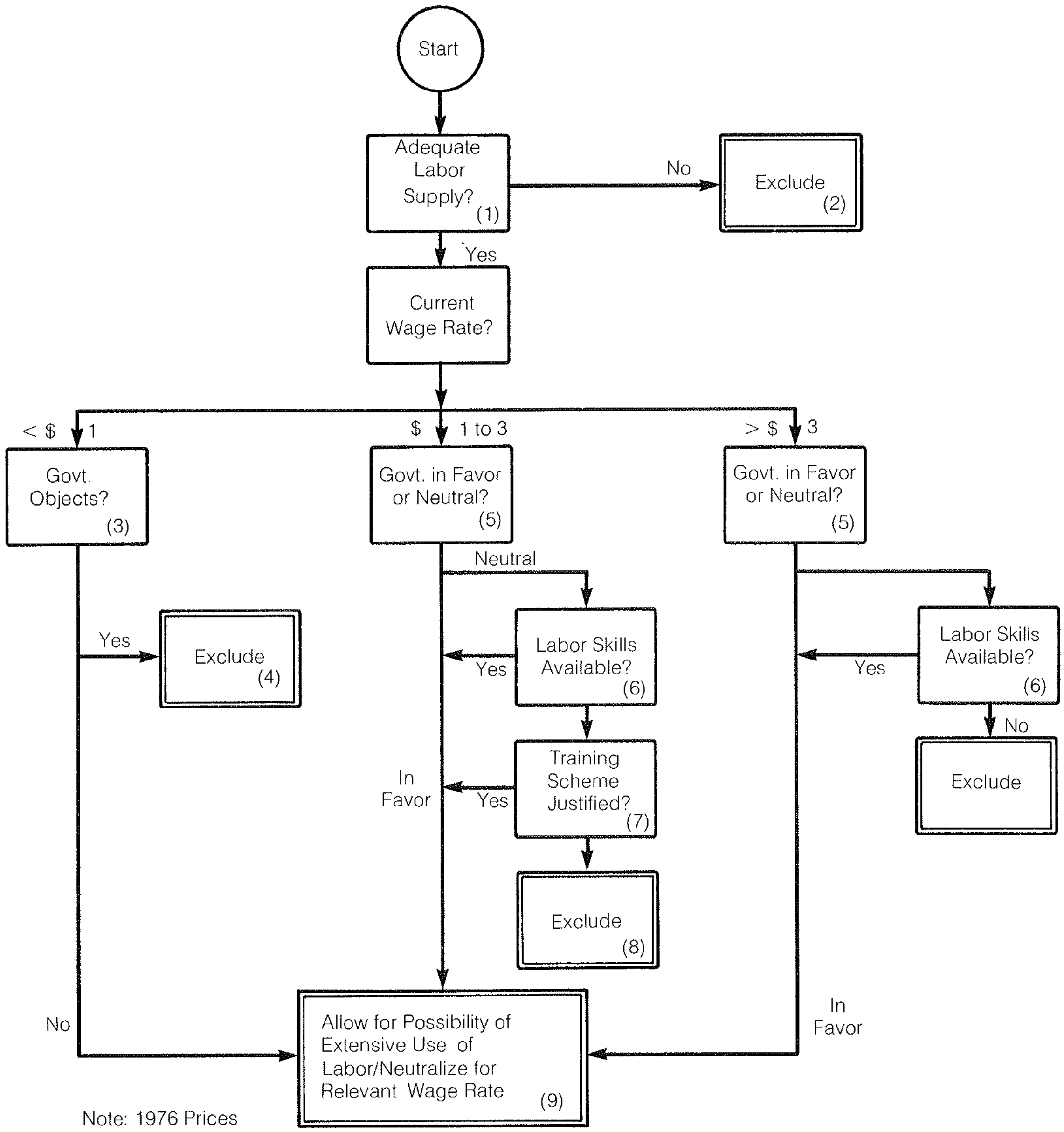
In the course of the World Bank's study of labor and capital substitution in civil works construction, a two-stage screening process was developed whereby individuals without a detailed knowledge of the trade-offs between labor and equipment might identify countries, projects, and parts of projects where greater use of labor might be appropriate. It is suggested that the first screen be applied at the country, region, or sector level with a 5-10 year development perspective; the second screen is designed to be directed toward the preparation of preappraisal stage of specific programs or projects and a 3-5 year perspective. These two screens are presented in the form of decision charts in Figures 23 and 24. The charts put into a more explicit structure several of the issues raised in the technical feasibility assessment and introduce financial and economic considerations in construction in the form of relative labor and equipment costs. Preliminary tests by the World Bank research group suggest some 33 countries might appropriately use more labor-based methods of construction. (That preliminary figure is now down to 20.) Tables 22 and 23 indicate the types and parts of civil works projects for which labor-based techniques might be appropriate given an unskilled wage rate within particular ranges.

The two charts and tables are based on productivities and costs observed in the World Bank studies in India and Indonesia, adjusted to mid-1976 prices; more specifically:

- equipment operating cost including delivery to site spare parts, and fuel; allowances made for depreciation and maintenance based on observations;

Notes:
(1) The yardstick wage rates shown in the screen may need to be adjusted as discussed in text.
(2) The abundance refers to the availability of labor for the current construction program; if in doubt, assume there is not an abundance.
(3) The attitude of government is an important parameter, which can only be assessed subjectively.
(4) There may be particular parts of the construction program that must be constructed by using equipment-based methods (e.g., dredging and large earth-fill dams).
(5) The important factor to assess is the likely changes in the ratio of daily unskilled labor wage to the cost of machines.
(6) This requires assessment of population growth, expected demographic changes, and nature of the labor market and middle-term construction program. If it is decided that adequate labor will be available, consideration must be given to the overall economic impact of labor moving to construction from other sectors.
(7) Most construction work can be done by labor-based methods, but some types of work are less suitable, either because (a) they are technically difficult to do by labor (e.g., dredging); (b) labor produces work of inferior quality (e.g., high-quality bituminous surfacing and compaction); or (c) they require large numbers of labor in a concentrated site (e.g., the construction of a dam in the dry season that must be finished before the rains). The types of projects suited to construction by labor-based methods are given in Table 3.
(8) The attitude of government is an important parameter that can only be assessed subjectively; if in doubt, assume a neutral attitude.
(9) The important aspect of management concerns local skills. If these skills do not exist in the country, either for labor-based or equipment-based methods, they must be imported, at least in the short term. In this assessment, consideration should be given as to whether it would be appropriate or desirable to set up training facilities for middle-level management.
(10) There may be exceptional programs that cannot use labor-based methods even though the appropriate unskilled wage is less than US$1.50 in 1976 prices. It may be possible to adapt the design to use labor-based methods, however.
(11) There may be exceptional programs that must use labor-based methods although the appropriate unskilled labor wage exceeds US$4.00 in 1976 prices (e.g., scattered and widely dispersed low-cost road programs in which the moving and set-up costs for each site using equipment would be excessively high in relation to the amount of work to be done).

Figure 24. Program/project screen (**13**).



Notes:

(1) If this question is likely to take considerable time and effort to answer, start at the second question and proceed through the screen. In this event, the question of labor availability need only be considered if the program/project proves to be one suitable for further consideration/neutralization. This factor is crucial and the assessment must at least consider (a) location, size, and timing of the program/project; (b) seasonal variability of labor; (c) potential sources of labor and need for labor camps; and (d) possible effect of the program/project on labor wages at the national/regional level. Unless a detailed analysis is carried out, it is not always easy to calculate the amount of labor required; as a first approximation, however, the maximum unskilled labor force needed can be determined by assuming that 30-40 percent of the total program/project cost (including overheads) will be paid as unskilled labor wages.

(2) If there is likely to be insufficient labor for the whole program/project, there may be enough to do parts of it; this would only be relevant, however, to large programs and projects. The parts of a program/project most suitable for labor are indicated in Table 23.

(3) Reaching this part of the screen with an unskilled wage of less than U.S. $1.00 (1976 price) implies that generally the government is not strongly in favor of using labor in construction; this specific question relates to the government's attitude to the proposed program/project.

(4) If the type of program/project being considered is ticked in Table 22 under the U.S. $1.00 wage column, there is a strong possibility that the government's attitude is leading to the use of a technology that is not cost-effective.

(5) If the answer to this question is unclear, assume that the government is neutral.

(6) This question applies to both manual and managerial skills.

(7) The cost of setting up a training program must be explicitly assessed.

(8) If the type of program/project being considered is ticked in Table 22 under the U.S. $1.00-2.00 wage column, the question of a training program should be considered in its wider context. Such consideration should look at construction generally to see if there is sufficient work of the right type to warrant setting up a central training program.

(9) At the program/project level, neutralization might include changes in design, contract documents and project packaging, and methods of finance. The intent is to remove any inherent bias toward the use of labor or equipment. In the case of competitive bidding then, the contractors doing the bidding might each select the factor mix he feels is appropriate, without being penalized for using more or less labor; this essentially makes the bidding process itself the ultimate screen when the lowest financial cost will determine the technology that will be used.

pavements tend to be designed for the minimum subgrade quality within each section, resulting in over design for other subgrade conditions. Labor-based methods, on the other hand, are well adapted to provide localized design flexibility.

Road design affects total construction costs and the distribution of costs among various activities, in addition to the choice of construction technology. The distribution of costs among activities for various road standards is shown in Table 21. Aside from the increase in earthwork percentage and the decrease in pavement and drainage-and-structures percentages with the lowering of design standards, it is important to note that the percentage of expenditures for production and haulage of road materials increases with lower design standards; thus, flexibility in the use of local materials may be one of the most important design considerations for labor-based rural road programs.

Project Type and Timing

Quality and design considerations are necessarily linked to the type of project, making some projects more suited to the use of labor than others. Moreover, low-volume road projects, by their very purpose and nature, are often short and scattered. Transportation, operations, and maintenance of equipment can be costly and time-consuming for projects located in remote areas; furthermore, the projects need to be large enough to fully utilize the capacity of the equipment. As a general rule, equipment-based methods tend to be better suited to larger, more concentrated projects. The small, geographically dispersed projects may be better served by locally available labor and associated methods, both for construction and maintenance. If all circumstances are favorable, however, there is no inherent reason why large projects cannot also be built by labor-based methods. Similarly, a remote work site away from the main sources of labor may make a labor-based approach less attractive as provision of ancillary services such as housing and transportation becomes necessary.

A commonly stated disadvantage of labor-based construction is the time required. The potential for productivity improvement in labor-based operations was discussed in Chapter 2. Aside from this, the overall planning and organization of the project, its locaiton, and logistical aspects, can have a major impact on the rate and timing of project execution. Labor supply, both seasonally and regionally, is clearly a factor. Often more important are the political and financial constraints that have been observed in numerous cases where long project delays have occurred in labor-based projects. Political forces sometimes insist that available budgets be spread over many different projects in different areas so that most, if not all, constituencies can benefit. Such a policy can produce inadequate funding for many of the projects involved.

Nevertheless, given sufficient financial resources, a regular and sufficient supply of labor, a competent supervisory staff, and a relatively unconstrained project site, labor-based methods may be able to keep pace with equipment-based ones. The 110-km Lancaster-Carlisle railway, built in two years, and the enormous volume of work involved in the Sarda Sahayak irrigation project are good examples. Other projects may simply be too demanding to use labor-based techniques. For example, the Indus Basin project in Pakistan would have needed some 30,400 donkeys to execute only a part of the work at peak times while the maximum available in the country was some 20,000. Other projects may be too confined, like the Neyreli lignite project in India where loaders and shovels removed overburden at a rate of 14,000 m^3/day, a rate that would have required 10,000 laborers and thousands of lorries to do manually. Roads, like railways and irrigation canals, however, are particularly well suited to labor-based construction because work can progress simultaneously at several points along the length of the project instead of strictly sequentially at a single point.

In cases where seasonality of labor is a problem, it may be possible to schedule certain activities best executed by labor for times when labor is available. In Colombia's Pico y Pala Program, for example, site preparation and earthworks are done by labor in the off-season for agriculture, and gravel surfacing is done by equipment, often long after the labor-based phase has been completed.

Delays in project completion should be taken into account in the financial and economic evaluation stages through quantification of overhead costs, benefits foregone, and delays in other projects, although this is often hard to do in reality.

Table 21. Percentage distribution of construction costs for three classes of roads in certain parts of Asia and the Far East (**7**).

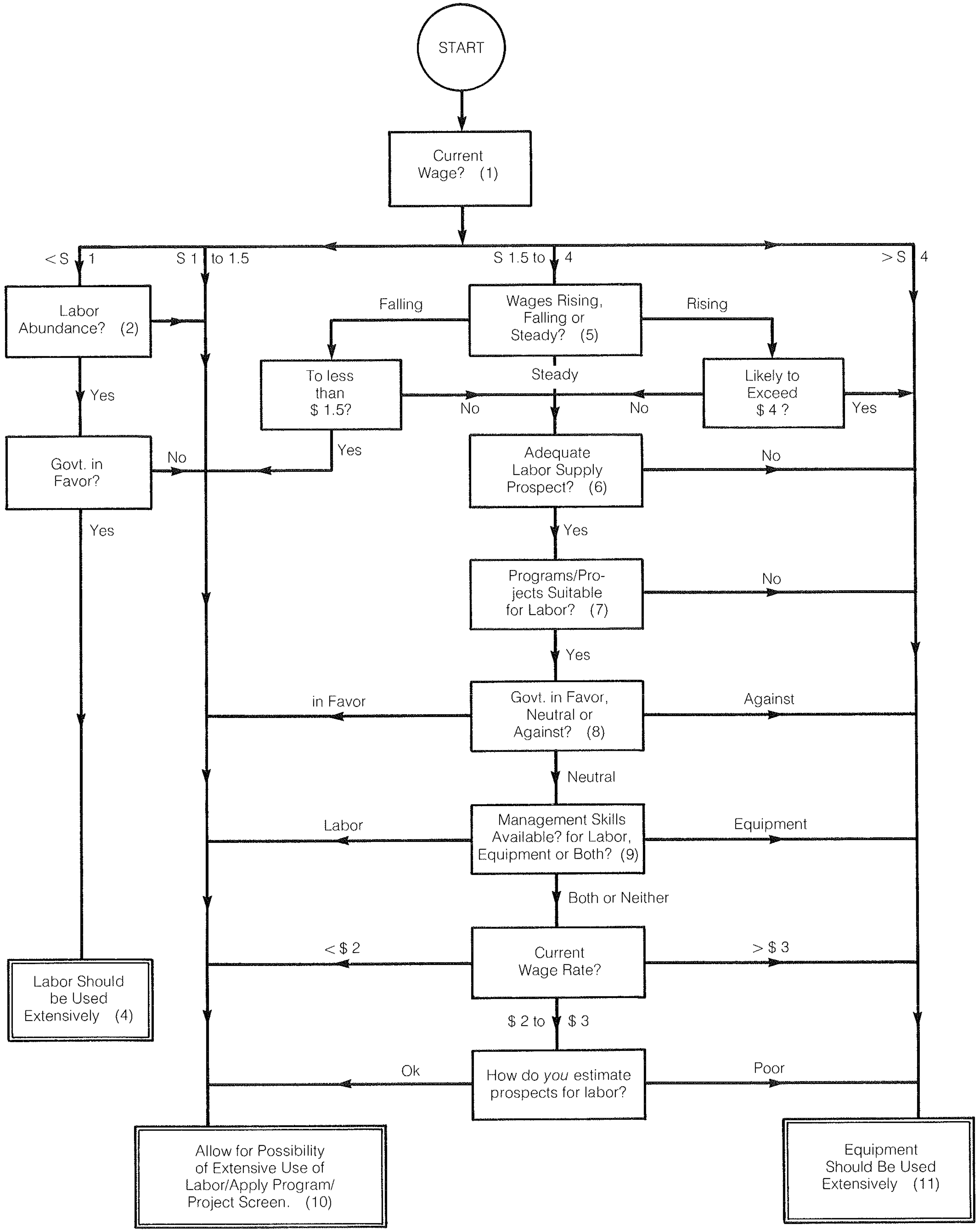
Operation	Road Type (%) Feeder	Secondary	Primary
1. Clearing	3	2	2
2a. Excavation of earth, haul less than 100 meters	20	16	14
2b. Excavation of earth, haul greater than 100 meters	12	10	9
3. Compaction and grading	12	11	10
4. Production and hauling of road materials other than earth	30	23	16
5. Base course and surfacing	9	18	25
6. Drainage and structures	14	20	24
Total	100	100	100

Availability of Resources

The availability of resources (labor, tools, equipment, materials, and managerial and supervisory expertise) has a major influence on the overall feasibility of alternative methods of road construction and maintenance. Availability means having the required numbers, at the right place, at the right time.

Sufficient labor, ready and willing to work, is a prerequisite for any labor-based construction effort. The assumption that there will be no difficulties in labor supply in a labor-surplus

Figure 23. Country/region/sector screen (**13**).



Note: 1976 Prices. See notes on page 39.

Table 22. Potential suitability of programs/projects for construction by labor-based methods at various daily unskilled labor wages (**13**).

Type of Program/Project	Comments (Size of Project, Degree of Dispersion, etc)	Man-day Labor Cost (US$) (1) 0-1.0	1.0-2.0	2.0-3.0	3.0-4.0
Surfaced roads (2)	Minor roads	•			
Gravel roads (3)	Dispersed projects	•	•	•	
	Average projects	•	•		
	concentrated projects	•			
Dirt roads	Very dispersed projects	•	•	•	•
	Fairly dispersed projects	•	•	•	
	Other projects	•	•		
Road widening, upgrading dirt roads by gravelling	Large concentrated projects	•			
	Other projects	•	•		
Periodic road maintenance programs	Dirt and gravel roads, very dispersed	•	•		
	Other dirt and gravel roads	•	•	•(4)	
	Other unsurfaced roads	•	•		
	Surfaced roads	•			
Small unlined canals and ditches	Small, dispersed projects	•	•	•	
	Average projects	•	•		
	Large, concentrated projects	•			
Large unlined canals and ditches		•			
Brick lining for canals and ditches		•	•(5)		
Routine maintenance of canals and ditches	Minor canals, very dispersed	•	•	•	•
	Other minor canals	•	•	•	
	Major canals	•	•		
Pipelines (6)		•(7)	•(8)		
Earthfill dams (incl. fishponds) (9)	Small dispersed projects	•	•	•(10)	
	Other small projects	•	•		
	Large, concentrated projects without important time constraints	•			
Masonry dams		•			
Rockfill dams		•			
Concrete dams (11)	Small (incl. weirs)	•	•(12)		
	Large (incl. gated barrages)	•			
Soil conservation & erosion control (13)		•	•		
Unsurfaced airfields		•	•(14)	•(14)	
Low-cost building	Traditional construction	•	•	•	
	Non-traditional construction	•	•		
Small bridges	Timber or masonry	•	•		
	Concrete	•			

Note: an asterisk indicates possible suitability. 1976 prices. Parts of large concentrated projects may still be suitable at labor costs higher than those shown,

(1) Daily unskilled labor wage rates may need to be adjusted as discussed in text.

(2) Minor roads are defined as those due to carry such light traffic that any delay caused by using labor-based methods would not seriously reduce user benefits. 500 vehicles/day is suggested as an upper limit for such minor roads.

(3) Provided haul lengths do not generally exceed 5 km (assuming tractor/trailer haulage).

(4) Periodic maintenance would include regraveling and resealing.

(5) Bricks should be used only if they can be produced locally, usually by labor-based methods.

(6) This applies to trench excavation, pipe laying, and trench back-filling.

(7) Manual methods of excavation are cost effective except in massive rock.

(8) Manual methods of excavation are cost effective except in stiff/hard/dense soils and in rock.

(9) Provided haul lengths do not generally exceed 1 km.

(10) The soil should not be harder than firm loose.

(11) Mixing should be done mechanically.

(12) Aggregates smaller than 25 mm are best produced by crusher but they can often be replaced by natural gravels won by labor.

(13) This would include contour ridging, watercourse construction, check dams in gullies, tree planting, and so forth.

(14) Applies only to small, remote airfields where the only means of access is by air.

Table 23. Potential suitability of activities for construction by labor-based methods at various daily unskilled labor wages (**13**).

Operation	Man-day Labor Cost (US$)		
	0-1.0	1.0-2.0	2.0-3.0
Site clearance	•	•	•
Excavation			
(a) ditches & trenches	•	•	•
(b) bulk (soft, loose soils)	•	•	
(c) bulk (other soils, soft rock)	•		
(d) caissons and open wells (soft, loose soils)	•	•	•
(e) caissons and open wells (other soils, rock)	•	•	
(f) terracing & contouring	•	•	
Backfilling pipe and culvert excavations	•	•	•
Loading & unloading bulk materials	•	•	
Short haulage			
(a) labor up to 200m	•	•	
(b) animals up to 1 km	•	•	•
Placing, spreading & shaping bulk materials	•	•	
Mixing concrete (cement or bituminous)	•		
Stone production			
(a) aggregate 25 to 50mm	•	•	
(b) undressed stone 50mm	•	•	•
(c) dressed stone	•	•	•
Bricklaying/masonry construction			
(a) Structures	•	•	•
(b) Pavements	•	•	•
Laying pipes			
(a) non-pressure	•	•	•
(b) pressure	•	•	•
(c) culverts (concrete)	•	•	•
(d) culverts (cor. metal)	•	•	•
Carpentry			
(a) formwork	•	•	•
(b) roof & bridge trusses	•	•	•
Reinforcement			
(a) bending	•	•	•
(b) fixing	•	•	•
Steelwork (structural)			
(a) fabrication	•	•	•
(b) erection	•	•	•

Note: An asterisk indicates possible suitability. 1976 prices. Daily unskilled labor wage rates may need to be adjusted as discussed in text.

- daily unskilled labor wage as received by labor for a day's work, and which could include value of food supply in lieu of wages; allowances made for overhead costs (estimated as some 70 percent of basic wage) including, for example, social charges, housing, transport, handtools, and other employer-supplied benefits. (13)

Break-even daily wage rates were developed on the basis of the measured productivities of equipment and labor. This rate is defined as the basic daily unskilled labor wage at which the total cost of carrying out a given quantity fo work by equipment would equal the cost of the same by labor. Daily unskilled wage rate is thus used as a convenient yardstick for assessing the relative cost-effectiveness of labor and equipment-based operations.

Conditions governing the relative costs and productivities of labor and equipment can vary considerably within a single country, as well as from one country to another. The screening process has been developed on the basis of data and conditions in India and Indonesia, and may not necessarily be a world-wide applicability. It is therefore important that these charts and tables be used only as general guides, and with caution, in other countries and conditions. Moreover, they may be used in an economic as well as financial sense using modifications, e.g., excluding all duties and taxes on equipment.

In using these charts and tables certain adjustments in the stated wage rate guidelines may be needed to allow for conditions within a particular country of interest. For example, variations in the relative rates of inflation in the costs of using labor and equipment since mid-1976 might be incorporated by multiplying the quoted rate by the ratio of the current price of representative pieces of equipment, spare parts, and POL to the mid-1976 purchase price of these items. Similarly, for the assessment of financial feasibility in a country where import duties are paid on equipment and fuel, the man-day rate guidelines would need to be increased proportionately, while expectations of unusually low productivity would call for a reduction in the rates. Some points to consider in assessing the wage rate to be used in a given case include

1. the wage should be that needed to attract sufficient numbers of people for the current work program;
2. in the case of a legal minimum wage in excess of the market wage, the former should be used for the assessment of financial feasibility;
3. if the wage varies geographically or seasonally, a rate applicable to the particular location and timing of the project should be used; and
4. no additions to the basic daily unskilled wage to cover overhead are needed, as they are already included in the analysis.

Cost-Effectiveness Analysis

The screening process can serve to indicate in a general way the programs, projects, and parts thereof potentially suited to the use of more or less labor in a particular country. In the interests of a more complete financial assessment, three additional levels of analysis arise:

1. construction cost comparisons,
2. total project cost comparisons, and
3. overall project benefit-cost comparisons.

Construction cost comparisons are the most straightforward and frequently used analyses for evaluating alternative technologies from the level of individual activities or tasks to the overall project. The main shortcoming of these comparisons is the inability to account for differences e.g., product quality, project design, and timing arising from the use of alternative technologies) that may influence future project costs and benefits. In the case of low-volume roads it is often possible to keep these differences to a minimum through technical equivalence among designs. If this is not possible, the analysis might be extended to a total project cost comparison in which maintenance and user costs are also evaluated.

If a wide range of projects is to be compared, a fuller spectrum of project benefits and costs may be included in overall project benefit-cost comparisons. The developmental impacts of the road, in the form of generated traffic and induced agricultural production, are often relevant benefits in the case of low-volume roads. Moreover, introducing new technologies for construction may generate significant costs and benefits beyond any single project through the simultaneous development of social institutions like health and nutrition services and support activities like contractor training and development, and small tool improvement and production. Some of these costs may be accounted for in project overheads, but others may need to be dealt with more explicitly.

Each of the three levels of analysis is discussed in turn below, with major emphasis on the first.

Construction Cost Comparisions

Financial viability of alternative methods of construction is a direct function of the factor productivities and prices, project quantities, and other costs (overhead) associated with construction. Construction cost comparisons for a financial feasibility analysis entail:

1. identification of the number and type of construction activities and tasks, and an estimate of project quantities;
2. identification of technically feasible alternative technologies of interest for each activity or task, and assessment of the required resources and their productivities;
3. determination of the market, or prevailing prices of the various resources;
4. calculation of the unit cost of each alternative (multiply productivities in step 2 by prices in step 3 and sum across the resources);
5. calculation of the project cost of each alternative (multiply unit costs in step 4 by project quanties in step 1 after adjusting for the particular technology if necessary);
6. evaluation of indirect, overhead, and any other costs associated with each alternative (may be expressed as lump sum cost, as factor to be applied to unit cost in step 4 or project cost in step 5 and carried through, or as factor to be applied to resource prices in step 3 and carried through);
7. calculation of the total construction cost of each alternative (add direct and indirect costs in steps 5 and 6, respectively); and
8. after doing this for all activities and tasks, calculation of total construction costs for rational combinations of alternative technologies (sum across activity/task costs in step 7).

Comparisons among alternative technologies may thus be made at various points along the way at the activity/task and project level. This assessment procedure remains relatively straightforward as long as the number of activities/tasks and technologies is limited, or where there is limited interest in mixing the technologies.

In a country where labor-based methods are being considered for the first time, local experience and basic data needed for cost comparisions may not be fully available. Chapter 2 discusses breaking the construction process into various activities/tasks and gives an indication of the range of labor-equipment mixes potentially available. To keep the assessment manageable, activity/task identification should concentrate on a small number of important and technically flexible activities/tasks; this includes those representing a major portion of project costs, and those upon which important activities/tasks might depend. Estimation of project quantities associated with each of these is primarily of concern in situations when the quantities might vary with the construction technology, as in the case of design varying with technology, or labor working to closer tolerances and more selectively than equipment.

The sensitivity of factor productivities to environmental and institutional conditions is also observed in Chapter 2. Nevertheless, the various manuals and handbooks available and forthcoming (**2, 6, 7, 18**) do have significant inventories of alternative methods and associated data that may prove useful in preliminary estimates, as well as suggestions for modifying these data in light of country and local conditions and for collecting further productivity data. Elimination of certain technologies may be possible at this point in the assessment due to their having particularly low productivities relative to similar alternatives (e.g., in transporting soil a given distance, where the productivity of labor using shovels is half that using wheelbarrows), or to the existence of certain work attitudes (e.g., men refusing to use headbaskets). The alternative technologies under consideration must be technically feasible in terms of the criteria discussed above and the required resources available. Assessment of resource demand, supply, and balance is a consideration at the project level as well as activity/task level; Table 24 and Figure 25 demonstrate a rather detailed resource analysis for a 3-km flood control embankment project as an example.

Converting these physical productivities to a cost basis for comparision requires assessment of the prevailing prices of the various factors of production, namely labor, equipment, tools, animals, and materials. Foreign exchange components might best be handled separately. In the case of labor, hourly wage rates for different types of labor are needed. This information may be most readily obtained from a labor market survey in the project area. Estimating these rates requres information about how the wages are determined (e.g., market forces, government, unions), origin of the labor force (e.g., local area, imported), competing demands for the labor (e.g., agriculture, other construction projects), and seasons during which work is to be done (e.g., sowing, harvest, other). Estimates of the equivalent of payments in kind, like food and clothing, as well as taxes, insurance, and other items directly related to the hourly wage should be included in the rate. In performing cost comparisons, the wage used must be sufficient to attract the labor needed for project execution.

Table 24. Analysis of daily resource requirements for alternative methods of constructing two 3-km flood control embankments (**8**).

				Labor and Capital-Based Methods								
Operation	No. of Work Days	Quantity	Method	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Remarks
Site Strip	112	720,000m²	Labor Based	20 laborers; 12 buffaloes; 8 ploughs; 4 scrapers								Lead time, two weeks
	120		Capital Based	1 dozen; 1 laborer; 1 operator								
Excavate	160	384,000m³	Labor Based	24 laborers; 24 buffaloes; 24 ploughs								
			Capital Based	4 scrapers; 4 dozers; 8 operators; 8 laborers								
Load	160	384,000m³	Labor Based	300 laborers								For capital based, excavate, load, haul & tip all in one operation
			Capital Based	As for excavate								
Haul & Tip	160	384,000m³	Labor Based	240 laborers; 240 buffaloes; 240 carts								
			Capital Based	As for excavate								
Spread	160	384,000m³	Labor Based	20 laborers; 20 buffaloes; 20 scrapers								
			Capital Based	3 graders; 3 operators; 3 laborers								
Compact	160	384,000m³	Both Capital	3 rollers; 3 water tankers; 6 operators; 3 laborers								
Grass Slopes	25	180,000m²	Both Labor							144 laborers		Grass in May, light rains
The Whole Project	200	—	Labor Based	38 supervisors			36 supervisors			6 supervisors		Local supervisory staff
			Capital Based	6 supervisors			6 supervisors					

The hourly price of engine-powered equipment should include ownership costs of depreciation, interest, maintenance and repair, and miscellaneous items such as insurance, tax, and storage, as well as operating costs of fuel, lubrication, tires, and other equipment consumables. Estimation of hourly equipment rates involves certain basic data and assumptions as to purchase price, equipment life and utilization, fuel consumption, interest rate, maintenance and repair facilities, and so forth. Technical Memorandum No. 10 (see **11**) covers equipment costing in some detail. Standardized hourly hire rates may already be available and can be used as long as they include the various cost components. For animal-powered equipment, animals, and simple tools, the primary cost components are the capital outlay and maintenance. Workers on the project may own these resources and may receive a higher hourly wage to cover their expenses. Alternatively, these may be owned by the public works department or contractor, or may be purchased from the public works department by the workers in the course of their employment. In any case, an hourly rental rate may be developed using a scaled-down version of estimating rates for engine-powered equipment. Materials are priced in quantity terms where the price includes purchase or production and transport costs. These are of concern in the cost comparison only in situations where the amount, type, and/or method of production might vary with the factor mix used in construction.

Overhead costs associated with a road project might be grouped as those associated with project logistics and those with management and administration on and off the site. Logistical costs may include transport and set up of equipment and tools; transport of workers; temporary structures for storage of materials, tools, and equipment; and camps for the workers, including facilities for health and sanitation, eating, and sleeping. The number and magnitude of these cost items depend upon the type and location of the road project as well as the factor mix used in its construction. Estimation of trans-

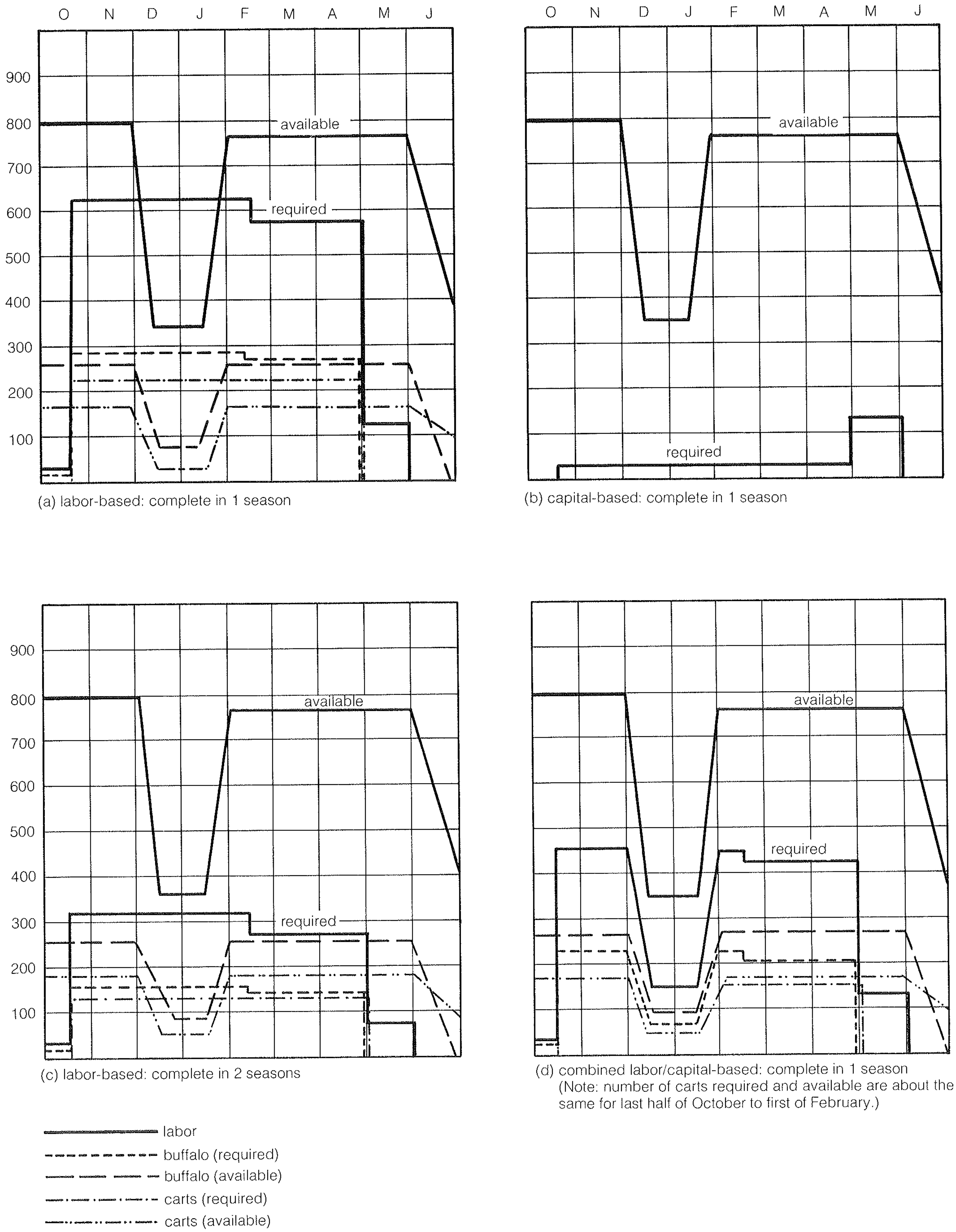
Table 24. (Continued)

Operation	No. of Work Days	Quantity	Method	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Remarks
				Combined Labor and Capital-Based Methods								
Site strip	112	720,000m²	Labor Based	20 laborers; 12 buffaloes; 8 ploughs; 4 scrapers								
Excavate	160	236,250m³	Labor Based	18	18	5	5	17	17	17		Same number of laborers, buffalos and ploughs
Load	160	236,250m³	Labor Based	225	225	63	63	213	213	213		Laborers
Haul & Tip	160	236,250m³	Labor Based	180	180	50	50	170	170	170		Same number of laborers, buffalos and carts
Spread	160	236,250m³	Labor Based	15	15	4	4	14	14	14		Same number of laborers, buffalos and scrapers
Excavate, Load, Haul & Tip	160	147,750m³	Capital Based	1	1	2 2	2	2	2	1		Each unit is 1 scraper, 1 dozer, 2 operators, 2 laborers
Spread	160	147,750m³	Capital Based	1	1	1 2	2	2	2	1		Each unit is 1 grader, 1 operator, 1 laborer
Compact	160	384,000m³	Capital Based	3 rollers; 3 water tanks; 6 operators; 6 laborers								
Grass Slopes	25	180,000m²	Labor Based							144 laborers		
The Whole Project	200	—	Labor Based Capital Based	24 4		8 4		24 4			6 6	Local Supervisory Staff

port costs for equipment and tools requires information as to transport distances, tonnage of transported goods, and unit vehicle transport costs; set up and dismantling costs may be expressed as a function of purchase price; transporting labor for projects removed form the vicinity of the labor supply may be on a daily basis. Table 25 gives a sample calculation of such costs. Note also that in the sample calculations shown, an approximate 15 percent reduction in production time per day occurs for a 5-km haul, and an approximate 33 percent reduction occurs for a 20-km haul (unless starting times are staggered, in which case the trucks must be used more than 8 h). The productivity of the crew and equipment must be reduced to account for nonproductive travel time. Storage facilities and workers' camps entail building costs, including transport of goods to and from the site, erection and dismantling, depreciation of the facilities, and operating costs including provision of food, health care and other services, and upkeep. Logistical costs like these are most readily included as direct add ons to resource costs. In India, for example, contractors report costs for migrant workers living in temporary grass houses as some 10 percent of their wage rate (transport: 3-7 percent; housing, water, firewood: 5 percent) (2). In a feasibility study of the Indus Super Highway in Pakistan, site workshops were estimated at two percent of equipment costs and labor camps at two percent of unskilled labor costs (5). The share attributable to logistical overheads, however, might be expected to vary inversely with the scale of the project.

Managerial and administrative overheads on the site may include staff personnel, office and housing facilities, and site transport. The size of the staff may be rather large if labor-based construction techniques are to be used, labor camps are necessary, or unskilled workers are to be paid in cash and kind. As for off-site overheads, these may include staff, office, transport, and related expenses of the regional branch and/or headquarters of the concerned governmental agency, and activities like health and nutritional services, tool and contractor development, and overall program planning. In comparing two reasonably similar technologies, overheads above the site level and even certain site level ones may reasonably be ignored. Comparison of extremes in technology, however, may necessitate evaluation of all overheads. Including the broader support activities (health services, tool development, etc.) is probably best handled in an overall project benefit-cost analysis. Allocation of managerial and administrative overheads among the resources and activities/tasks of con-

Figure 25. Availability analysis of resources for alternative methods of constructing two 3-km flood control embankments (**8**).



(a) labor-based: complete in 1 season

(b) capital-based: complete in 1 season

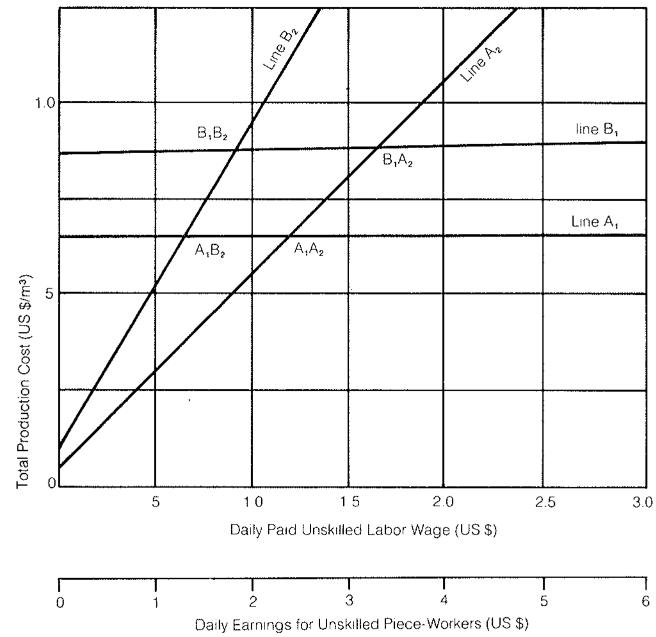
(c) labor-based: complete in 2 seasons

(d) combined labor/capital-based: complete in 1 season (Note: number of carts required and available are about the same for last half of October to first of February.)

Table 25. Sample calculation of daily transport of labor to site (**2**).

Assumptions:		
Labor wage	$ 1.00/day	
Flatbed truck 10-ton, rate including fuel, driver, etc.	$10.00/hour	
Average travel speed	30 km/hour	
Average distance per trip to pick up labor, one way (i)	5 km	
(ii)	20 km	
Turnaround time per trip (loading, waiting)	10 minutes	
Truck capacity	50 men	
Number of trucks per labor unit of 500 men	5 vehicles	
Calculations:	Pick-up distance (i) 5 km	(ii) 20 km
Trip time, out and return, home	0.5	1.5
No. of truck-trips per day (morning and evening), 2x500/50	20	20
Labor transport input veh-hr/day (=trips x time)	10	30
Labor transport cost, per day	$100	$300
Total truck input, hours per day, 5 x 8	40	40
Total labor wage cost, per day, 500 x $1	$500	$500
Conclusion:		
Percent of total truck input spent on labor transport	25%	75%
Cost of labor transport as percent addition to wage bill	20%	60%

Figure 26. Break-even man-day costs for the earthworks task with 60-m haul distance and average topsoil in India (**13**).



Note: 1976 prices. Total production cost includes overhead. Pieceworkers spend more time per day on the site and a greater portion of their time working, resulting in daily earnings about twice those of daily paid workers.

Task includes excavate, load, haul and spread in borrow-to-fill work.

Subscripts 1 and 2 correspond to different construction methods:
[1]D7 dozer and
[2]Wheelbarrow and labor.

Lines A and B correspond to different sets of institutional conditions:

A: Good supervision/site organization and incentive payments to labor (e.g., in the labor-based case, this entails piecework payments and good supervision in contract work—overhead runs maybe 70 percent of direct costs).

B: Poor supervision/site organization and no incentive payments to labor (e.g., in the labor-based case, this entails daily paid work and poor supervision in force account work—overhead runs may be 30 percent of direct costs).

struction is difficult; a time or cost basis is possible as an approximation. As an example of the distribution of construction costs, figures for Kenya's experience in the labor-based rural access roads at the end of 1979 as a percentage of total construction costs are labor, 36 percent; equipment, 20 percent; materials, 6 percent; site overhead, 16 percent; regional support overhead, 12 percent; and headquarters overhead, 10 percent.

Alternative technologies may thus be compared at the activity/task level on the basis of unit costs or project costs, with or without overhead costs included, and at the overall project level on the basis of direct or total construction costs. Care must be exercised in making these comparisons, however, in that certain costs, overheads in particular, may be sensitive to the blend of capital and labor and the scale of operations. Moreover, mixing of technologies may encounter some difficulties in that activities/tasks are often not fully independent. For example, certain items of equipment (e.g., trucks) may be used in more than one operation, and their substitution may affect their overall utilization rate on the project; or scheduling of labor-based operations followed by equipment-based ones may be a problem. The best and more appropriate approach, particularly in the case of low-volume roads, is probably a simple tabulation of the results, and common sense that leaves room for judgmental decisions as to reliability of costs, balancing of resources, and so forth, where cost differences among alternative combinations of resources may be small. Table 26 gives an indication of the kind of resource and cost table that might be developed for comparison or selection purposes.

This same basic analysis may be undertaken for a range of labor wages in order to determine the break-even wage. Figure 26 shows a graphical assessment of the break-even wage between two methods of short-haul earthwork in India. The International Labour Office manual on labor-intensive road construction (7) extends the analysis to situations where more than one factor may be uncertain, but may be confined to a range of values. Break-even analysis may then be used to determine the maximum and minimum break-even values for unskilled labor productivity, wages, and equipment hire rates for two combinations of resources.

Total Project Cost Comparisons

Variation in product quality and design in conjunction with alternative methods of construction is discussed earlier in this

Table 26. Sample tabulation of resources and costs for various construction tasks (**2**).

Task	Resource	Quantity of Work (q'ty units)	Forecast Productivity (units/ resource day)	Resource Days Required (number)	Lost Time Factor	Effective Working Days (number) TT	AT
		(1)	(2)	(3) −(1) (2)	(4)	(5)	(6) −(5) ×(4)
ELHUS earthwork, haul 20 average soil	labor	72,000 cu.m	2.0	36,000	0.9	200	180
	wheelbarrow		4.0	18,000	0.9	200	180
ELHU gravel, quary to roadside, haul 2km	labor	12,000 cu.m	1.5	8,000	0.9	200	180
	tractor, 50hp (incl. driver and assistant)		30	400	0.8	200	160
	trailer, 5t		15	800	0.8	200	160
ELHUS water for compaction, haul 1 km	tractor, 50hp (incl. driver and assistant)	4,000 cu.m (i.e., 4ml)	40	100	0.8	200	160
•	water trailer, 4000 L		40	100	0.8	200	160
•	labor (say 4 per trailer)		10	400	0.8	200	160
• • • • • etc.							

Note: ELHUS = excavate, load, haul, unload, spread
AT = available time (defined as total time less lost time)
TT = total time
Indirect Cost Factor = largely logistical overheads
Overhead Factor-Site = on-site managerial/administrative overheads
Admin = off-site managerial/administrative overheads

chapter. In situations in which alternative design/technology mixes do not produce technically equivalent products, extension of the cost comparison to include maintenance and user costs is necessary. Certain trade-offs clearly exist between the initial road construction costs and the future road maintenance and user costs; the situation is similar between maintenance and user costs. Construction costs tend to increase with improved design standards, while maintenance and user costs decrease. Flexibility with regard to the technology used in construction also tends to decrease with rising design standards. Cost comparisons in this broader context additionally allow for consideration of staging of the road project (i.e., constructing a new road to a lower performance standard than is projected as ultimately needed, with the expectation of upgrading the road as demand develops). Alternative methods of maintenance and associated policies might also be evaluated.

Financial viability of alternative methods of construction in combination with variations in product quality and design in this context depends upon the sum of construction, maintenance, and user costs, discounted over time. Assessment of maintenance policies, procedures, and costs, road performance and traffic, and user practices and costs, in addition to the evaluation of construction costs discussed above, are the primary constituents of a total project cost comparison.

Maintenance costs are a function of the maintenance policy, road deterioration, and maintenance techniques. The various maintenance activities/tasks of low-volume roads and the spectrum of possible methods of execution are indicated in Chapter 2. The maintenance policy adopted should minimize the sum of maintenance, user, and construction costs. The labor-based maintenance option whereby people living along the road are responsible for its upkeep, as in

Table 26. (Continued)

Units of Resource Required	Direct Rate (U.S. $/day) (AT)	Indirect Cost	Overhead Factor		Unit Cost (U.S. $/unit)			Project Cost (U.S. $)		
			Site	Admin	Direct	Site	Total	Direct	Site	Total
(7) −(3) (6)	(8)	(9)	(10)	(11)	(12) −(8) (2)	(13) −(12) × (9) ×(10)	(14) −(13) ×(11)	(15) − (1) ×(12)	(16) − (1) ×(13)	(17) − (1) ×(14)
200 100	1.0 0.2	1.25	1.2	1.1	0.5 0.05 } 0.55	0.82	0.91	39,600	59,000	65,500
44 2.5	1.0 30.0	1.25 1.05	1.2 1.1	1.1 1.2	0.67 1.00	1.00 1.15	1.00 1.38	8,000 12,000	12,000 13,800	13,200 16,600
5.0	5.0	1.05	1.1	1.2	0.33	0.38	0.46	4,000	4,600	5,500
0.6	30.0	1.05	1.1	1.2	0.75	0.87	1.04	3,000	3,500	4,200
0.6	6.0	1.05	1.1	1.2	0.15	0.17	0.21	600	700	800
2.5	1.0	1.25	1.2	1.1	0.10	0.15	0.17	400	600	700
									• • • • etc.	

Kenya, provides a demand-responsive maintenance that can be appropriate for low-volume roads.

Vehicle operating costs, value of travel time, and composition and volume of traffic flows comprise road user costs. Vehicle operating costs are a function of environment, road geometrics, surface type and condition, and vehicle characteristics. These costs include running costs like fuel, oil, tires, and maintenance, and annual fixed costs like depreciation and interest. Travel time costs pertain to the time value of persons and cargo holding costs; their estimation, although desirable, is difficult both conceptually and operationally. Estimates of expected traffic over the various sections of the road plus the costs for the various vehicle types yields road user costs.

Maintenance and user costs over the life of the road must be discounted to the present value or annualized using the prevailing rate of interest. Combining these with construction costs expressed in similar terms for various combinations of design and technology for a specified project may indicate the least-cost alternative. The International Labour Office manual on labor-intensive road construction (7) discusses the estimation of these maintenance and user costs and the total cost comparison evaluation procedure. It cites several references of possible value, particularly the World Bank and Transport and Road Research Laboratory studies in Kenya (29).

Overall Project Benefit — Cost Comparisons

When evaluating a broad range of projects all benefits and costs should be included, while comparisons among alternative design/technology mixes require including indirect effects only when they differ notably across the alternatives. A change in the alignment of the road that affects the area of influence, or a change in project timing that delays the incurrence of certain benefits and costs might necessitate including them in a cost comparison.

It might be argued that an assessment of indirect effects should be extended to include the costs and benefits associated with such institution building and support activities as contractor and tool development, intervention in nutrition and health, and overall program planning and development that can accompany the introduction of a labor-based program. The forthcoming World Bank handbook (2) proposes handling these costs as off-site overheads directly attributed to the resources in use; this approach, however, fails to include the resultant benefits.

Having evaluated the benefits and costs to be included in the overall analysis, the alternatives may be ranked according to traditional benefit-cost evaluation procedures: net present value, benefit-cost ratio, and internal rate of return.

SOCIOECONOMIC FEASIBILITY

Market or prevailing costs are those costs normally measured in any business transaction. In a normally operating competitive economy the prevailing prices reflect relative factor scarcities such that decisions based on these prices yield an efficient allocation of resources that maximizes social welfare. It is a well-known fact, however, that in many developing and even industrialized countries, the market prices of resources may diverge from their true social costs. Decisions based on these prices, such as those of the profit-maximizing entrepreneur, can thus result in less than optimal use of resources. This calls for redoing the assessment discussed above of the feasibility of alternative means of construction and maintenance of low-volume roads using the social value of inputs and outputs over the life of the project. This is particularly important in cases where the more labor-based techniques do not appear to be financially feasible. Market price distortions in developing countries typically inflate labor costs and deflate equipment costs, thereby biasing the assessment toward the use of equipment.

The shadow or accounting prices used in socioeconomic feasibility assessment may simply reflect the true relative scarcity of the resources (or efficiency prices), or they may go further to reflect certain developmental objectives (or social preferences) as well. Such pricing mechanisms used in this context effectively broaden the single-objective analysis of minimizing cost to a multiobjective analysis, whereby other national goals and social objectives such as growth and equity might be incorporated. It may be appropriate to try various sets of prices reflecting different approaches to the question of optimal allocation of resources available to the economy. Alternatively, application of the concept of utility theory, instead of a pricing mechanism, might be used in the framework of a multiobjective assessment in situations where it may be difficult to measure the various attributes in monetary terms. For the purposes of evaluating the socioeconomic feasibility of various resource mixes in construction and maintenance of low-volume roads, the approach might reasonably be limited to the use of shadow prices. A brief discussion follows of some of the reasons underlying the potential inappropriateness of market prices for analysis, and the development and use of shadow prices in the assessment of construction and maintenance alternatives.

Potential Inappropriateness of Market Prices

Use of market wage rates, market prices, and the official foreign exchange rate in situations where these prices are distorted may lead to the adoption of inappropriate versions of project alternatives. Price distortions may result in wasting scarce resources like capital and foreign exchange and underutilizing abundant resources like unskilled labor. Two examples serve to illustrate the use of adjusted or shadow prices in such situations:

> Unemployed workers in a given country receive unemployment benefits amounting to 40 percent of the current daily unskilled labor wage. If the government uses some of these unemployed workers on productive investment projects, their wage should be valued at 60 percent in evaluating these projects. That is, the government is committed to pay unemployment benefits amounting to 40 percent of the current daily wage whether or not these workers are hired for the proposed projects. A private entrepreneur, on the other hand, should use the current wage rate in his profitability analysis. That is, he will have to pay the hired labor out of his pocket because the government will stop the unemployment payments as soon as the worker is hired; unless, of course, the government reimburses the private entrepreneur for such payments.
>
> In another country the government is considering hiring self-employed workers for a road project. These workers will be paid the current market wage of US$2 a day on the project. At present, however, these workers pick wild berries, which they sell at the end of each day for US$1.5. Daily wages on the road project therefore should be valued at US$1.5 by the government, because each worker hired means a loss of US$1.5 of output daily. The private entrepreneur, on the other hand, should again use the US$2 rate unless the government subsidizes the difference.

The prices of any or all of the resources used in construction, as well as the discount rate, may be distorted when valued in market or prevailing terms under conditions in developing countries. Market rates for unskilled labor tend to be inflated because of governmental policies including minimum wage laws and social security taxes, the influence of unions, and extended family cultural situations.

Imported equipment market prices will be understated if the local currency is overvalued at the official foreign exchange rate. This is often intensified by the availability of foreign loans exclusively for equipment at concessionary rates of interest. The failure on the part of the official exchange rate to adequately reflect the gains or losses to the economy from obtaining or giving up an additional unit of foreign exchange naturally affects all resources using foreign exchange. The net effect is to encourage the choice of technologies that require a high proportion of imported goods and a low proportion of domestic ones.

The market wage of skilled labor and the market price of local materials is also subject to distortion, although the direction is less clear. For example, the production of materials requires use of labor and foreign exchange; their relative proportions determine whether market prices are higher or lower than their shadow prices. A monopoly in the supply of materials might result in the producer setting market prices higher than they might be in a free market situation. Government subsidization of investors through low interest loans may result in lower production costs and thus lower market prices than if interest rates had not been lowered.

The market rate of interest in developing economies tends on the average to be understated, resulting in even further bias toward technologies that demand capital. The interest rate serves as an indicator of the marginal return on capital (in equilibrium in a perfectly competitive economy) that equals the rate of decline of the value of consumption over time; the lower the rate, the slower is the decline. Imperfections abound in the capital market in both industrialized and developing countries. Governments typically impose ceilings on the interest rates applied by a country's financial institutions to encourage investments by small borrowers, favoring con-

Table 27. Costs (pesos) of alternative techniques of building the Capas-Botolan road in the Philippines at market and shadow prices (**4**).

Technical data		Method	Man days (M)	Market	Shadow price	
Item	Quantity		Equipment (E)	price	Low wage high rental	High wage low rental
Clearing and grubbing	22 ha	1	M: 5 256	43 704	20 016	37 620
			E: bullcarts and tools	7 050	4 370	4 370
		2	M: 615	6 238	3 178	5 308
			E: bulldozers and trucks	51 912	49 437	36 237
		3	M: 1 074	9 112	4 311	7 800
			E: bulldozer and handtools	37 426	45 291	33 695
Excavation (average) 100 m haul)	160 000 m³	1 and 3	M: 57 696	569 784	245 703	503 434
			E: bullcarts, wheelbarrows, ploughs and pneumatic roller	246 216	165 715	140 371
		2	M: 2 226	22 505	19 397	20 821
			E: bulldozers, graders, sheepfoot and pneumatic roller	940 829	1 141 653	836 732
Soft rock excavation	2 982 m³	1	M: 5 160	42 246	78 440	36 480
			E: handtools and wheelbarrow	3 080	2 957	2 957
		2	M: 289	4 839	3 046	3 632
			E: dynamite and bulldozer	49 558	41 384	31 590
		3	M: 2 442	21 409	10 491	18 521
			E: dynamite and wheelbarrow	24 006	20 938	19 618
Excavation for structures	790 m³	1	M: 725	6 352	2 975	5 225
			E: handtools from item 105a	0	0	0
		2	M: 651	6 320	2 620	5 443
			E. handtools from item 105a	0	0	0
		3	M: 651	5 332	2 281	4 612
			E: handtools from item 105a	0	0	0
Foundation fill	125 m³	1	M: 36	300	044	258
			E: dump-trucks and payloader	750	638	638
		2	M: 55	458	197	384
			E: dump-trucks and payloader	798	492	347
		3	M: 58	480	195	425
			E: farm tractor and trailers	567	695	467
Overhaul	143 000 station meter	1	M: 900	7 200	2 880	6 300
			E: bullcarts	7 200	3 915	3 915
		2	M: 45	540	432	432
			E: dump-trucks and payloaders	19 830	12 930	9 090
		3	M: 74	740	473	614
			E: farm tractor and trailers	7 602	9 983	6 706
Borrow base (5 km)	11 100 m³	1	M: 3 005	25 992	13 480	22 580
			E: dump-trucks and payloader	89 163	37 308	35 108
		2	M: 329	3 651	2 480	2 817
			E: dump-trucks and payloader	88 260	67 904	47 877
		3	M: 4 330	37 896	18 810	41 000
			E: farm tractor and trailers	68 506	71 046	48 600
Concrete	381 m³	1, 2 and 3	M: 1 308	13 100	2 823	10 870
			E: concrete mixer	11 416	14 096	9 350
Reinforcing steel	34.5 tons	1, 2 and 3	M: 412	3 600	1 680	2 610
			E: iron cutter and bender	290	278	278
Reinforced concrete pipes	645 m	1, 2 and 3	M: 3 656	32 860	18 348	27 708
			E: handtools			
		1, 2 and 3	Materials: concrete and steel bar	172 014	146 682	146 682
Total cost (Cost per km)		1	Equipment, materials and labour	1 282 317	706 448	996 754
				222 624	122 647	173 048
		2	Equipment, materials and labour	1 429 018	1 533 057	1 198 208
				248 093	266 156	208 022
		3	Equipment, materials and labour	1 262 359	783 839	1 023 361
				219 160	136 083	177 667

Note: Methods: 1 = labor-based
2 = equipment-based
3 = modified labor-based

Shadow Price: The low wage-high rental and high wage-low rental combinations give the likely range of the social costs of building the road by alternative techniques

The purely labor-based method was not in fact implemented; both of the other methods were used.

sumption tomorrow as opposed to today. In developing countries where current consumption is already low, however, the tendency is to resist further restraint that may allow future generations a higher level of consumption. As a result, the social rate of discount in developing countries is generally above the market or prevailing rate.

Development and Use of Shadow Prices

Estimating shadow prices and the social rate of discount remains a complex process that is still open to considerable discussion. Numerous alternative formulations exist in the literature, each with certain strengths and weaknesses that are more or less appropriate in particular country or project scenarios. National goals and development objectives enter rather importantly into the derivation of these adjustment factors. It makes sense, therefore, that these be estimated by a team of economists working closely with the public planners for use in the nation as a whole, or at least on a regional basis, and for the various categories of investments facing a developing country. The overall decision to use shadow rather than market prices in project evaluation is a high-level one, and can have a significant influence on the projects to be implemented. In the particular case of technology choice, the socioeconomic assessment of the alternatives might be most appropriately perceived as a complementary tool to the financial assessment. Nevertheless, in the interest of avoiding duplication of work and of keeping the assumptions underlying their estimation reasonably consistent, it is worthwhile centralizing the derivation of the adjustment factors in the national planning agency for the social pricing of alternatives.

Several approaches to the formulation of shadow prices currently exist; the main ones are those of UNIDO (25), OECD/Little and Mirrlees (24, 27), and Squire and van der Tak (26). Much has also been written and discussed on the pros and cons of each and their similarities and differences. The February 1972 issue of the *Bulletin of the Oxford University Institute of Economics and Statistics,* for example, contains nine papers on the UNIDO and OECD approaches. The International Labour Office Manual on labor-intensive road construction (7) may be of more immediate assistance in this area.

In the very simplest of situations and worlds, one might estimate the shadow price of labor along the lines of the two brief examples cited above. However, conditions such as open versus seasonal unemployment, and developmental objectives such as present versus future consumption and rural versus aggregate consumption, clearly have a significant effect on the resultant shadow prices. The use of different approaches to the derivation of shadow prices can similarly affect their values, and potentially the projects ultimately selected for implementation. Although estimated shadow prices may not be completely accurate expressions of the true social value of inputs and outputs, they are generally a better measure of that value than is provided by market prices.

Given a representative set of shadow prices, any of the various levels of the financial feasibility assessment outlined above might be done using social rather than market values for the various inputs and outputs. For example, the screening process might be used to ascertain the potential suitability of certain programs, projects, or parts thereof to the greater use of labor on the basis of the shadow wage of unskilled labor. Table 27 gives an assessment of the construction costs for alternative means of building the Capas-Botolan road in the Philippines under market prices and under two sets of shadow prices covering the range of social costs. Although the labor-based and modified labor-based methods fare well in this particular example, significant changes in cost are evident across the three pricing schemes. Such an assessment of construction costs might be extended as necessary to include maintenance and user costs as well as other quantifiable project benefits and costs, all at prices representing their true social value rather than their market price.

In summary, the assessment of the socioeconomic feasibility of alternative means of construction and maintenance of low-volume roads represents the final step in evaluation. In a situation where using more labor in construction is both technically and financially feasible, it will probably also be economically and socially desirable without going through this final assessment. On the other hand, if the use of labor-based techniques looks technically feasible but the financial feasibility is doubtful, the final step of investigating socioeconomic feasibility is necessary. If this too looks doubtful, and there is reasonable confidence in the shadow prices being used (perhaps most readily achieved by using more than one set), then the proposal to use more labor in this manner might be set aside at least as long as circumstances remain the same. If, on the other hand, labor-based techniques look feasible in socioeconomic terms, they should be seriously considered for the economic and social well being of the nation as a whole. One final point, of course, is the fact that it is the financial cost that represents the actual outlay of money for the road.

CHAPTER 4

Issues In Implementation

At this point, the existence of a wide range of alternative technologies for low-volume road construction and maintenance has been recognized, and a framework within which policymakers, planners, and chief engineers might begin to evaluate these alternatives in technical, financial, economic, and social terms has been identified. In considering the utilization of alternative technologies, a wide variety of issues arises that might be broadly grouped as national and local level concerns. The introduction of labor-based alternatives to rural road programs where equipment was previously used is still in the early stages of experimentation. Much of what can be said at this point is based on the few programs that have been implemented to date in such countries as Kenya, Honduras, and Mexico, and much of what can be said about those programs is necessarily more speculation than experience.

This section of the synthesis draws heavily upon the various manuals that have been or are being published by the International Labour Office, World Bank, and the Agency for International Development, pertaining to the implementation of labor-based construction and maintenance techniques (2, 7, 8, 9). The intention here is not that this section also be a manual, but rather that it present an overview of the issues and concerns that might arise. These are most appropriately discussed in terms of two overlapping levels:

1. the national or program level, which entails more policy-related issues like orientation and goals of the program, financial arrangements, training and contractual procedures, support activities, program organization, staffing, and start-up; and
2. the local or project level, which entails more of the details of planning and implementation at the site such as mobilization and site organization, work scheduling, resource supervision, and project monitoring and control.

The extent of the discussions regarding these various issues is a function both of their particular relevance to the use of more labor in construction and maintenance and of the level of knowledge acquired to date. The manuals cited above should be referred to for the full details.

NATIONAL LEVEL — THE PROGRAM

A labor-based program of low-volume road construction and maintenance can be considered as a rural public works program. The issues and concerns that arise in the course of initiating rural public works programs might be broadly grouped as those pertaining to

1. conception and planning of the program,
2. creating an environment that is supportive of the program,
3. program organization and financing, and
4. start-up and full-scale operation of the program.

Conception and Development

Identification of Program Goals

Rural public works programs by their very nature have multiple objectives and are therefore often seen as an attractive means for addressing the interrelated problems of unemployment, income distribution, and economic growth while at the same time providing needed economic assets. Program objectives can range from concentrating on creating employment to emphasizing the creation of economic assets. Such variations in objectives reflect differences in national ideologies and development models, the nature and severity of underlying problems, and priorities with which governments regard these problems. A country that experiences the problems accompanying widespread rural unemployment might consider a labor-based program of low-volume road construction and maintenance as one of the more promising public works options available to help deal with these problems.

All public works programs generate employment while producing useful economic assets. Public works programs can be classified according to their dominant employment objectives and intended effects on target groups. Four common classification are

1. relief programs,
2. long-term employment programs,
3. income augmenting programs, and
4. low-cost infrastructure programs.

Each of these schemes is useful at different times and under different circumstances; a particular program begun with one set of objectives may move to others over a period of time. However, only asset creation programs are primarily concerned with building or improving real assets like roads, and at the same time increasing the efficiency of unskilled labor. Labor is regarded more as a rational productive resource than as a recipient of income assistance under such programs. Asset creation programs, therefore, address the fundamental structural problems underlying rural poverty, rather than simply trying to relieve the present consequences of the problems.

Assessment of Overall Feasibility

In order to assess the need for and general feasibility of a labor-based program of low-volume road construction and maintenance among other public works activities, planners need detailed information on a number of issues.

First and foremost, data on the extent, location, and seasonality of unemployment and underemployment are required to assess the appropriate size, timing, and location of the program.

Understanding the economic and social characteristics of the target group is important if program benefits are to be adequately projected. To benefit from a public works program, the target group must either be willing and able to be employed in the construction phase and thus receive wages, or be in a position to derive benefits from the operating phase through increased opportunities for employment, enhanced productivity of owned assets, or increased access to services. The reasons behind rural unemployment, the pattern of nonagricultural activities, and other factors affecting the target group's ability and desire to accept additional employment must therefore be known.

To properly plan public works investments, it is essential to have a good assessment of the quantity and quality of existing facilities. For rural road programs this requires information on the existence, location, and condition of rural road assets, and the potential for developing them to meet future demands. Data on future transport needs that may arise in conjunction with investments in other sectors are also required in order to determine the scope for low-volume rural roads and predict program benefits. Data on the nature of income and asset distribution (particularly land) in areas where roads are planned are needed to ascertain the distribution of program benefits. Information on population density, disaggregate unemployment, and the response of labor at different wage rates is necessary to determine whether sufficient numbers of workers might be available for road projects without impairing agricultural activities.

Finally, information as to managerial and technical competence and resources, both public and private, at the local, regional, and national levels is essential for the administrative design and implementation of the rural roads program.

Rural road programs, among other public works programs, can be useful instruments in many countries that experience rural unemployment and poverty. While there is no clear-cut "rural works" profile, the composite picture of a country or region that is likely to be successful in such a program might be as follows: a high dependence on agriculture, heavy population pressures on agricultural resources, settled population patterns, instability in production of food crops, and an administrative capacity sufficiently developed to provide the needed decentralized skills.

Establishment of Initial Program

Successful labor-based programs will extend over several years, will encompass multiple projects, and ultimately will employ thousands of workers. As with any complex discipline, competence in the implementaton and execution of labor-based techniques comes only with experience. Field studies by the World Bank and the International Labour Office confirm that the most pressing need for assistance in developing this competence occurs during initial program development. Once under way, well-managed labor-based programs become self-sufficient in subsequent monitoring, justification of candidate projects, and administration.

Labor-based programs cannot be quickly introduced. A long time period is needed to properly validate and sustain labor-based efforts. This is because it is necessary to establish their technical and economic feasibility, including program design as well as data collection and analysis, and to develop their institutional and administrative support requirements. Typical rates of work accomplishment under labor-based methods also must be considered. During this initial stage, a country must mobilize the opinion of its professional civil service behind the labor-based effort — particularly the engineering staff of the road authority. In many instances, the problem of obtaining an enthusiastic commitment may pose a serious obstacle to the successful implementation of labor-based methods. The educational conditioning toward more advanced technologies is well known; accompanying fears of a loss of professional prestige or discrimination in salaries and promotion are other ideas that may be associated with the implementation of labor-based techniques, and these may be further complicated by an attitude that manual labor is undignified and degrading.

Experience has shown that the best way to begin is with relatively small demonstration projects having three objectives:

1. to demonstrate the feasibility of labor-based methods by constructing a reasonable number of small-scale, pilot, rural road projects in various locales and terrains;
2. to build the foundations (mainly through staff training and experience) for the organizational and administrative capabilities needed to support sufficient applications of labor; and
3. to encourage private industries and concerns (e.g., local contractors and hand tool manufacturers) to contribute to current efforts and their future expansion.

Properly administered demonstration projects prepare the way for an eventual full-scale program encompassing many sites and types of rural road projects. However, it is important to recall that demonstration projects will often represent the first organized use of labor-based techniques within a country's socioeconomic environment since shortly after World War II. Project planning, supervision, and monitoring must therefore be careful and complete, lest credibility be lost at this early stage. At the same time, cooperation among the involved public and private agencies must be facilitated, the program staff must be recruited and trained, and all concerned parties must be convinced of the merits of this new approach.

The final step in program development is to determine procedures for program management and control. As an asset creation program, a labor-based rural roads program strives for the efficient use of labor resources throughout program life. This may be done by

1. identifying and designing rural road projects that may be built and maintained competitively by labor-based methods relative to equipment-based techniques,
2. designating labor for selected project tasks for which it is well suited (e.g., short-haul earthworks or selective quarrying), and
3. improving the productivity of the labor (e.g., through better management, enhanced health and nutrition, more appropriate and better quality tools, and training).

This requires that labor-based planning and management during the full-scale program occur interactively at two levels. At the central or national level, planners must be able to initiate and coordinate public sector activities and provide private sector incentives directed toward the successful use of labor-based technologies. A second level exists in close proximity to the dispersed field sites where projects are actually underway. Here the functions are to monitor work accomplishments and costs; administer payments, medical aid, and nutritional assistance to workers; and provide detailed technical supervision and inspection.

The interrelationships between central program planning and site implementation components must be continuous throughout the program duration. For instance, program planning may identify those projects or activities that initially appear to be most favorable for demonstration validation of labor-based methods. Data subsequently collected from pilot projects at the sites may in turn be used to refine these initial technical and cost estimates, thereby influencing future program planning decisions. Similarly, as better field data become available, the need for further monitoring at the site level can perhaps adjust the type, quantity, or detail of data required.

Creating a Supportive Environment

Institutional Measures

The likelihood of program success will be enhanced if certain attitudinal and educational measures are adopted for the professional implementing staff, along with certain contractual procedures for project execution.

Education

Even when administrators and engineers have received an education that should enable them to envisage the use of alternative technologies, their approach may be biased. The environment from which the "best-practice" techniques are standardly borrowed is one in which labor is scarce, hence the tendency to equate efficiency with equipment-based methods. It has repeatedly been demonstrated, however, that labor-based methods of low-volume road construction can be competitive with equipment-based options in low-wage, labor-abundant economies; moreover, wherever they are not, requirements of financial competitiveness must be weighed against those of social and economic desirability. The inclination of the professional staff to use equipment-based methods also stems from the opinion that operational problems involved in managing many laborers can be avoided by using these techniques. While this may well be true, it has been shown many times in many countries that the problems of labor management are not insurmountable.

Also, there are very real problems involved in using heavy equipment in developing countries that should not be ignored, such as shortages of spare parts, late deliveries, cannibalization of equipment, and lack of skilled manpower. Moreover, the cost of equipment breakdowns and underutilization is often left out when assessing the efficiency of such equipment.

Because overly specialized training has at times prevented engineers and technologists from considering alternative solutions to a given problem, diversifying training curricula to include discussions of intermediate or appropriate technologies using practical illustrations should be encouraged. Special seminars and training courses could be organized using material designed to enhance the acceptability of technological alternatives, and demonstration projects could be used to give such techniques social sanction.

Contract Procedures

The contract bill of quantities is a key element in the project documents and bidding process. Alternative designs for all or part of the work or alternative specifications for the required engineering performance to permit the use of labor or equipment-based techniques must necessarily be reflected in alternative items in the bill of quantities. This should leave the bidder free to choose those alternatives that make best use of his particular expertise and resources. Work quantities of similar character are typically grouped together, so that the tendered rates are in effect average rates covering the range of circumstances anticipated. The usual grouping, however, may be inappropriate for labor-based methods (e.g., operations involving haulage) and should thus be varied as appropriate to alternative technologies. It may also be useful to subdivide work items in the way the work is to be carried out and paid for by the contractor, particularly when the contractor is relatively inexperienced or of limited financial resources. Payments for locally obtained materials should be considered in much the same way as for manufactured materials. It may also be desirable to adopt differing methods of work measurement for similar work executed under different technologies. For example, when labor is employed on a piecework basis, work could be measured at the borrow pit rather than measuring the completed work in place in the embankment. Adjustments of this nature should result in a relatively unbiased contract bill of quantities.

Bidders can prepare their tenders based upon these modified contract documents and their perceived financial feasibility criterion (described in Chapter 3). The changes introduced into the terms of bidding and the contract and associated documents to augment their technological flexibility may, however, result in bids that are not directly comparable on the basis of cost alone; they may differ in timing, cash flow, performance, and life, among other factors. Bid evaluation should take this into account as quantitatively as possible, and the methods of evaluation should be made explicit to all bidders at the outset.

Support Activities

Other measures in support of and complementary to labor-based road construction include assistance to local contractors, development of local industry in the form of tool and simple equipment manufacture, and health and nutrition support measures for the workers.

Local contractors can be a vital component in the implementation of labor-based methods of low-volume road construction in the long run, although force account will often be used in the early stages. From the outset, the road authority should be actively engaged in the identification of potential small contractors. These might be foremen of the force account operation, headmen of nearby villages, or small local entrepreneurs engaged in construction-related activities. The potential contractors may initially possess only limited ability to undertake even small projects or portions of projects, as they may typically have few formal skills in contracting or construction management, and may be financially unable to experiment with unfamiliar technologies. Therefore, the identification and development of small contractors should be undertaken as early as possible, so that over time, through a program of training and assistance, a sufficiently large number of local contractors would become available to undertake an expanding volume of work.

This is not to say that the work cannot be performed by force account, or that there are not certain advantages to an in-house approach. An established force account can sometimes be mobilized rapidly, can perform work subject to design and quantity uncertainties, and can generally work to more flexible design and quantity uncertainties, and can generally work to more flexible design standards than can concerns under contract. Furthermore, departmental forces can potentially use technologies and materials that conform more closely to real resource availabilities rather than those evoked by prevailing market prices. Where a local contracting industry is lacking, force account operations provide an attractive alternative to the use of foreign contractors while simultaneously providing the training necessary to eventually establish a local construction capability.

Force account operations generally enjoy greater flexibility because their activities are not subject to the financial sanctions often imposed on contractors—although this also leads to some disadvantages. Because departmental forces are externally financed and do not compete for work, they may have less incentive to maintain or increase cost efficiency because quality and/or volume of production can often be reduced to meet budget requirements. In short, the force account approach may involve a basic conflict of interest that can result in inefficiency and inadequate productivity. Further, the development of a major departmental construction capacity may have a dampening effect on the development of a competitive domestic contracting industry, which would likely be more efficient than departmental forces for the full range of construction activities. The force account agency may eventually dominate all rural road construction and lose sight of its primary functions of administration, coordination, supervision, and maintenance.

In principle, private contractors have the necessary flexibility and incentives to execute rural road construction projects efficiently, although existing contractors often show little inclination toward labor-based methods. Because large contractors have generally developed specialized expertise in using heavy equipment, they are unlikely to consider labor-based technologies, which are perceived as management-based, time consuming, and generally inefficient. Potential labor-based contractors thus seem more likely to arise from the foremen, overseers, and supervisors of force account operations who already are familiar with labor-based methods. Because they are likely to be lacking training in technical and business practices, the potential contractors should be given access to instruction in matters of operational efficiency. It might be profitable for the road authority to set aside sufficient funds to provide the necessary technical advisors with some background and experience in labor-based contracting. Topics to be covered could include the fundamentals of bidding and contract documentation, including specifications, methods of payment, etc.; estimating costs and pricing of bids, including risk analysis; record keeping and programming of works; financial planning and budgetary control; personnel management; and on-the-job training.

Small contractors in general, and those attempting labor-based construction for the first time in particular, may require short-term financing to meet start-up costs, such as labor mobilization, erection of camp sites, and procurement of tools, light equipment, and materials, and during operations to ensure cash-flow and liquidity. However, local contractors typically have no collateral with which to secure commercial credit. The road authority could provide financial assistance through improved payment provisions in the contracts. These might include advances for mobilization and procurement, which could be recovered during contract execution; prompt payment for completed work; alternative mechanisms to the usual performance bonds and bank guarantees for government guarantees for registered local contractors; and reduced level of retention monies — although some should probably be retained throughout the maintenance or warranty period. Working capital loans through the banking sector, as mentioned above, are also a possibility but probably not before the contractors are relatively well established.

Organization and Financing

Administrative Structure

A labor-based program of low-volume road construction and maintenance is in many respects a unique type of development program that requires organization and cooperation at many levels of government and the participation of private interests. As a result, organizational forms and concepts that may be unfamiliar to the professional civil service may be necessary. Given a full understanding of program objectives, decisions must be made as to which agencies and what governmental levels have the capacity to administer the program. Centralized control has proven inadequate in the past; development planners should therefore consider decentralized options available outside the national government for developing an administrative structure that must be innovative, highly flexible, and conducive to internal communication.

Decentralization is necessary for the efficient planning, organization, and implementation of any rural road program for several reasons. First, it is impractical for an overly centralized administrative structure to develop detailed project plans, select judicious locations and implementation procedures, and maintain close and substantive supervision over all project works in a widely dispersed program. Second, including the local population, leaders, and institutions in the process of project selection, design, and supervision helps to incorporate local conditions and needs, enhances interest in and support for the program, ensures proper use of funds and maintenance of completed works, and mobilizes supplementary local resources. Third, the responsible involvement of local administrative and technical agencies in all phases of the project increases their competence and efficiency and enhances their prestige among the local population.

The role of the central government in any large-scale national program remains crucial, nevertheless, because certain policy and planning decisions must of necessity be taken at the national level. Even when functions and powers are delegated to local administrative or technical agencies, there remains the need for some minimal central control over key procedures. Governments intending to initiate ambitious labor-based programs must thus determine at the outset what planning and policy decisions the central government is to make and what powers it will retain; what functions should be delegated and how the recipients of these functions should be determined; and what control be exercised over the recipients of these functions to ensure the achievement of overall programs.

Centralized administrative control over local project activities should include the provision of guidelines for site selection, technical designs, and work procedures; the establishment of systematic reporting and progress monitoring procedures; the establishment of effective accounting and auditing procedures; and frequent inspection of project sites by senior personnel from the agency responsible for the program. Aside from these, the active involvement of local institutions and leaders in project selection and supervision may in itself be the most effective guarantee of proper use of authority delegated to local administrations.

Financing

The administrative organization cannot be expected to accomplish the program objectives without an adequate and continuing budget. The regularity of program activities will depend to a great extent on the timeliness with which the central government allocates program resources to regional and local administrations. Moreover, considerable flexibility in procurement and disbursement procedures will help to ensure the timely supply of labor, materials, tools, and equipment to dispersed project sites. This flexibility could be reflected in granting regular advances, under a predetermined ceiling, to meet project execution costs.

Labor-based methods are often criticized for their slow pace and excessive delays. Preliminary research in India has confirmed this view, although further investigations have shown delays were more often than not due to an interruption in project financing. There is a strong tendency to try to spread a limited budget across to many projects when labor is being extensively employed. This happens less frequently in equipment-based projects because there is more recognition of certain minimum budgets for such sites. Moreover, it is often argued that labor can be more readily hired and fired, while equipment is difficult to shift among sites and expensive to leave idle.

Such attitudes are detrimental to labor-based programs, whether pilot programs or full-scale operations; a labor-based rural road construction program cannot succeed without a guaranteed, long-term budget and regular cash flow. The Ministry of Finance should designate funds solely for program use, with annual allotments directly under road authority control. Positive and persistent action on the part of the road authority in this area is important. The Ministry of Finance may not understand the fragility of labor-based methods, believing they can be interrupted with little consequence; however, intermittent and irregular work schedules will significantly reduce productivity and inhibit rational planning.

Implementation and Operation

Pilot Program

The pilot program serves to demonstrate and test the use of labor-based construction methods on a small scale. It represents a commitment to build a limited number of rural road projects within a relatively short time and at a cost and quality comparable to that for similar works executed by equipment-based methods. If labor-based construction is shown to be feasible on a wider scale, the pilot program will also have laid the groundwork necessary for program expansion by introducing labor-based techniques within an actual working environment; in so doing, the organizational, administrative, and local industrial skills required for a larger program are built. The importance of this work in terms of data collection (apart from its role in asset creation) is in formal undertaking of field observations and reports, analysis of site costs and productivities, and if need be, modification of project design, administration, or support activities. Figure 27 suggests a basic structure for such a pilot program.

These several aspects of the pilot program collectively define what will be termed demonstration projects. Experience has shown that a program of demonstration projects lasting from two to four years is helpful for the introduction of labor-based methods in countries that are unfamiliar with them. Among their important results are staff training and resolution of the unavoidable administrative and organizational problems that arise when an unfamiliar technology is first introduced. However, the most valuable contribution of the pilot program lies precisely in its quality of demonstration. A rural road actually built by hand, at a cost and to a quality comparable with equipment-based methods, not only validates the professional judgments of planners and engineers but also removes any lingering doubts about the appropriateness of labor-based technologies.

The gradual expansion of the pilot program as the demonstration projects progress will allow mistakes and shortcomings to be identified and corrective action taken, while the scope of labor-based methods is still quite limited. Similarly, the road authority will be given the opportunity to collect reliable cost information regarding the use of unskilled labor in actual road construction, permitting refinement of feasibility estimates. In addition, relationships will be established in supervisory staff-labor force ratios, and the costs of labor and staff training will become more certain as actual conditions in the country are taken into account instead of averages from international experience.

Larger Program

Full-scale program implementation represents labor-based rural road construction at maturity (see Figure 28). With technological feasibility already established, central planning can be focused more on the efficient role of labor-based methods in asset creation, which will entail both the construction of rural roads and the enhancement of labor productivity. Thus it is incumbent upon the implementation staff to maintain and expand the institutional framework that is set up during the pilot program, to increase program flexibility through new applications of labor-based methods, and to promote the necessary incentives and support services for laborers and small contractors.

Project Formulation

Appropriate guidelines for project design should be developed early in the program. As a minimum, ranges for the following criteria should be presented, subject to revision as the program progresses:

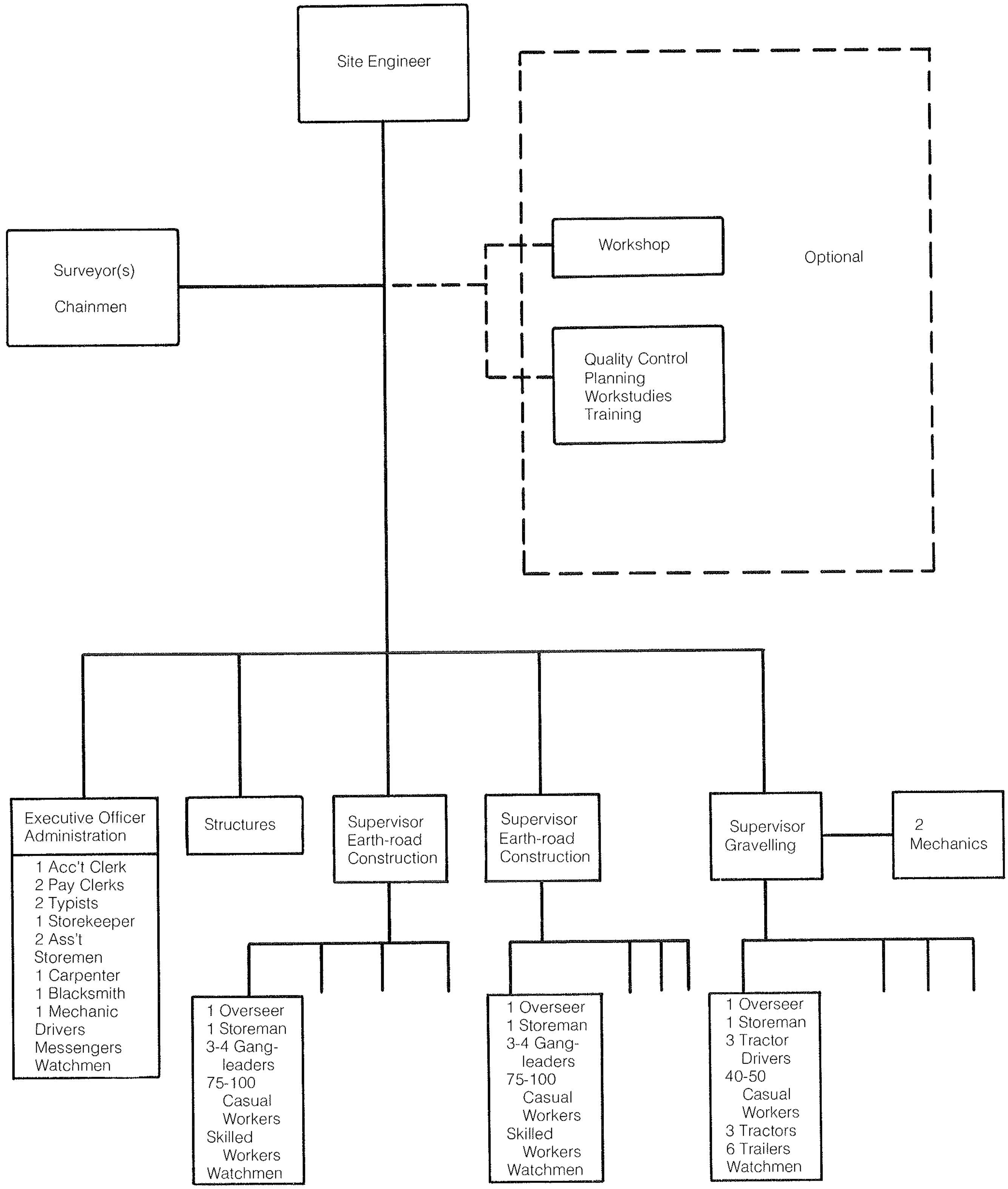
1. appropriate geometrics, including cross-section and alignment;
2. maximum grades for different surface types;
3. appropriate structural designs;
4. variability in project scale and timing to conform with anticipated variations in the labor supply;
5. ranges of costs for different standards;
6. anticipated maintenance requirements for different designs; and
7. labor requirements for different construction tasks and methods.

One of the purposes of the pilot program is to assemble this sort of information, because the lack of cost and productivity data for a range of designs and technologies precludes the identification of the most appropriate formulations of potential projects.

Substantial local participation in project identification is important to the success of the program. Villagers will know best their needs for projects and their capacities to implement them and will have detailed knowledge about the local conditions that are important in project design. Involving the local community also has the important advantage of mobilizing local energies and interests behind the program. If it is "their" project, the chances of creating public involvement and ensuring continuing maintenance are increased. The types of projects eligible under the program, however, should be limited and their range of construction methods clearly defined, with periodic reviews to be sure they accurately reflect the priorities of the program. In addition, attention should be paid to creating long-term employment when deciding which projects to include in the rural road program. Moreover, the long-term effectiveness of the program will depend to a significant degree on the extent to which the road projects are coordinated with other agricultural and rural development activities.

Once potential road projects have been identified, project evaluaters will need to determine the most appropriate combination of route, design, and technology for each project. Other less efficient alternatives may then be ignored when comparing the project against other public investments. To be effective, this process must ensure that for each possible route and desired quality of output, a range of design specifications and construction methods is identifiable and feasible. Where the specified standards appear to require the use of equipment, it is necessary to question not only the need for mechanical equipment but also the routing and specifi-

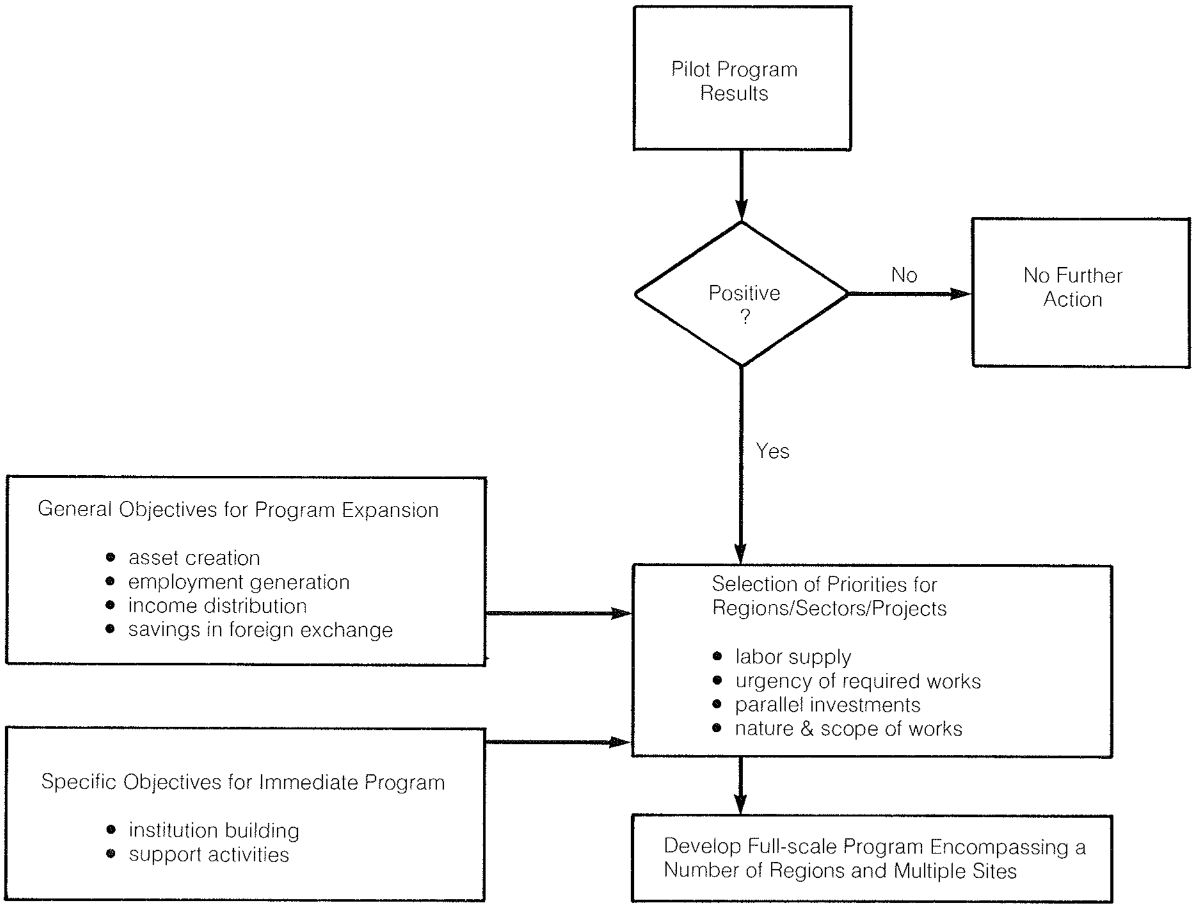
Figure 27. Possible structure of the pilot program (**2**).



cations themselves. The following questions should be posed and answered:

1. Are the design standards specified really necessary on this route?
2. If the design specifications were altered on this route, could an alternative method of construction be substituted that is more appropriate to the greater use of local labor and materials while providing a road of comparable quality?
3. Is it absolutely certain that there is not an alternative way of achieving the desired results by altering the specified route, design, or technology?

Figure 28. Developing the full-scale program (**2**).



If the above issues have been addressed, it is likely that the most appropriate formulation of the project has been identified.

Labor Supply and Services

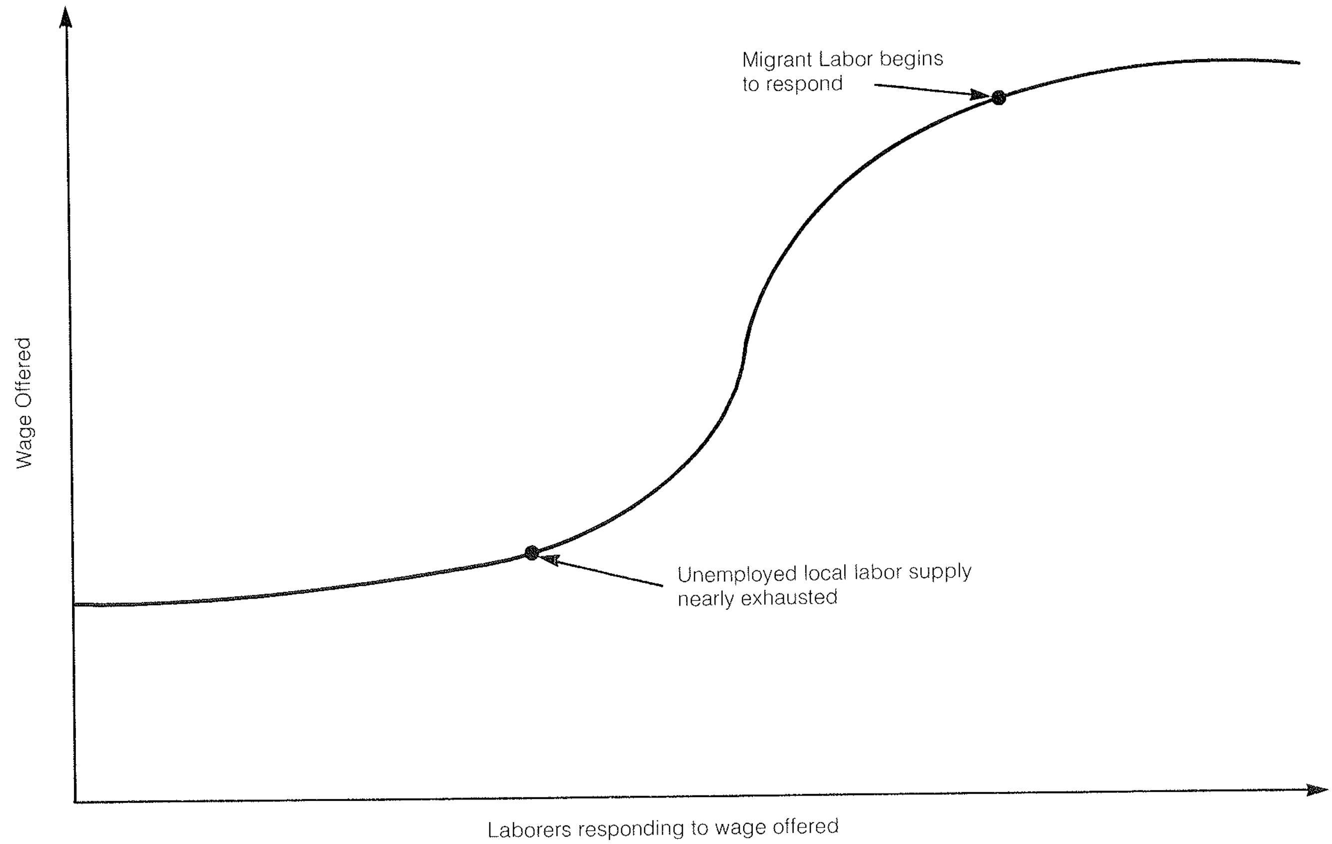
Project engineers must prepare a detailed labor survey on overall conditions prevailing within the program area, including those laborers within walking distance of potential sites and those who may have to be transported or housed. The number of laborers available at a particular time and location depends on a number of factors, principally:

1. the wage offered in relation to prevailing wages and availability of employment opportunities;
2. the conditions of employment, including the method of payment, hire period, housing and medical facilities, nature and social status of the work, and methods of work, among others;
3. the source and type of labor—for example, local versus imported or family/social group versus all male; and
4. the method of recruitment—for example, village leader or labor contractor.

In general, the more labor required, the greater must be the wage to attract that labor, although the shape of this supply curve varies according to local conditions. Experience in India suggests that, as shown in Figure 29, the wage stays near a relatively minimal level until all the genuinely unemployed local workers have been absorbed; if more labor is required, it rises rapidly until it becomes attractive for labor to migrate from other areas, at which point the wage levels off again at this higher value. Although its general shape remains valid, the supply curve is naturally affected by regional wage disparities and seasonal pressures from other sectors, particularly agriculture. Enquiries among local administrators and agricultural lending institutions may indicate the potential size of the labor force at different times of the year and at different wage rates, although precise estimates only come from experience. It is important that projects be selected and designed such that their implementation does not exert undue pressures on the agricultural sector, either in terms of labor availabilities or wage levels.

It is imperative that laborers be paid promptly and in full each pay day. It is equally important to ensure that wages are commensurate with production and vice versa, and that fraud is prevented. The inevitable paperwork that must be done before funds are released by the central authority, whether directly to workers in the case of force account or to contractors in the case of contract work, requires an adequate and competent staff if this is to be done regularly and on time. If food is part of wages, local development organizations or administrations should be enlisted to distribute the food, preferably on rest days or holidays. Payments in cash should be at least monthly, and in food fortnightly. At the initiation of project work, however, it may be advantageous to make payments more frequently.

Figure 29. Possible form of labor-supply curve (**2**).



In some labor-based projects it may be necessary to provide extensive site facilities for the labor force, which may result in sizable project overheads. In cost terms, however, these facilities may be seen as a form of remuneration and an incentive to work; that is, laborers given adequate living and working conditions will respond more readily to management. The size and sophistication of the camp will depend upon the length of time it is occupied and the size of the project. There are, however, certain basic requirements not the least of which is a clean and sufficient supply of water for drinking, cooking, and washing. In difficult cases this may require the provision of water bowsers or drilling of wells. Provision of adequate medical facilities and services is also clearly important, and is a function not only of the size of the labor force but also its general state of health.

The provision of food and other consumer goods is important both from the standpoint of attracting workers and from that of the workers' health and nutrition. International comparisons indicate that a healthy young male can move nearly 3 m^3 of earth per day; nutritional studies in India and Bangladesh suggest that such effort requires 3,000 to 3,500 calories per day. Cereals, such as wheat or rice, provide roughly this caloric quantity per kilogram. Both as a work incentive and to improve the nutritional standards of the entire family, two to three kilos of foodgrain per worker per day has become an international standard, with some programs paying lower commodity wages to women. Food payments serve both to reduce inflationary pressures and to improve nutritional balance and resistance to infection, thereby enhancing worker productivity and morale over the longer term. They can also facilitate nutritional education by acquainting workers with commodities high in food value. Certain problems may also arise, however, both in the acceptability of commodities to workers and in the distribution of rations. Payment in kind may also reduce the incentive for agricultural self-sufficiency and should be limited to workers who benefit directly from the operational phase of the project and to part-time laborers.

Staffing and Training

One cannot overemphasize the importance of good management in relation to the success of labor-based methods. It is the manager after all who must create an environment conducive to high labor productivity. He must not only be technically and administratively competent, but must also be somewhat of a behavioral scientist. He must have a thorough understanding of such factors as ethnic differences, family and village hierarchy, attitude toward work, and psychological involvement of the laborers in his project. At the very least he must ensure that the rates of remuneration provide sufficient incentives, and that the labor gangs are composed such that each member is working with his fellows and not against them. Greater emphasis must be given to those leadership qualities needed to motivate workers over long periods of time; labor characteristics may vary from site to site, requiring different styles and methods of leadership; and tasks that might be performed in a single machine operation may require several labor gangs, imposing the need to coordinate activities efficiently throughout project duration.

Unfortunately, there is a distinct lack of training in such management skills in developing countries, and it may be necessary to launch special programs for this purpose, such as that recently initiated by the Kenyan government for middle management personnel involved with labor-based rural road construction. Such training should be oriented toward supervision in such areas as bid and contract preparation, evaluation of bid submissions, responsibilities of site supervision, compilation of site records, payment procedures and provisions, work allocation and scheduling, and arbitration of disputes and grievances. It is desirable that such programs be regarded as an integral part of the duties of the national road authority so that courses might be directly related to the projects on which the trainees will eventually work.

The training program in labor organization and management should cover all staff and field supervisory positions, and should be available to planners and supervisory engineers from road authority headquarters, field and site supervisors employed by the road authority at the local level, and potential contractors who may replace force account labor as the program develops. In addition, appropriate organizational structures should be created to foster professional advancement at all levels, from senior staff to field supervisors. One way to do this is through the creation of a new operational division within the road authority that is devoted exclusively to labor-based rural road construction, thereby demonstrating the government's long-term commitment to labor-based methods and providing new job and career opportunities.

At levels below that of project engineer in general, and particularly at the overseer level, little formal technical education is needed because on-the-job experience is usually sufficient. A gangleader or headman is normally a casual worker with pay only marginally higher than that of unskilled workers, although he is chosen for possessing that undefinable quality called leadership. He is often the man who has brought a gang of labor to the site during recruitment. The overseer, on the other hand, should be a permanent employee of the road authority or an approved local small contractor. He must be able to perform simple planning and scheduling activities, instruct labor and gangleaders on work methods, control and monitor work performance, and prepare simple reports, although the most important quality is an interest in and aptitude for the motivation and management of labor. Because this quality is often not present in supervisors of machine operations or in staff members of large contractors who are specialists in equipment methods, it is particularly important to develop and promote local small contractors and road authority staff who believe in the potential of labor-based construction methods.

A unit- and site-level organization chart for staffing Kenya's labor-based rural road construction program is illustrated in Figure 30. Such an organization could be expected to build between 100 and 150 km of gravel feeder roads per year for every 1,000 workers employed; the exact output would depend upon terrain conditions, design standards, and construction methods. Given such staffing requirements, it is clear that the availability and experience of supervisory staff and local contractors may be a serious constraint on the rate at which a labor-based road construction program can be introduced.

LOCAL LEVEL — THE ROAD PROJECTS

Local level concerns in labor-based road construction primarily revolve around planning and implementing specific rural road projects.

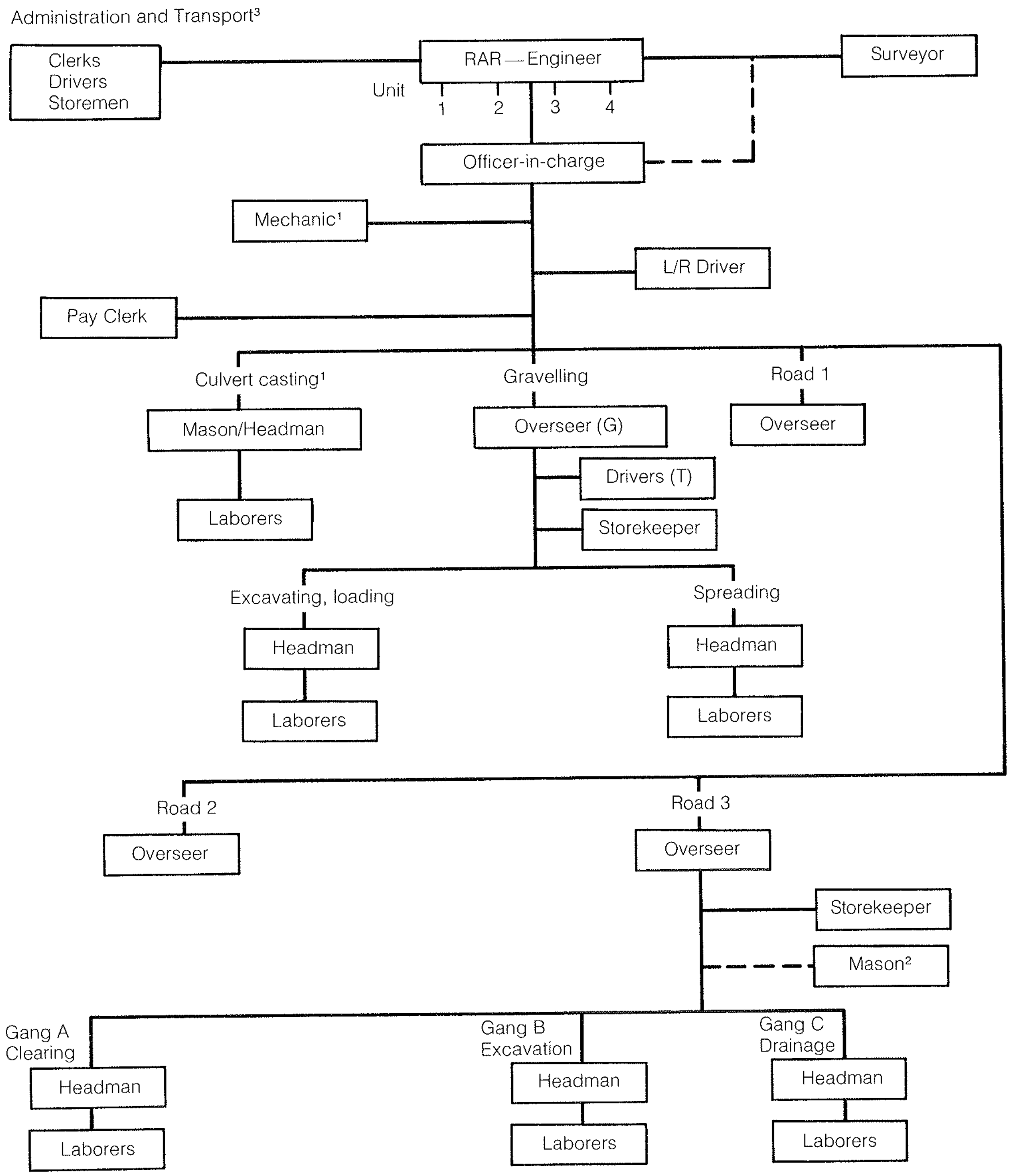
Scheduling the Work

The proper scheduling of work requires the balancing of resource requirements and resource availabilities. Important in any construction operation, scheduling is critical for the successful implementation of labor-based road construction projects. Figure 31 lists the major operations and manpower needs of a sample labor-based road project in Central Africa and shows the sort of labor availability-requirement curves that might prevail.

Given a proposed work schedule, the labor requirement curve in Figure 32 shows exactly what level of resource is needed at any particular time. The labor requirement curve helps in the overall organization and administration of the labor force because it is possible to plan support facilitites relative to the number of workers expected on the job and indicates the weekly wages to be disbursed. More importantly, the labor requirement curve can be compared with the labor availability curve to see where shortfalls and excesses in labor supply might be expected during the project to facilitate advance planning. As indicated in the figure, for example, labor requirements can be expected to exceed labor availability during a part of the peak agricultural season from day 180 to day 260 of the project. The options available in this case might include bringing in additional equipment during this period, reducing the gang size on various operations, or postponing certain preferably noncritical activities until sufficient labor is available. The first option would depend on the availability and cost of bringing in the additional equipment; it would generally be inefficient to bring equipment any great distance for such a short period. The choice between the other options would depend on the feasibility of increasing project duration, the effect on productivity of reduced gang size, and the possibility of rescheduling the project to conform better with the seasonal fluctuations in the labor supply. Such resource balancing can also be used to identify activities in which labor-based technologies might be used, because those that are not critical to project completion times allow greater flexibility in technology choice.

A recent innovation in the planning of civil construction projects has been the use of time-and-location charts. Figure 32 illustrates the use of the technique discussed above for a 5-km section of a road project. The diagram is a graphical representation of the major elements of the project: The plan of the road is drawn at the top of the diagram and chainage points are marked, as are all structures to be constructed that will have a major influence on the project. Other important features, such as areas of unsuitable fill material and the location of villages, can also be shown. However, it is desirable to keep the plan simple. The longitudinal road and ground profile is then drawn under the plan, showing areas of cut and fill and locations of borrow pits. The volumes of cut and fill can be marked directly on this longitudinal section, or if more detail is required, a mass-haul or block diagram can be added beneath the longitudinal section. Finally, the scheduling of work is shown for the project in terms of both time and location (hence the name of the method). The horizontal axis represents location, and the vertical axis time in days, weeks,

Figure 30. Unit and site-level organization chart for Kenya's Rural Access Roads Program (**2**).



(1) Centralized and shared between units wherever possible.

(2) Only when needed for structures, etc.

Note: Labor will be employed as required, but the total number of casual laborers (including headmen) per unit should not exceed 300.

RESPONSIBILITIES	
RAR-Engineer	4 units
Officer-in-Charge:	1 unit
Overseer	1 site
Headman	1 gang

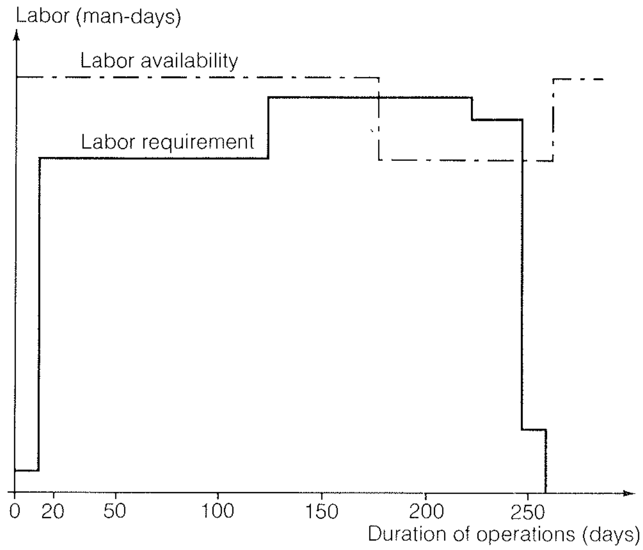
Figure 31. Illustration of labor requirements for a 100-km road construction project in Central Africa versus labor availability (**7**).

A. Labor Requirements:

Operation	Total Man-Days	Suggested Team Size
Opening a quarry	1440	12
Site clearance	840	12
Excavating and loading	34500	150
Hauling and dumping[a]	—	—
Spreading, shaping, watering, compacting	4500	30

[a]By means of dump trucks.

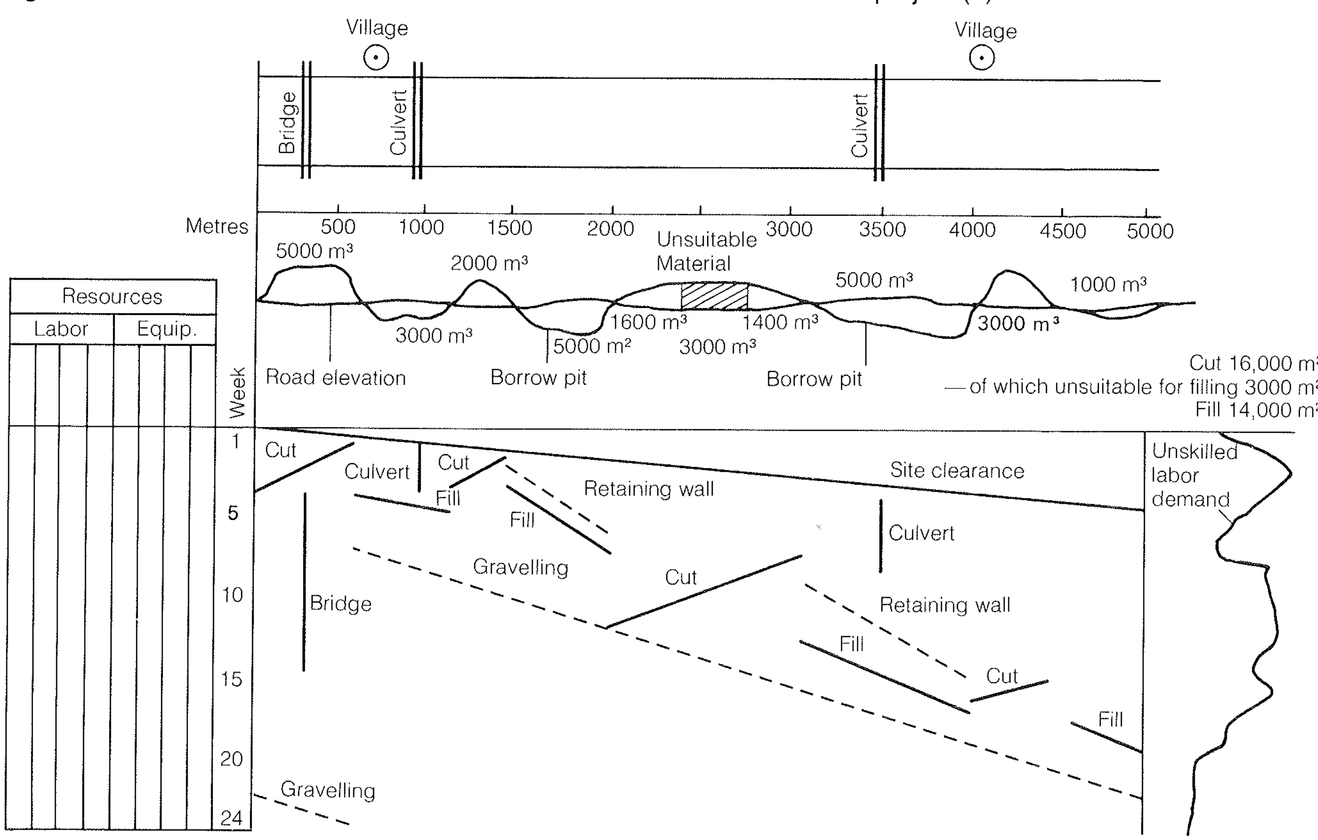
B. Labor Availability Versus Requirement.



or months. Each operation is planned and drawn on the diagram as a line, indicating location and time as well as any dependencies among operations. For example, in the figure site clearance is envisaged as a continuous process from week 1 at chainage 0 (m) through week 5 at chainage 5000; the fill operation between chainages 600 and 1200, on the other hand, cannot be effectively executed until the drainage culvert at chainage 900 is completed.

The important features of the earthworks operation, which is usually the major component of labor-based projects, can be readily understood from such a time-and-location chart. Examining the cut and fill operations in Figure 32 between chainages 0 and 1500, for example, and assuming a maximum efficient haul distance for the labor-based method of 300 m, it is clear that less than half of the cut area between chainages 0 and 600 can be efficiently transported to the fill

Figure 32. Time-and-location chart for 5-km section of a road construction project (**7**).



area between chainages 600 and 1200; the shortfall, however, can be made up by material from the cut between chainages 1200 and 1500, with the remainder from this area taken to the next fill area. By showing exactly where and when the excavated material is to be transported and comparing this with the capability of alternative haul modes, the diagram can be used as a guide to the choice of technology. Conversely, the time-and-location diagram may be adjustable to allow greater use of labor-based methods. Moreover, because the diagram also shows interdependence among operations, it is possible to investigate various ways of scheduling the work. For example, if sufficient resources are available, it would be possible to start at many points along the length of the project at the same time; thus, the site clearance operation, which is shown as progressing along the road, could begin in week 1 at several points along the road, requiring a greater amount of resources but a shorter amount of time to complete the overall operation.

Finally, the diagram can be used to calculate the total resources of various types required on the project during any given time interval, as shown at the left hand side of the diagram. The resource scheduling process can be as detailed or as simple as required. For example, 222 unskilled workers are required in week 5: 50 for the bridge construction; 70 each for the fill operations between chainages 600 and 1200, and between 1500 and 2000; 20 for the culvert at chainage 3500; and 12 for the site clearance operation. Similar calculations could be made for skilled workers, supervisors, and the whole range of equipment and small tools, giving a clear display of the resources required on a weekly basis. On labor-based projects the labor requirements curve might be directly plotted as shown, and the expected labor availability curve superimposed.

The time-and-location chart approach has been successfully used on some large rural road projects where it was well received by site managers and supervisors who found it readily understandable without formal training (7). Because it is relatively simple and efficient, the technique seems rather well suited as a planning tool for labor-based construction of rural road projects in developing countries.

Supervising the Resources

Effective planning and scheduling of labor-based construction methods requires a knowledge of the productivity of the various resources: labor, equipment, tools, and animals. At the same time, the productivities achieved by these various resources in performing their tasks are essential to the relative success or failure of the technologies being used. Although certain technical parameters, such as soil hardness, terrain, and haul conditions, among others, may be largely uncontrollable given project location and type, other key factors affecting labor productivity in particular may be addressed in the project execution stage. These may be broadly grouped under the title of resource supervision, or more specifically labor and worker management, incentives, appropriate tools and training, and worker health and nutrition.

Management

Proper management of labor is one of the most important factors influencing overall productivity. Unfortunately, it is also a very subjective and unquantifiable factor, including such elements as supervision, job organization, labor relations, maintenance of tools and equipment, and administrative arrangements. In addition, the techniques of labor management may vary with project size and from one site to another.

Supervision of the labor force is generally a most important element of labor management, and may be especially difficult for those managers and engineers with little experience in the implementation of labor-based methods. Particularly important is keeping up worker morale. This may entail avoiding needless or redundant tasks such as double handling of materials, and placing manual laborers alongside equipment performing similar work, because the greater mechanical output may be discouraging to the laborers. Also important is prompt payment, and proper setting of daily tasks relative to realistic labor productivity such that labor feels neither exploited nor unnecessary. Closely associated with worker attitudes is good labor relations between the workers and management as well as among workers. This involves effective communication as well as the recognition and accommodation to the extent possible of various social and cultural backgrounds and practices.

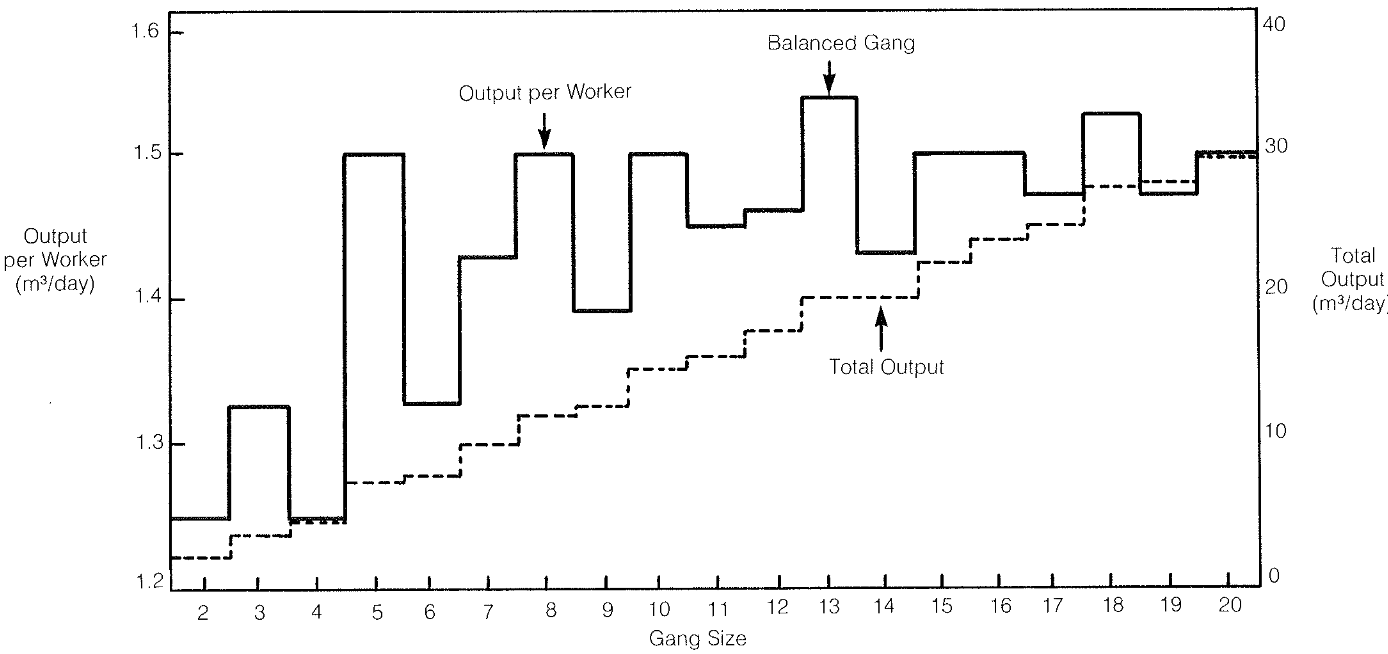
Job organization, apart from job scheduling, can also have major effects on labor productivity. Because it is generally impossible to achieve maximum productivity across all activities within a task, the appropriate organization of overall task productivity, or gang balance, is essential to the implementation of labor-based technologies. A simple example of the gang balance problem is the excavate/load/haul/unload task, using manual excavation and loading by one group of laborers and hauling by wheelbarrow by a second group. For given soil and haul conditions, there will be an optimum proportion of excavators/loaders to haulers for task balance. Figure 33 illustrates the case for gang sizes from 2 to 20, where the most efficient mix is 8 haulers to 5 excavators/loaders. Assuming an actual gang strength of 15, the "extra" laborers may be utilized as follows:

1. 8 haulers and 7 excavators/loaders (each excavator/loader has some idle time),
2. 9 haulers and 6 excavators/loaders (each excavator/loader has some idle time), or
3. 10 haulers (each hauler has some idle time) and 5 excavators/loaders.

In all three cases, worker productivity is lower than that potentially obtainable from 15 laborers. The second case is the most efficient, however, because daily production is equal to the output of the nine haulers; while in the first and third it is equal to that of the 13-member gang because the additional labor is not used effectively.

The above example illustrates how task-level productivity can be obtained by comparing the outputs of constituent activities. The output for a given task is dictated by that activity within the task with the least output. It is also generally true that the more complex a task, the greater the difference between the actual task-level productivity and the theoretical productivity synthesized from the activity-level data. A gang balance allowance of perhaps 10 percent can be included to provide a more realistic estimate of the task-level input coefficients. Stage-level productivities are similarly synthesized from task-level productivities. Proper management techniques can help to reduce time loss through such measures as preventive maintenance of tools and equipment, protection of partially completed works from weather, and maintaining good labor relations.

Figure 33. Productivity versus gang size for the activity of excavate/load/haul/unload.



Notes:
Excavator/loader productivity = 4 m^3/day;
Hauler productivity = 2.5 m^3/day;

Balanced gang is, therefore, 8 haulers to 5 excavator/loaders = 13 workers with total output of 20 m^3/day or 1.54 m^3/day output per worker.

Training

In addition to the requisite tools and simple equipment, labor must possess the skills and knowledge necessary to use them effectively. On-the-job training, through simple instructions/recommendations made in the course of daily work as well as through more formal training sessions on the site is essential to the success of any labor-based construction program. Training of supervisory staff, as discussed above, is clearly an important ingredient in this. Both the site engineer and his supervisors must be willing and able to demonstrate various jobs to the laborers in their charge. Each staff member should be given specific responsibility for training those under his direct command.

In countries with little or no tradition in labor-based technologies, labor productivity is nearly always low initially. Laborers often do not know the proper use of even simple hand tools. Adequate training procedures in the correct handling of tools and avoidance of physical strain are essential to make the work less arduous and the labor more productive. Initially, the main emphasis of training in these cases should be placed on the gang leaders who are in constant contact with the workers. The training should be carried out on the site to enable as many laborers as possible to benefit directly from the demonstrations. Training in the proper handling of tools is more likely to be successful if the workers are convinced that it will help them complete their work more quickly. An often effective approach is placing new workers alongside those with more experience. Manual work is best taught by demonstration: A worker must be shown how to properly use an unfamiliar tool. Even for the most common tasks using the simplest of hand tools, productivity can be substantially increased by proper training of the labor force.

The following points are generally applicable to on-the-job training:

1. Make sure each person is doing the job for which he was trained;
2. Analyze performance without ridicule or causing embarassment, giving credit for good work and suggesting improvements where needed;
3. Make only recommendations that will be directly applicable in the work in the next few days;
4. Use the same terminology and technical language as were used in previous training;
5. Limit the number of recommendations given at one time; and
6. Subsequently return to see if the instructions have been absorbed; if so, offer encouragement, and if not, repeat the instructions.

Monitoring and Control

One of the primary functions of project management is the exercise of effective control over production in order to achieve the proposed work schedule. Of course, this presupposes the existence of a schedule against which results can be measured, with the work schedule itself being based upon predetermined or anticipated performance standards (e.g., project duration, quality, and cost). Therefore, control means not only comparing actual with scheduled production, but also continuously revising the work plan as additional and better information becomes available. Reliable measurement of resource productivity, the ration of output to input for a given set of parameters, and the volume of work involved is essential for both project scheduling and control. Reliable measurement further aids in the calculation of unit costs, development of incentive payment schemes, and future program planning, including validation of the appropriateness of various construction technologies in light of site experience and establishment of productivity standards.

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