# TECHNOLOGY ADAPTATION FOR RURAL ROAD DEVELOPMENT IN DEVELOPING COUNTRIES

by

SAMUEL MINTZ

B.A., M.A., University of the District of Columbia
(formerly Federal City College)
(1969, 1971)

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Signature of Author ____________________
Department of Urban Studies and Planning
January 4, 1979

Certified by ____________________
Karen R. Polenske, Thesis Supervisor

Accepted by ____________________
Ralph Gakenheimer, Chairman
Departmental Committee on Graduate Students

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## ABSTRACT

The widespread application of inappropriate technologies in countries of the developing world is of increasing concern to national governments and the international community, especially under conditions where these countries exhibit capital scarcity and an abundance of labor. The essence of the problem lies in the inability of imported (capital-intensive) technologies to absorb surplus agricultural labor, particularly in rural areas. These technologies evolved under a different set of resource endowments and factor proportions as well as climatic and topographical conditions than those of developing countries. From the standpoint of adapting technology or selecting an appropriate technology, road construction is of special importance, given the amount of capital resource that it generally commands and the fact that it offers a wider range of possibilities for labor-capital substitution than does manufacturing or other civil works projects.

This study investigates the extent to which alternative production technologies involving different factor combinations of labor and capital can be substituted during the construction of rural roads. The study identifies political, economic and technical constraints that bias the choice of technology towards the adoption of highly capital-intensive methods at the planning and design phases of the decision making process.

The above has led to the formulation of a framework for analyzing factor substitution involving, first of all, a theory of labor-capital substitution; secondly, a methodological approach using social-cost benefit analysis techniques; and finally, the criteria which a design decision must

depend upon. All of these combine to form a rational decision making basis for project planners and engineers to adopt socially optimum or appropriate technologies.

Thesis Supervisor: Karen R. Polenske

Title: Associate Professor of Urban and Regional Studies

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I wish in addition to express my gratitude to all of my friends whose continued encouragement enabled me to complete this thesis. I am also grateful to Ms. Kat Gallagher for her patience and superb typing.

Finally, I wish to extend my wholehearted thanks to my family, particularly my mother, whose confidence in me was overwhelming, and to dedicate this thesis to the peasants of Africa, Asia and Latin America whose immense contributions to national development are oftentimes overlooked by development planners and national decision makers.

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# CHAPTER 1

# INTRODUCTION

There is a growing need for development planners to pay closer attention to the appropriateness of modern technologies used for rural road construction in the countries of Africa, Asia and Latin America. Recognition of such a need is primarily based on the observation that rural road technologies or techniques of production widely applied in developing countries are in many respects unsuited for their development needs.[1] Typically, these technologies are highly capital-intensive and the magnitude of their required investment in terms of capital are quite considerable. This creates a situation that is generally unfavorable to developing countries whose capital is in relatively scarce supply and whose labor endowments are in abundant supply. Under these circumstances, the situation is far from being satisfactory and has resulted in unemployment and underemployment in most developing countries.[2]

## 1.1 Capital-Intensive Technologies

Generally speaking, capital-intensive road technologies are highly productive and can quite often provide quick solutions to basic problems of creating infrastructural facilities to support the development of natural resources within certain market factors.[3] However, the evolution of Western technology is, in fact, the direct result of objective conditions prevailing in the countries of Europe, North America and Japan. These countries have a different set of factor endowments and factor proportions with respect to their human and natural resources, as well as different climatic and topographical conditions. Thus, the wholesale introduction of these technologies into countries of the developing world usually raises more problems than they can solve. They are often costly relative to the incomes of the local population, they require a social infrastructure which usually does not exist, and their disruptive cultural consequences tend to be more sudden than in their countries of origin. But perhaps the most serious of all are the consequences that result in the unemployment and the underutilization of the labor force.[4]

As far as appropriate technology for rural road development is concerned, solutions to this problem will necessarily require agencies and governments to be far more selective in the choice of technology--i.e., imported equipment, plants, and method of production--that they adopt to accomplish their development objectives.

Since at present the prevailing practices of road construction by private contractors and, to a large extent, by most government agencies in developing countries are

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* In this thesis, the reader will note that appropriate technologies and optimal technologies are used interchangeably and are defined as a set of alternative factor-combinations that maximize social savings under localized conditions. We do not insist that alternative technologies exist in all circumstances, but that historically biases against such have been to some extent economically and technically unfounded.

highly capital-intensive, a shift in the production techniques could result in substantial employment generation. This would be especially important in rural areas where employment is generally underutilized, underemployed and characteristically seasonal in nature.[5]

The table below (Table 1.1) indicates different construction technologies for rural road projects in Nepal by comparing the ratio of capital to labor. The table reveals the substitution possibilities in different stages of construction process given Nepalese conditions. It is interesting to note the category of standard labor-capital input ratios as against the technology applyed by the Chinese in all of the construction operations. While it is not entirely clear from the table what is meant by the category standard, it is presumed to refer to some internationally accepted practice. The point, however, is that alternative technological choices for road construction are available to national and regional governments in the developing world but, for reasons that will be determined by this study, alternative (optimal) technologies are excluded from the decision making process.

## 1.2 The Employment Problem

It has been estimated that in the 1970's and most of the 1980's the labor force in the developing world (excluding the Peoples' Republic of China) will grow at an annual rate of 2.5 per cent[6] (See Table 1.2). Before 1940, it was about

Table 1.1

Capital-Labor Input Ratios for
Different Road Construction Projects in Nepal

| Stage of Construction | Chinese | Indian | Nepali | British | Russian | Standard |
|---|---|---|---|---|---|---|
| | Project Constructed By | | | | | |
| 1. Site Preparation | | | | | | |
| Cost (per $10^4m^2$) | 5,660 | na | na | na | 10,564 | 3,936 |
| Capital-Labor Ratio | 0 | na | na | na | 21.93 | 4.96 |
| 2. Earthwork | | | | | | |
| Cost (per $10^4m^3$) | 121,144 | 75,159 | 55,457 | 137,748 | 210,352 | 94,421 |
| Capital-Labor Ratio | 0.20 | 1.16 | 0.03 | 3.79 | na | 10.80 |
| 3. Sub-Base/Base | | | | | | |
| Cost (per $10^4m^2$) | 59,492 | 79,376 | na | na | 41,428 | 49,307 |
| Capital-Labor Ratio | 2.31 | 0.60 | na | na | 20.51 | 40.09 |
| 4. Surfacing | | | | | | |
| Cost (per $10^4m^2$) | 14,128 | 69,518 | na | na | 57,074 | 23,884 |
| Capital-Labor Ratio | 2.21 | 13.57 | na | na | 11.55 | 19.25 |
| 5. Total Project | | | | | | |
| Cost (per km) | 420,625 | 325,782 | na | na | 701.054 | 332,168 |
| Capital-Labor Ratio | 0.32 | 1.18 | na | na | 174.79 | 11.99 |

Note: These were costs and labor-capital ratios observed for Nepalese construction projects. The costs are expressed at market prices in Nepalese currency (Rs10.10=$1U.S. in 1973). The capital-labor ratio is the cost of capital divided by that of labor.

Source: Hans, D. and Binayak Bhadra, Comparative Evaluation of Road Construction Techniques in Nepal, Parts 1-4, Preliminary Report prepared for the International Labour Office (Geneva: December 1973).

Table 1.2

Estimates of the Growth of the Labor Force in Developing Countries: 1950-1980

| | Percentage Rate of Growth | | | | | |
|---|---|---|---|---|---|---|
| | 1950-1965 | | 1965-1970 | | 1970-1980 | |
| | Total | Annual | Total | Annual | Total | Annual |
| Developed Countries | 17.6 | 1.1 | 15.8 | 1.0 | 10.0 | 1.0 |
| Less Developed Countries | 28.1 | 1.7 | 39.0 | 2.2 | 25.2 | 2.3 |
| REGIONS | | | | | | |
| Other East Asia | 30.7 | 1.8 | 56.5 | 3.0 | 35.3 | 3.1 |
| Middle South Asia[a] | 23.2 | 1.4 | 33.1 | 1.9 | 21.6 | 2.0 |
| Southeast Asia[b] | 32.3 | 1.9 | 43.0 | 2.4 | 28.0 | 2.5 |
| Southwest Asia[c] | 31.8 | 1.9 | 50.4 | 2.8 | 31.3 | 2.8 |
| West Africa | 38.9 | 2.2 | 40.2 | 2.3 | 25.8 | 2.3 |
| East Africa | 21.1 | 1.3 | 30.8 | 1.8 | 19.8 | 1.8 |
| Central Africa | 16.0 | 1.0 | 19.4 | 1.2 | 12.9 | 1.2 |
| North Africa | 17.5 | 1.1 | 45.7 | 2.5 | 29.0 | 2.6 |
| Tropical S.America | 48.3 | 2.7 | 55.6 | 3.0 | 34.7 | 3.0 |
| Central America | 52.0 | 2.8 | 62.7 | 3.3 | 39.1 | 3.4 |
| Temperate S.America | 25.7 | 1.5 | 25.0 | 1.5 | 16.0 | 1.5 |
| Caribbean | 31.1 | 1.8 | 40.6 | 2.3 | 25.8 | 2.3 |

Note: Excludes Sino-Soviet countries

a Includes Ceylon, India, Iran and Pakistan
b Includes Burma, Cambodia, Indonesia, Malaysia, the Philippines and Thailand
c Middle Eastern countries

Source: Turnham, D. *The Employment Problem in Less Developed Countries: A Review of Evidence*, Employment Series No. 1, Development Center Studies (Paris: O.E.C.D., 1971).

1.0 per cent. This situation is already serious with "open employment" in countries in Africa, Asia and Latin America (See Tables 1.3 and 1.4). After examining the extent and nature of unemployment in Southeast Asia, Oshima concludes that:

> "...a rough estimation would be that for something like one-fourth to one-third (at the least) of a year on the average, each agricultural member of the farm labor force is idle."[7]

He goes on to suggest that:

> "...if we take into account the substantial under-estimation of farm labor because of seasonality in demands which leads to lower participation rates, the idleness could amount to at least one-third of the year."[8]

The degree of potential future unemployment as revealed by the above rates cannot but suggest more fundamental questions regarding the choice of production technologies that are appropriately applied to these conditions. The growing urgency of these problems requires direct and immediate measures, such as rural public works projects that are

Table 1.3

Rural and Urban Unemployment Rate in Various Developing Countries

| Country and Year | | Urban Rate | Rural Rate | Notes |
|---|---|---|---|---|
| Africa | | | | |
| Cameroons[a] | (1964) | 4.6 | 3.4 | survey |
| Morocco | (1960) | 20.5 | 5.4 | census |
| Tanzania | (1965) | 7.0 | 3.9 | survey |
| Asia | | | | |
| Ceylon | (1959/60) | 14.3 | 10.0 | survey |
| | (1968) | 14.8 | 10.4 | survey |
| Taiwan | (1968) | 3.5 | 1.4 | survey |
| Korea | (1965) | 12.7 | 3.1 | survey |
| India[b] | (1961/62) | 3.2 | 3.9 | survey |
| Syria | (1967) | 7.3 | 4.6 | survey |
| Iran | (1956) | 4.5 | 1.8 | census |
| | (1966) | 5.5 | 11.3 | census |
| Philippines | (1967) | 13.1 | 6.9 | survey |
| W.Malaysia | (1967) | 11.6 | 7.4 | survey |
| America | | | | |
| Chile | (1968) | 6.1 | 2.0 | survey |
| Honduras | (1961) | 13.9 | 3.4 | census |
| Jamaica | (1960) | 19.0[c] | 12.4[d] | census |
| Panama | (1960) | 15.5 | 3.6 | census |
| | (1967) | 9.3 | 3.8 | survey |
| Uruguay | (1963) | 10.9 | 2.3 | census |
| Venezuela | (1961) | 17.5 | 4.3 | census |
| | (1968) | 6.5 | 3.1 | survey |

a Males
b The unemployed "available" but not seeking work are included in rural areas, but not in urban areas
c Kingston
d All of Jamaica less Kingston

Source: Turnham, <u>op. cit.</u>

Table 1.4

A Measure of Rural and Urban Underemployment by Hours Worked

| | Percentage of Employed Persons Working Less Than X Hours | |
|---|---|---|
| | Rural | Urban |
| Ceylon, 1968 | | |
| Less than 20 hours | | |
| Male | 10.7 | 5.0 |
| Female | 17.5 | 5.6 |
| Chile, 1968 | | |
| Less than 41 hours | | |
| Male | 18.2 | 24.3 |
| Female | 3.15 | 29.3 |
| Taiwan[a], 1966 | | |
| Less than 42 hours | | |
| Male | 4.8 | 5.2 |
| Female | 19.1 | 12.1 |
| Korea[b], 1963/67 average | | |
| Average less than 40 hours | | |
| Both sexes | 46.0 | 17.0 |
| India | | |
| Less than 43 hours | | |
| 1958/59 | | |
| Both sexes | 41.2 | |
| 1961/62 | | |
| Both sexes | | 24.3 |
| Philippines[c], 1962 | | |
| Less than 40 hours | | |
| Male | 30.4 | 14.8 |
| Female | 71.2 | 36.7 |
| Tanzania, 1965 | | |
| Less than 40 hours | | |
| Both sexes | 40.0 | 18.0 |
| Venezuela, 1969 | | |
| Less than 41 hours | | |
| Both sexes | 39.3 | 40.4 |

a Non-agricultural and agricultural workers
b Farm and non-farm households
c Agriculture and non-agricultural industries

Source: Turnham, *op. cit.*

capable of absorbing large labor forces.

In the rural areas of the developing countries where surplus labor is widespread, the application of capital-intensive technologies for rural road* construction cannot be justified on the same grounds as that of, for instance, petroleum or steel production.[9] This is largely because a wider range of factor-combinations with labor-intensiveness is technically possible -- especially with low-volume roads.[10] Thus, enormous possibilities are offered by a shift to labor-intensive techniques for increasing employment opportunities and absorbing underutilized labor in rural areas.

## 1.3 Purpose and Scope of Research

This thesis is concerned with assessing the extent to which alternative production technologies, involving various factor-combinations of intensive labor techniques and capital-intensive methods in rural road construction, can be substituted for those presently in use. This issue is addressed in order to determine the optimal choice of technology for maximizing employment opportunities in labor-abundant economies.

The relationship between maximizing employment opportunities and the choice of technology for rural road construction will be demonstrated using an analytical framework

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* Rural roads are defined as roads with low traffic volumes in predominately agricultural areas. They are sometimes called feeder roads, development roads, penetration roads and tertiary roads by transportation planners and development economists.

in practice.

Technically, it may not be possible to specify a set of factor-combinations designed to use less capital and increase labor to produce a desired output.[11] That is to say, for a given level of output and quality, alternatives to the present capital-intensive techniques widely applied in developing countries are perhaps not feasible, technically speaking. On the other hand, to the extent that technical feasibility could be determined, it does not necessarily follow that economic feasibility could be justified on the basis of economic criteria alone. No decision about the selection of a certain technology, strictly speaking, is entirely economic or technical. There are social and political consequences that must be judged in the decision making process, as well.

## 1.4 General Methodological Approach

This thesis sets out the major principles central to the analysis framework and structural components of problems associated with making the optimal technology choice for rural road construction.

In light of the issues raised above, this thesis undertakes an examination of the problem through the following questions:

1. What are the factors that influence the choice of a technology for constructing rural roads, including: a) productivity of various inputs; b) project design standards; and c) project cost associated with method

of construction and maintenance?

2. What is the range of socio-economic, institutional and environmental factors that affect the choice of technology?
3. What are the determining elements in the selection of an optimal technology choice for rural road construction that serves to maximize employment opportunities?

The answers to the above questions will serve to establish the bases for a framework in the decision making process to select the most appropriate technology for application in the developing countries.

While recognizing that institutional factors are important in assessing the degree of labor-capital substitution for rural road construction, this research does not explicitly treat this issue because these factors may vary in degree and improtance from country to country. In this regard, the author believes that for purposes of this research it is sufficient to indicate in a general way how institutional factors may combine with other factors--i.e., socio-economic, engineering, environmental, etc.--to favor a certain technology.

To the extent that institutional factors are the most important elements in the selection of a certain set of production techniques (which is not hypothesized in this study) further research would be required to test this hypothesis.

In the preceding discussion we have provided a general description of one of the problems associated with the inappropriate choice of technologies for rural road construction. This problem was described as one of underemployment and unemployment in rural areas resulting from the inability of imported production techniques to absorb surplus agricultural labor. These techniques have been observed to be highly efficient and productive but, due to their capital-intensity, they fall short of expanding employment opportunities in rural areas. The problem, therefore, is conceptualized as one of appropriate production techniques that induce employment opportunities.

Chapter 2 deals with research efforts undertaken in the past by the international community to promote the use of appropriate technologies for rural road development in developing countries. The focus of this chapter is a general appraisal of previous work in the field, with particular emphasis on: a) problem conceptualization; b) existing practices in road construction; c) methods of analyses; and d) choice selection and implementation. This chapter is also intended to lay the basis for demonstrating a framework for making the optimal technology choice selection.

In Chapter 3 of this thesis, an analytical framework for examining the issues and the structure of problems in selecting the optimal technology is presented. This analytical framework addresses the issue of employment generation in rural areas through the adoption of appropriate production technologies under localized conditions. The discussion is intended to analyze the degree of substitutability of the production factors--i.e., equipment and labor--using methods of social cost-benefit analysis. In addition, we will discuss how economic, engineering, institutional and physical factors affect the choice of technology. The implications of a choice selection are also addressed in this chapter, looking particularly at: a) foreign exchange rates; b) interest rates; and c) wage rates.

In Chapter 4, we will argue that the framework for the choice of technology in rural road construction does have global dimensions and that the methods for analyzing such a choice are themselves adaptable to different developing countries. This will be accomplished through presenting case study materials.

These four chapters are summarized in Chapter 5, which serves to provide a holistic understanding of the problems, methods, framework and implications, which are not always made explicit in the decision making process for a choice of technology.

The reader should be aware that this research has not sought to develop a planning manual or, for that matter, a set of planning guidelines for use by project planners, engineers, economists and decision makers concerned with the development of rural roads in developing countries. Rather, the objective of this research is to identify the issues that influence the choice of technology and to suggest a framework that seeks to analyze these issues in their interrelationships such that the most socially optimal technology is chosen.

This understanding is intended to attract attention to and promote the application of appropriate technologies for rural roads among those interested in development planning as applied to the conditions of countries in Africa, Asia and Latin America.

# CHAPTER 2

# PREVIOUS RESEARCH ON TECHNOLOGY ADAPTATION

## 2.1 Introduction

As the preceding chapter has shown, rising pressures to provide greater employment opportunities in developing countries, especially in the rural areas, is of increasing interest to national and regional governments and international lending agencies. Many organizations, agencies and institutions of the international community have been conducting research into the possibility of employment generation through civil works projects -- especially road projects.

The work reported on in this chapter of the thesis is intended to draw together some of the earlier studies concerned with the theory of labor-capital substitution and more recent empiric investigations into this matter -- in order to provide a summary of what has been done on the one hand and to try to indicate some shortcomings of this work as well as to suggest new areas of research.

The literature reviewed can be broken down into two general categories, i.e., engineering and economics. The literature search was limited to studies written directly or closely related to the issue of labor-capital substitution in road construction, although not exclusively. In addition, some very useful research concerning labor-capital substitution has been conducted with respect to manufacturing industries.[1] It would have been superfluous to have included the vast amount of materials in the field of civil engineering that have direct bearing on the issues addressed in this thesis. What was of most relevance for this research was the issue of labor-capital substitution in rural road construction in terms of: a) problem conceptualization; b) existing construction practices; c) methods of analyses; and d) choice of technology.

## 2.2 Criteria and Meaning of Appropriate Technology

There appears to be an absence of a generally accepted definition of what constitutes an appropriate, low-cost, intermediate or alternative technology. What is most apparent in the literature is the ambiguity surrounding this issue. Perhaps this ambiguity is justified because there can be no single set of criteria or no single concept of appropriateness. For the most part, if there was such an acceptable definition it would perhaps be open to subjectivity, e.g., value judgments, many of which themselves are inappropriate or at least in conflict with the most objective circumstances.

In general, technology can be viewed as that component of a peoples' culture which enables them to extend their human, physical and mental powers in order to adopt, utilize and ultimately control the physical and social environment for the sustenance of daily life and its continued survival.[2] The question of appropriate technology seems to imply an approach for identifying a specific set of factor combinations, i.e., labor and capital to be applied in specific conditions to produce a desired output. The choice of such a technology would then be dependent upon the availability of factor inputs taken together with the social, economic, cultural and environmental characteristics of a given country or region.

For some (those practicing in the field) this has meant using the most readily available factor inputs to accomplish a certain task under unusual conditions. For others, it has meant the application of indigenous or traditional technology. Yet for others it has meant a sort of intermediate approach that lies somewhere between the more traditional techniques that he/she is aware of and the more advanced techniques which he/she was probably trained in.

The United Nations makes the following observation on the appropriateness of technology:

> "The criteria of appropriateness that are pertinent to the choice of technology cannot be appreciated in terms of technology alone. The choice is affected by value judgements as to the economic features that characterize a good society. Accordingly, questions of appropriateness can be raised in connection with solving each of the three basic economic problems that face any society: What is to be produced; How is it to be produced; and For whom is it to be produced."[3]

The above three questions are considered distinct by some planners, but this view is continuously being questioned. It seems that decisions about what to produce imply a certain idea about the way in which input factors combine to produce a certain output. This indicates how things are to be produced. And, finally, decisions or inflexible technologies which lead to superfluous labor.[7] The first hypothesis can be demonstrated by Figure 2.1. The aggregate supply and demand relations are denoted by DD' and SS', representing a typical industry under competitive market factors. The wage rate is believed to settle at (E) if the market operates at competitive conditions. Conversely, if policy measures were introduced by the national government or as a result of trade union pressure, the wage rate (W') would increase to level (W). On the other hand, if monopsonies exercise a strong influence in setting wage rates, which is is usually the case, the wage rate would fall to (W'), thereby understating its true cost.* The former, however, overstates the true cost of labor.

The general approach (two factor approach) by Eckaus appears to have significant theoretical value, but little attention is really given to the problem of institutional constraints that affect the market price factors.[8] Moreover, Eckaus does not suggest ways of bringing the imperfections in market prices into line with their true value.

The second hypothesis on inflexible technologies or limited technologies is concerned with limited opportunities for technical substitution. This situation is believed to be due to inappropriate factor endowments--i.e., the relative availability of labor and capital. Under these circumstances, the full range of technological alternatives are not properly defined. In the most extreme case, only one factor combination is available, which strongly suggests that

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* Monopsonies can be considered as buyers or employers who, by virtue of their strength in bargaining for labor, possess the power to influence wage rates.

about for whom things are to be produced are themselves dependent upon what is produced. Thus there is a complete circular decision, flow having implications for the range of criteria that influence appropriate production techniques.

## 2.3 The Factor Proportion Problem

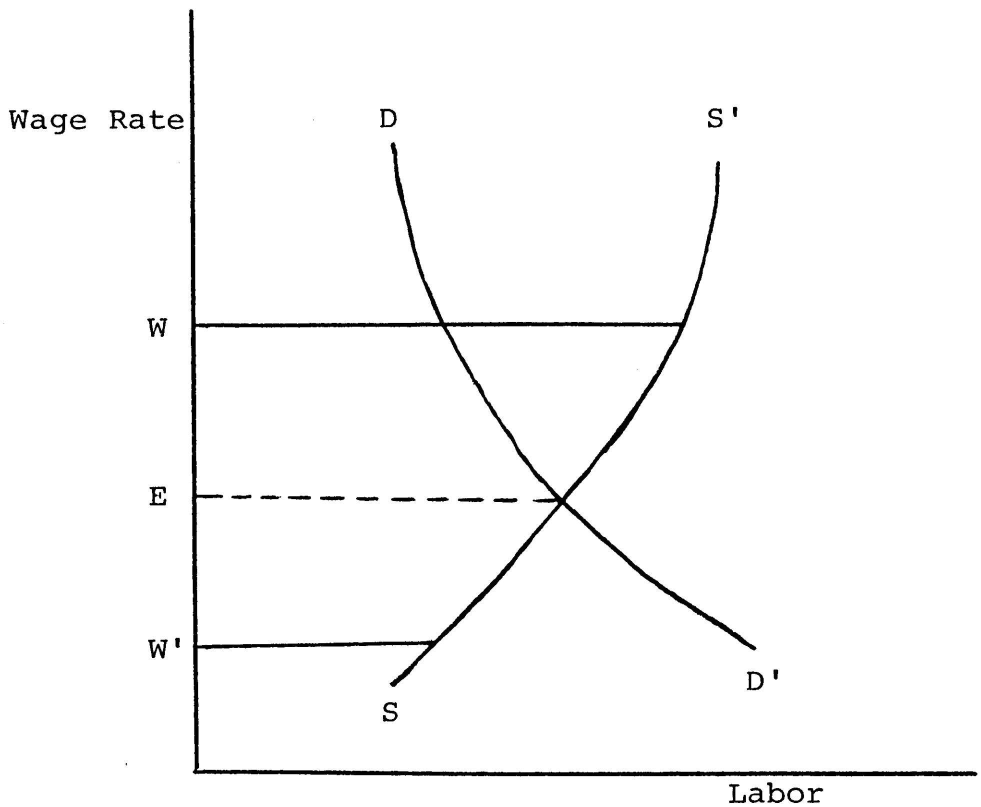
Eckaus' pioneer article provides a useful theoretical basis for examining the issues of unemployment and underemployment in developing areas as it relates to labor-capital substitution.[4] Although he is not concerned with rural road construction, this theoretical formulation seems to have widespread implications which cut across a sectoral approach. Eckaus states that, to a considerable degree, conditions of unemployment and underemployment may be the result of factor market imperfections and limited technical substitutability of factors, with divergences between the proportion in which goods are demanded and in which they can be supplied with full use of available factors.[5] He goes on to suggest that:

> "Factor-market imperfections which limit factor mobility create unemployment problems in underemployed areas with low per capita incomes and limited capital resources which are not different in kind but are much different in degree from those existing in the more advanced countries."[6]

In approaching the problem of underemployment, two hypotheses were suggested by Eckaus. The first assumes that available technology would permit the full use of the labor force at relative prices, but the source of unemployment lies in imperfections in the pricing system. The second assumes that there are limitations in the existing technology or

FIGURE 2.1

Imperfections in the Labor Market Hypothesis




Source: Derived from Eckaus, R.S. "The Factor Proportion Problem in Developing Countries," in the American Economic Review, Vol. XLV No. 4, September 1955, p. 541.

the technology originates in conditions that make it inappropriate for localized applications. A graphical representation of this phenomenon in its simpler form is shown in Figure 2.2.

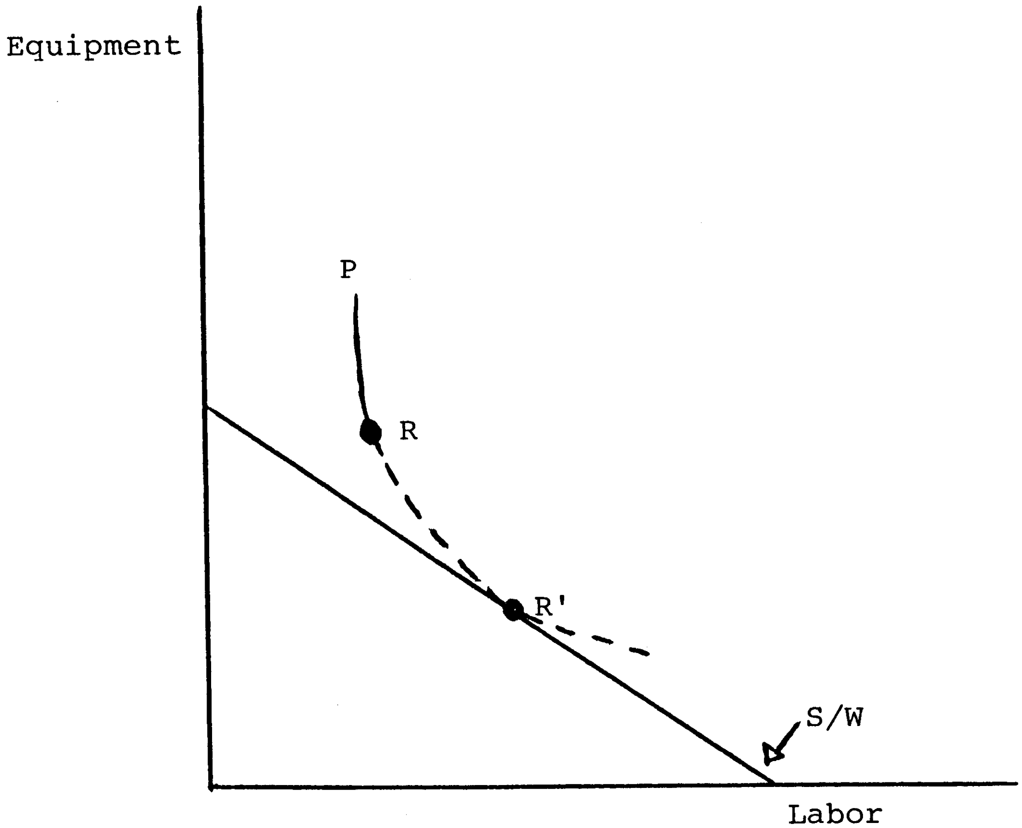
In the preceding sections we have indicated that the literature on labor-capital substitution suggests a theoretical framework that relies on two hypotheses -- inappropriate choice of production techniques and imperfections in the market price of factor inputs -- labor and capital and the inflexible technology or limited opportunities for labor-capital substitution. The following discussion is intended to explore the prevailing practices in rural road construction and to examine previous studies conducted or commissioned by international agencies concerned with labor-capital substitution.

## 2.4 Present Road Construction Technology

In general, there appears to be a wide range of technological alternatives available to construct rural roads, but these have not been adopted to a larger extent by countries of the developing world. Production techniques which are labor-intensive have been systematically excluded from the range of technological choices, oftentimes due to: a) a lack of awareness by project engineers and international consultants; b) unfamiliarity with national policy objectives which are oftentimes unclear themselves; and c) improper criteria for project evaluation. These tendencies have increasingly led to the adoption of highly capital-

FIGURE 2.2

Inflexible Technology Hypothesis




Note: P = Level of production

R = Factor-Combination chosen

R' = Optimal Factor-Combination

S/W = Ratio of Equipment to Labor at Shadow prices

Source: Suggested by Irvin, G.W. et al. in Roads and Redistribution: Social Costs and Benefits of Labour-Intensive Road Construction in Iran (Geneva: International Labour Organization, 1975), p. 19.

intensive construction methods in economies that exhibit an abundant supply of labor and capital scarcity.

## 2.5 Labor-Capital Substitution

This thesis is limited to issues of the technical and economic stages of production techniques given different institutional and environmental factors. The focus is addressed particularly to the planning stage of rural road projects. Formal studies concerning these issues beginning in the early 1970's were initiated by two international technical-assistance-oriented agencies -- the International Labour Organization (ILO) and the International Bank for Reconstruction and Development (IBRD or the World Bank). The aim of these two projects, which represent the major work in the field, was to draw on the world's experience in detecting and applying appropriate technologies in the production process.

The two projects used entirely different approaches in determining appropriateness. The labor-capital substitution project of the World Bank uses financial costings of labor and technology and tries to identify technical modifications in the labor and capital components of technologies given specific tasks, suited to objective conditions prevailing in developing countries. With an increasing supply of labor to substitute for capital, the focus was on the reduction of financial cost associated with the specific tasks in the construction process.[9,10,11]

The ILO Project sponsored under the World Employment addressed the issue of employment generation through the construction of rural roads in developing countries. This project attempts to measure the appropriateness of alternative technologies in terms of improvements in income distribution among the population. Two studies were conducted by ILO which represent a major effort to promote appropriate technology -- ILO-Iran and ILO-Thailand study. Both of these studies, for the most part, are concerned with deriving and applying shadow prices to factor inputs in order that these inputs reflect their true cost to the national economy.[12,13] Drawing on research conducted in the Iran and Thailand studies, the ILO has, in addition, prepared a manual on the use of labor-intensive techniques in road construction.[14]

Other studies concerned with labor-capital substitution in road construction were done by Vaidya in Nepal and Muller in Africa.[15,16] Both of these studies were focused on the issue of factor-input productivity and did not treat in any significant detail the issue of factor prices.

### 2.5.1 The World Bank's Approach

The research undertaken by the World Bank was concerned with measuring factor productivity and identifying alternative technologies and design standards for application in developing countries. What prompted such an effort was in part due to the recognition in the 1960's that developing countries having sizable unemployment problems could alleviate this problem by selecting production techniques that support larger opportunities for employment. It was, in addition, recognized that 30 to 40 per cent of development funds were being absorbed by civil works projects that were highly capital-intensive.[17]

The initial study by the World Bank was directed at the appropriateness of highway design standards. The work was conducted by Moavenzedah at MIT beginning in 1969 and resulted in the development of a mathematical model -- the Highway Cost Model.[18] Lack of empirical data to test the model prompted the World Bank to initiate field studies to generate primary data. The first study was conducted in Kenya by the Transport Road Research Laboratory of the United Kingdom.[19] Further research which was intended to build upon the work in Kenya was done in India and Brazil.[20]

The design standards study was aimed at developing a method for selecting highway design standards and maintenance procedures adaptable to country use but did not include what production techniques should be used in the application of these standards and procedures. In 1971 a World Bank project was commissioned to focus particularly on labor-capital substitution.[21] The project was divided into three phases:

Phase I: Completed in 1971; focused on a survey of the existing literature on problem formulation for road construction using calculating methods derived from manuals. The report included both an engineering and economic bibliography with annotated entries in the engineering bibliography.

The findings were:

a) the substitution of labor for equipment is technically feasible for a wide range of construction activities for roads of various qualities;

b) the economic feasibility of the substitution of labor for equipment depends on relative factor prices and factor productivities under different conditions; and

c) certain environmental parameters are peripherally important. These include the physical environment, the size or scale of the project and the time available to complete it, the work incentive, the organization and management, and the health and nutritional standards of the labor force.

Phase II: Completed in 1974; was conducted in India and Indonesia. The study focused on on-going construction projects involving observations of 30 construction projects with particular emphasis on the productivity rates for labor and equipment. The Indonesian case was significant because two projects (labor-intensive and capital-intensive) were closely located and could be observed simultaneously.[22]

The report contains the following conclusions:

a) "Techniques currently in use in civil construction are either highly labor-intensive or highly capital-intensive; no significant 'intermediate' techniques have been observed. Where attempts have been made to combine traditional labor-intensive methods with modern equipment operations -- e.g., hand loading of trucks -- the resulting "mixed" methods obtain such inefficient use of the equipment that it, in fact, requires more capital than a fully equipment-intensive operation and is therefore highly inefficient.

b) Traditional labor-intensive techniques currently in use are not economically competitive with modern capital-intensive techniques, even in labor abundant economies when labor is priced at a fraction of market wages. This is because 1) existing labor-intensive techniques are employed in an atmosphere where primary emphasis is on employment creation rather than efficient use of labor, and 2) existing methods are primitive and do not employ elemental mechanical techniques effectively, if at all. These factors result in extremely low labor productivity.

c) Management and supervision of large labor forces require skills, experience and organizations quite different from equipment-intensive operations. Labor-intensive methods should not be attempted without careful advance planning, organization and training, particularly in regions where these methods have not been commonly practiced.

d) Even in labor-abundant countries there are frequently shortages of labor at different times and places; indeed, the social cost (shadow value) of labor fluctuates widely with season and location. Unless construction authorities are prepared to pay higher wages during peak periods...projects may suffer costly interruptions. Shadow value corrections of market prices becomes a complicated proposition, and application of a single norm could lead to harmful results.

e) Health and nutritional standards have a significant impact on productivity of the labor force. Anaemia, induced by a combination of parasitic infestation and iron deficiency, has been shown to be widespread, often in severe stages, among construction workers in at least one country. Experiments suggest that programs of improved nutrition can have a significant impact on labor productivity in these cases."

The World Bank's Phase II Study performs a sensitivity analysis in conjunction with a cost minimizing production routine to derive a set of economical optimal technologies under varying price conditions. The study also uses a logarithmic production relationship fit by regression analysis techniques to model the relationship among factor inputs, product outputs and the different institutional and environmental parameters of activities and tasks in the production process.

2.5.2 The ILO's Approach

The World Employment Program of the ILO began in 1969. Under this program, projects were designed to assist national decision makers and project engineers in formulating policies and plans with the objective of increasing employment opportunities and redistributing incomes. The program was cognizant of the special feature of construction activities which offers a wider choice of labor-capital substitution than does manufacturing.

Along these lines, studies related to the feasibility of labor-intensive road construction were undertaken. The studies (conducted in Iran and Thailand) attempted to answer three basis questions:

a) Is it feasible to find technically efficient labor-intensive techniques for road construction?

b) Is the adoption of these techniques desirable from the point of view of employment and income distribution objectives, i.e., is it socially desirable?

c) If so, what fiscal or other mechanism is needed to insure that private construction is the socially optimal technique?

In stark contrast to the conclusions by the World Bank's labor-capital substitution study--i.e., Phase II--the ILO concludes that even at market prices, labor-intensive techniques are desirable. The study goes on to conclude that a swith to a different road constrution--i.e., more labor-intensive--will necessarily involve: a) detailed specification of the different technology by the consulting engineer at the project design stage; b) the National Government may find it necessary to provide a financial transfer (subsidy) to encourage the private sector to adopt alternative production techniques as a result of extra costs incurred; and c) the specification of alternative technologies in contract documents taken together with effective supervisory methods in the application of the new technology.[25]

The difference in the approaches of the World Bank and the ILO is perhaps explained by their concerns, introduced into the analysis by each of these organizations. That is to say, the World Bank as an international lending agency is more concerned with productivity and capital investments that receive the highest return economically, which may not be the most socially optimal solution under conditions where there is unemployment. On the other hand, the ILO conducted its research under its World Employment Program, which may suggest a(n over-)sensitivity to the unmployment problem and perhaps less (not enough) emphasis on the issue of labor productivity and how it can more effectively combine with equipment to get the highest output per unit of labor and capital.

Other research by the ILO resulted in a manual on labor-intensive road construction. The manual is intended to provide development/transportation planners and project engineers involved in road construction with a methodological framework for the choice of production techniques.[26] This is aimed at encouraging the use of labor-intensive techniques without a sacrifice to social profitability. It is useful to mention here that the manual is organized into four parts: 1) the economic considerations; 2) the civil engineering aspect; 3) the institutional factors relating to construction; and 4) the problems of reorganization and management in labor-intensive projects.

2.5.3 Vaidya's Approach

The research undertaken by Vaidya was a country-specific approach of road projects in Nepal.[27] He presented a comparative evaluation of road construction techniques by the Peoples' Republic of China, the U.S.S.R., the United Kingdom and India, as they were applied to Nepalese conditions. These production techniques ranged from highly capital-intensive ones used by the Soviet Union to highly labor-intensive ones used by China. Perhaps the significance of Vaidya's research rests not so much in his theoretical and methodological formulations, because they are open to criticism. Rather, the significance lies in the fact that this is perhaps the first attempt at comparing production techniques from different countries to road projects in a single country; at least the literature does not indicate any previous work in this area at that time. Vaidya is concerned with the productivity of the factor inputs, but does not attempt to examine the issue of market price imperfections and views the problem of productivity more from the standpoint of expertise in management and the type of technology selected. Nor is Vaidya concerned to any significant degree with the problem of seasonality in employment, although the project under construction and supervision by the Chinese Government did indicate how the work program was affected due to this problem.

### 2.5.4 Muller's Approach

A case study of low-cost road construction aimed at promoting labor-intensive methods was done by Muller in 1970.[28] The study is concerned with productivity of factor inputs. Muller disaggregates the construction process into activities and attempts to explore opportunities for labor-capital substitution by each activity. He uses a cost reduction method (least-cost) to compare labor-intensive techniques against capital-intensive techniques by each activity type.

The significance of Muller's work perhaps rests in the fact that the project design called for capital-intensive construction methods. Due to inadequate management and supervisory personnel, lack of maintenance facilities for equipment, inadequate supply of spare parts, etc., the project resulted in being adapted to the availability of resources in the area. This adaptation, for the most part, meant labor-intensive construction techniques. Muller does not argue for labor-intensive construction techniques, at least not directly, but rather is concerned with achieving an "optimum balance" between labor-intensive and capital-intensive methods.[29]

## 2.6 Choice of Technology: A Summary

On balance, the literature reviewed--particularly the ILO studies--make a strong case for the application of labor-intensive production techniques in road construction for developing countreis. All of the sources seem to aggree that there is no question of the technical feasibility for substituting labor for capital, especially in low-volume rural roads. The argument seems to be centered around the economic feasibility of labor capital substitution. There are two major aspects to this question. The first is focused on the productivity of the factor combination and the issue of what conditions influence labor and capital productivity. The second issue is that of factor prices. The literature emphasizes the circumstances under which factor prices are being distorted and suggests ways to resolve this situation through the application of shadow pricing techniques.[30,31,32]

Perhaps the most important conclusion reached in the literature is that alternative production technologies to those widely applied in developing countries do exist. The issue -- left unresolved to some degree-is under what circumstances and using what criteria can the most optimal technology be selected, given the relative available of factor mixes?

# CHAPTER 3

# AN ANALYTICAL FRAMEWORK FOR TECHNOLOGY CHOICE

## 3.1 Introduction

This chapter is a discussion of a framework for analyzing appropriate production techniques in rural road construction. It examines the impact of the relative availability of factor inputs, e.g., labor and equipment on cost, as well as how these inputs could be put to their optimal use.

In Chapter 2 we stated that one of the important reasons why production techniques are capital-intensive is in part due to the methodology used by development planners for computing the cost associated with the factor inputs. In a further review of the literature we not only found that the methodology used was inherently biased in favor of capital-intensive production techniques, but that institutional and economic factors also favored a capital-intensive approach. Thus, in the present chapter, a framework for assessing the degree of factor substitutability for rural roads is structured. Such a framework has a three-dimensional structure:

1) Theoretical conceptualization of labor and capital substitution
2) Social cost-benefit approach
3) Design criteria

In transportation planning there are several levels at which the problem of selecting the optimal technology could be approached. First, at the level of the development planner where major choices of alternatives in overall technologies are available or in the timing of investments in relationship to other projects or even in the spatial distribution of projects. These are decisions that commit resources to transportation.

Secondly, at the level of transportation planning iteself, where one would be concerned with the selection of the system's configuration, of modes, of transfer and storage points, and of other features that affect the level of service of the system. Thirdly, at the level of detailed engineering design, possibilities may be available for introducing changes in the factor input ratio. And perhaps, finally, at the level of operating the system, other possibiliites for cost reductions by changing the labor-capital mix may exist.

The level investigated in this thesis was that of examining the opportunities for factor substitution in the construction phase of rural roads. This involved an interpretation of the manner in which production techniques are selected, especially during the planning and design phases of rural road projects. The approach adopted here is synonymous with "least cost" or "lowest cost" technologies because we are concerned here with maximizing social savings through the introduction of labor-intensive production techniques.

In the context of capital resource limitations characteristic of developing countries, careful consideration must be given to the various factors that influence the cost of constructing rural road facilities. In general, these factors can be summarized as follows:

1) Construction practices widely applied in developing countries are often carbon copies of those from more developed countries. These practices may not be suitable, given the different conditions. This is more pronounced when the technology is unable to absorb unemployed and underemployed labor in the rural areas due to its capital-intensive nature.
2) Relative availability of labor and, in some instances, its lower cost may make the substitution of labor-intensive techniques more viable in some of the construction activities and perhaps make the project even more economical. The project start-up date and phasing of the construction activities could possibly be affected under these circumstances.
3) Relative availability of skilled labor may restrict the use of certain equipment that requires skilled operators, thereby affecting the projects' feasibility by the introduction of skilled labor from other regions or from abroad at extremely high costs. Similarly, restricted availability of equipment maintenance facilities may also influence the methods of construction and factor inputs.

The importance of applying appropriate production takes on added importance given the above conditions.

## 3.2 Conceptual Framework of the Problem

A fundamental question involved in the selection and application of appropriate technology is the ambiguity surrounding what is an appropriate technology. Surely economic criteria alone are insufficient to make such a judgement while, on the other hand, technical feasibility cannot justify a particular production technique either. Other criteria for investment decisions and their consequences must also be considered.[1]

In terms of rural roads, typically with low volumes, there are continuous costs to the users associated with use of the road, commonly referred in the literature as user costs. These costs are the sole responsibility of the user and not the owner of the facility. There are also social costs, such as maintenance, that come about as a result of the road's existence and the vehicles that use it.

Both in the construction phase and in maintenance of the road, capital and labor inputs are necessary whose application to the road preclude their application elsewhere in the economy, resulting in opportunities foregone.[2] The selection of a particular road design implies the selection of vehicles that may use the road. That is to say that rural roads, while being typically over-designed in terms of their geometrics and use, are still inadequate to support high traffic volumes with heavier loadings than are generally found on higher standard roads.[3] Therefore, the vehicle profile may be restricted to smaller vehicles -- i.e., pick-ups, jeeps, small and medium-size trucks, etc--that can negotiate the road.

The choice of road design and the manner in which it is to be constructed and maintained influence the type of labor that is to be applied to the operations. This in turn will affect the distribution of income and the supply of labor needed in other sectors of the economy. The choice of production techniques in particular will affect the factor combination of labor and capital, thereby affecting the requirements for foreign capital and the rate of foreign exchange.[4]

These are some of the most obvious consequences that may result from the choice of technology and its associated costs. Other circumstances must likewise be considered. If the national or regional objective is economic development, it therefore follows that cost incurred through development projects must explicitly take this objective into consideration as a way of measuring the cost to the economy.[5] Moreover, an analysis that seeks to serve as a basis for a decision on the application of appropriate technology must be capable of disaggregating the cost factors in such a way that the real cost to the economy can be estimated.[6] To accomplish this, three important requirements for the analysis are suggested:

a) The selection of the two-factor--e.g., labor and capital--approach (production function), in a way that will permit the estimation of various levels of factor-combinations;

b) An analytical approach that incorporates the use of shadow pricing techniques to relate these factor inputs to the overall economy such that the impact of the costs to the economy can be quantified; and

c) The construction process itself must be disaggregated into stages in order to determine the following elements:

   i) Activities--involving loading, hauling and unloading a particular material

   ii) Tasks--piecework involving excavation, loading, hauling, unloading and spreading

   iii) Method--the way of performing an activity or task with a certain factor-mix of labor, equipment, and materials.

These items in turn have implications for Item (a) above with respect to quantities and associated cost.

It should be pointed out that a two-factor production function as opposed to a multi-factor which includes an analysis of materials is an approach that is more relevant for low-volume rural roads. This is because low-volume rural roads typically are designed to support lower traffic levels than are roads with higher design standards. From the standpoint of construction, these roads do not require material inputs -- i.e., bitumen for surfacing, lime for stabilizing the sub-base, and Portland cement and corrugated metal pipes for drainage structures. In the case of higher standard roads, bituminous surfacing, sub-base stabilization and drainage structures could make up a substantial part of the construction cost. However, since these inputs are not generally used in lower standard rural road construction, they were not considered as a parameter that would have significant affects on the two-factor approach used in this research.

3.3 Theory of Labor-Capital Substitution

The question of choice of technology is essentially that of which method of production to use to achieve a desired result. In almost all cases, this has been interpreted as a question of the intensiveness of capital in the production methods to be applied.

In rural road construction, the optimal choice of technology can be viewed as one product denoted by (P) and two factors, namely capital or equipment and labor, denoted as (E) and (L), as shown in Figure 3.1.[7]

The curve shown in Figure 3.1 is called an isoproduct curve, also known in the literature as an isoquant, meaning equal products.[8] In economic theory, the isoproduct curve represents all of the most efficient combinations of factor inputs--e.g., labor and capital--which can be combined to produce a certain level of output (P).*

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* The reader should note here that the isoproduct curve may not assume such a smooth concave shape in real world situations. In actual fact, the shape of the curve between any two points is not very clearly understood by economists and engineers, but it is believed that the curve assumes a concave shape. The issue of whether there are two or more points on the isoproduct curve that are tangent to the isocost line is subject to debate. The literature seems to accept that there is only one point of optimality on the isoproduct curve and that any movement away from this point

As suggested elsewhere in this thesis, the optimal choice of technology is synonymous with "least" or "lowest cost" technology. Therefore, for a given level of output (P) there will be a corresponding factor-combination of (E) and (L) on the isoproduct curve that will represent the minimum cost of technology.[9] However, this point (P) can only be determined if the prices (or relative prices) of the factors inputs (E) and (L) are known.[10] The labor price in terms of one unit of equipment is taken as being the number of labor units which one unit of equipment will buy. Conceptually, this can be represented by a straight line connecting one unit of equipment measured off on the vertical axis with some "x" units of labor measured off on the horizontal axis. All of the points along such a line are of equal value and are commonly referred to as the isocost line.[11] Given this condition and by the same logic two units of equipment will trade off against "2x" units of labor or, representatively, N units of (E) against "nx" units of labor such that a family of parallel lines are defined for any given price.[12] The point at which the isoproduct curve is tangential to the isocost line is determined as the minimum cost of production (P).[13]

The relative value of equipment and labor can be represented by C/W, as shown in Figure 3.1. The prevailing road construction technology is given by point (R) such that at point (R) the total equipment used is OA and the total labor is OC. This technology is said to be sub-optimal because a reduction in cost calculated at C/W (the ratio of equipment costs to labor costs at shadow prices) can be achieved by moving along the isoproduct curve to point Re.[14] This shift in technology (factor-combinations) will result in AB less equipment being used and an increase in labor by CD. If the

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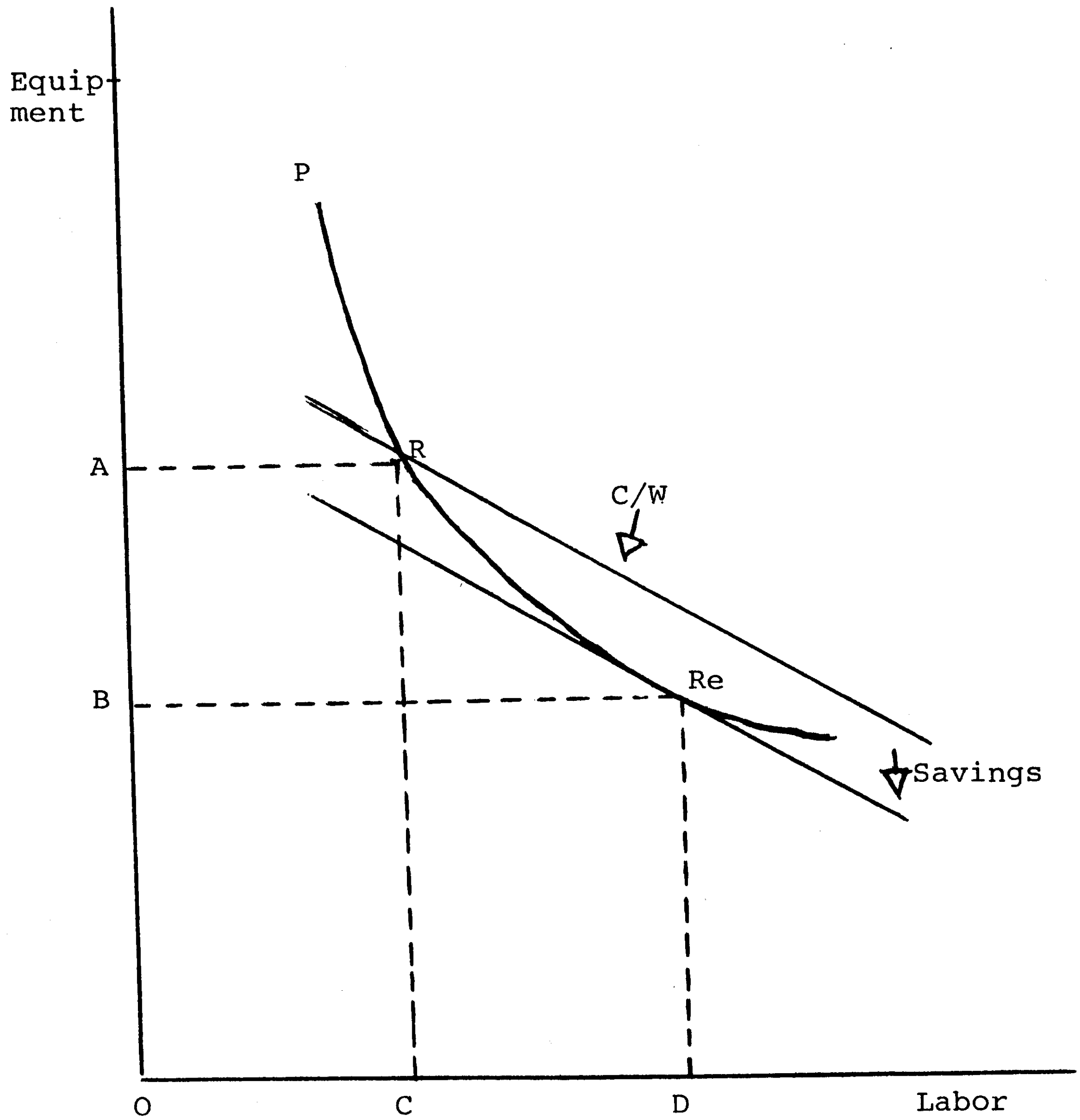
*(cont.) of optimality will result in increased costs. The other assumption is that the input factors are homogeneous, which is conceptual in nature. The truth is that almost never are the input factors homogeneous, especially with respect to labor.

FIGURE 3.1

Optimal Technology Choice



project objective is to generate more employment, this seems in general to be dependent upon realizing social savings.[15] This in turn appears to depend on the slope of the isoproduct curve and the relative value of the factor inputs, in social terms, or with respect to their true value to the economy.[16]

The choice of technology can be an important instrument in generating employment and the use of social cost-benefit analysis to determine the optimal technology can be of even more importance.* The maximization of social savings serves to amplify the relationship between employment generation in the pursuit of efficient production policies.**

Given all of the above, it may be useful to demonstrate why prevailing technologies widely applied in countries of the developing world may not be suitable to the objective of maximizing social savings. In Figure 3.2 the set of appropriate technologies on the isoproduct curve are not clearly defined or, more precisely, the isoproduct curve is not fully defined over the range of technologies available (R to Re). Under the most extreme circumstances, only (R), a

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* Social cost-benefit analysis refers to the quantification of costs and benefits to a project when the cost inputs are shadow priced and then taken with the benefits they are discounted to their present value. Typically, a ratio is established such that if $\frac{\Delta B}{\Delta C} > 1$, the project is considered viable.

** Social savings being maximized as suggested here may be ambiguous to the reader. In actuality, what is being maximized are the present value of future consumption gains that comes about through a switch to an optimal technology where the input factors are valued in terms of consumption.

single technology is available.[17] This situation could perhaps imply that the technologies are imported from countries with different factor endowments. On this assumption, there is no question as to the range of choices by decision makers because the choice has obviously been made.

On the other hand, Figure 3.3 seems to indicate a divergence between social prices (C/W) of equipment and labor and their market prices, denoted by (C*/W*).* Under this condition, the technology adopted by the private sector would differ substantially from the technology that might be considered by the government.[18] The private sector is concerned with maximizing profits, which is at R, while the government desires technology that is socially optimal at (Re). At least in theory this should be the case, but in actual planning practice the situation may be to the contrary because governments are not always aware of the most socially optimum technology.

The preceding discussion presented a general theoretical framework of the substitutability of factor mixes of labor and capital for various levels of production technologies. We have attempted to demonstrate the common conceptualization of the relationship between a change in the production technique or change in technology as a two-factor isoproduct representation. That is to say, a change in techniques can be illustrated by a movement along the

* The reader will note that social prices denoted by C/W are taken as the ratio of equipment costs to labor costs at shadow prices. These prices are sometimes referred to in the economic literature as planning prices or accounting prices to indicate a distinction between the prices valued at their market value and prices adjusted to reflect their true opportunity cost.

FIGURE 3.2

Factor Inputs Improperly Defined

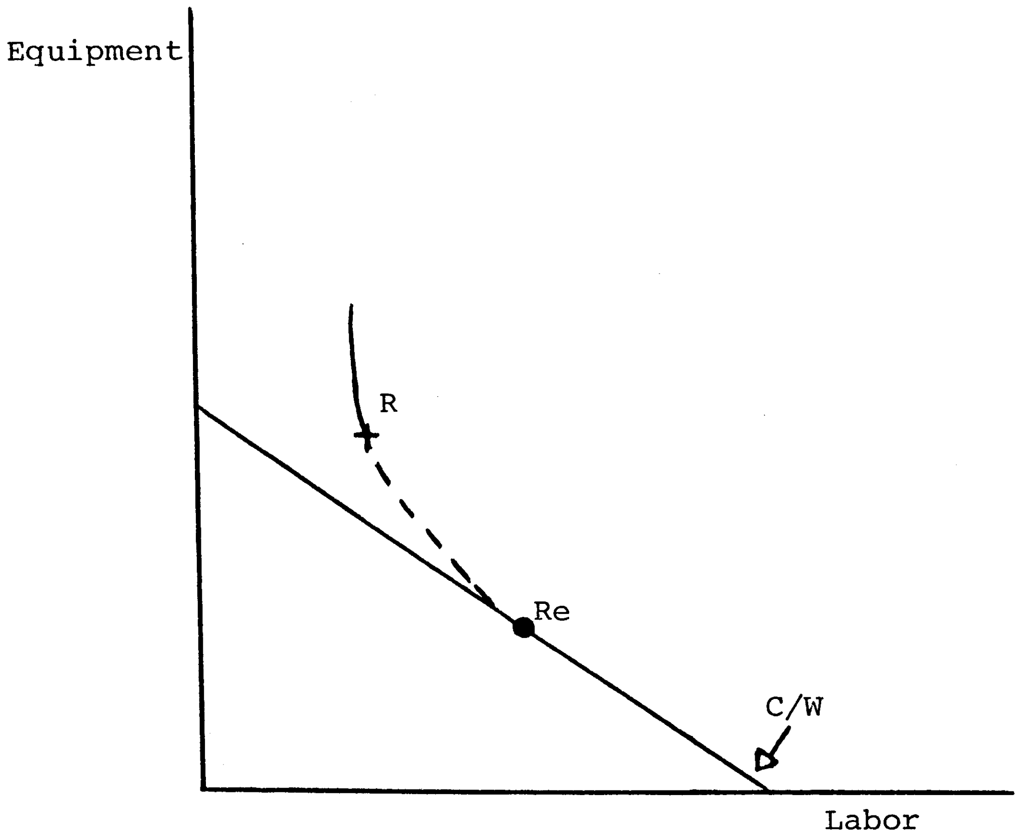
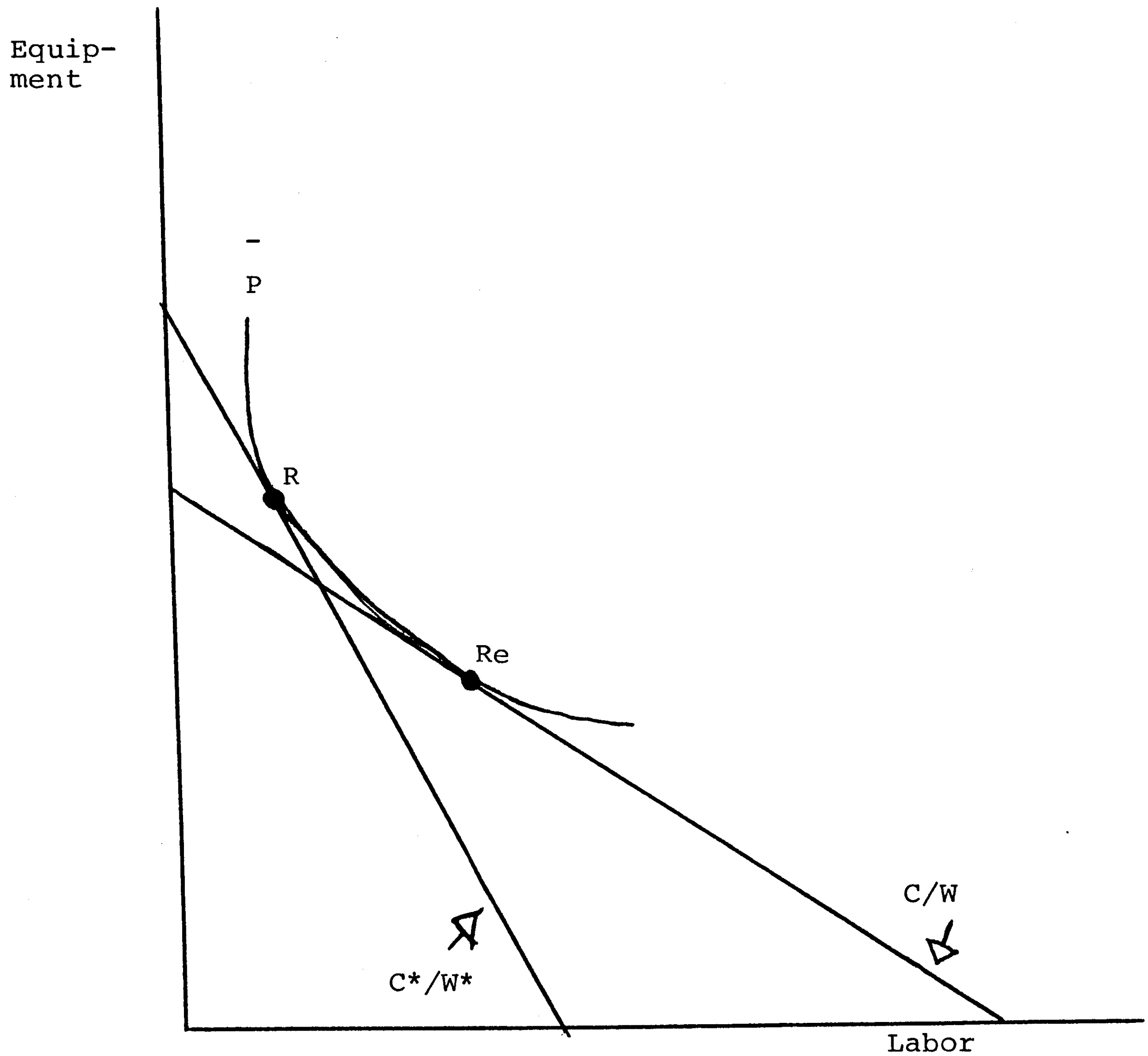


FIGURE 3.3

Factor Inputs at Market and Shadow Prices



isoproduct curve.

### 3.4 A Social Cost-Benefit Approach

In an earlier part of this thesis, we indicated that if appropriate production techniques are to be applied in rural road construction, their factor costs must be disaggregated in such a way that the real cost to the economy can be quantified.[19] Procedurally, this involves an estimate of the physical quantities of the factor inputs associated with each alternative technique for accomplishing each task in the construction process. Specific data requirements include the wage rates for skilled and unskilled labor, the unit prices of imported equipment and other materials in terms of their foreign exchange and the unit prices of materials that are available on the local market. In addition, it is important to know the rate of foreign exchange in order to translate foreign exchange costs into local currency costs.

A typical practice of engineers and planners in the economic evaluation of rural road projects is only to calculate factor prices of labor and equipment at market prices.[21] Economists, however, do not believe that market prices accurately reflect the relative value of factors of production in some developing economies.[22] This is because market prices cannot provide national governments with a satisfactory indication of the economic costs to the the nation of a particular factor-combination (technology).*

These national costs, commonly referred to in economic literature as social costs, need to be calculated with an adjustment to their market value in order to bring them into line with their real cost to the economy.[23] Moreover, social costs in developing economies need to be considered separately from market cost because market prices are oftentimes suppressed, inflated or distorted. This sort of situation usually occurs in three areas:

i) in wage rates for labor, especially unskilled labor;

ii) with interest rates; and

iii) in the rate of foreign exchange.

Thus it is essential in project evaluation that market prices are adjusted to reflect the true social value of the factor-inputs or the relative scarcity of labor and capital.

With this in mind, and given the price distortions in interest rates, foreign exchange rates and factor inputs, two important questions immediately surface: a) what are the bases of these distortions in the market; and b) would it not be more reasonable to do away with the distortions rather than simply try to bring them into line by adjusting them, as has been suggested?

In response to the first question, Sfeir argues that these price distortions are indicative of market interfer-

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* The reader will note that factor combinations, factor inputs, production techniques and production technology are used interchangeably in this thesis. The author does not view any of these as having substantively different meanings. The choice of usage is really a matter of preference and aesthetics.

ence due to institutional constraints.[24] Institutional constraints are manifested by monopolies demanding or supplying goods, services or other resource inputs or they could occur through governments' introducing policies that set wage rates without due consideration to wages at competitive prices. Other institutional constraints could be the introduction of import tariffs and quotas that may impose undue restrictions on the "free flow" of the market.

These are the constraints commonly articulated as the origins of price distortions by "free market economists."[25] On the other hand, Hughes of IBRD traces the origins of price distortions in developing countries to the introduction of subsidized credit for large- and medium-scale industries and to income tax concessions given to private entrepreneurial groups.[26] Hughes further suggests that heavy protectionist policies have had the effect of introducing a bias against agricultural development and other sectors by reducing the potential market for agriculture and inputs while simultaneously raising the cost of production.[27] A consumer market for luxury goods is thus created. This consumer market gravitates or is centered around the national bourgeoisie who benefit from these price distortions in the economy. Opportunities for exports that benefit the economy are discouraged due to high production costs. In these circumstances, the protectionist policies of the national government tend to be reinforced, thereby protecting luxury import items and their inputs.[28]

The second question could be answered in the affirmative at the outset. Yes, it would be more reasonable to do away with these distortions altogether! But the question becomes, reasonable for whom? It was implied above that special interest groups benefit directly from these price distortions. It is doubtful whether these groups are willing to abandon their privileges; at least history does not support such a contention. Perhaps to do so would require far-reaching social changes initiated at lower levels or even in most instances outright social revolution. In the immediate circumstances, progressive national policies could be breaking up monopolistic enterprises and attempting to bring factor proportions more in line with their market values. On the other hand, encouraging investments in labor-intensive production methods is yet another possibility for eliminating price distortions.

In most of the developing countries, the probability is that the severity of price distortions is not likely to disappear nor is it likely that adequate policy measures will be introduced to correct the situation in the near future. Thus, the shadow pricing approach by development planners offers an alternative for measuring a projects' true social worth.

### 3.4.1 Market Rate of Interest

"In shaping their investment and fiscal policies, national governments will have to choose between encouraging savings and investment and thus future growth versus immediate increases in consumption and living standards."[29] One of the main goals of the national government is to allocate the national resources in a way that will maximize the consumption level of its citizens. It can be argued that the amount of consumer goods available on the market at any given period is largely a function of previous investments.[30] By the same logic, current investments should therefore realize their fruits at some future period. The following paradigm better illustrates this point:

Let us suppose that a current investment yields a stream of net consumption benefits from current year 0 to, say, some future year T and where T is the project's investment life:

$$B_0, B_1, B_2 \ldots B_T$$

We might then assume that the overall consumption derived from the project is equal to

$$B = B_0 + B_1 + B_2 + \ldots + B_T \ldots \qquad (3\text{-}1)$$

where B is defined as the sum of the net benefits from current $B_0$ to future year $B_T$ or, as it is defined in the economic literature, as the net aggregate consumption.

Equation (3-1) implies the simplistic notion that society would be willing to value one dollar's worth of consumer goods today the same as one dollar's worth of consumer goods at any time in the future. No country or individual behaves in this manner. This is especially true under circumstances where current consumption involves essential goods such as subsistence food, subsidized housing, etc. Thus, the net aggregate consumption benefit of an investment project could be better represented by the expression:

$$B^* = V_0 B_0 + V_1 B_1, + V_2 B_2 + \dots V_t B_t + \dots V_T B_T \qquad (3\text{-}2)$$

where B* equals the discounted or present value of net aggrgate consumption benefits and $V_0, V_1, V_2 \dots V_T$ are discount factors. The discount factors indicate the amount that future net benefits must be discounted to make them comparable to current net benefits. The value of the discount factor of $V_0$ is equal to 1, thus:

$$B^* = B_0 + V_1 B_1 + V_2 B_2 + \dots V_t B_t \dots V_T B_T \qquad (3\text{-}3)$$

On the assumption that consumption in one year is valued more than consumption in the next two years and consumption in the next two years is valued more than that in the next three years, and so on, we get the following representation:

$$1 > V_1 > V_2 \dots > V_T$$

If the discount factors decline over time at some constant percentage rate, we get:

$$\frac{V_t - V_{t+1}}{V_{t+1}} = \text{constant} = i$$

Then

$$\frac{V_t}{V_{t+1}} - 1 = i$$

and

$$\frac{V_t}{V_{t+1}} = 1 + i$$

or

$$\frac{V_{t+1}}{V_t} = \frac{1}{1+i}$$

where i in the expression is commonly referred to as the social rate of discount or the rate which consumption, as valued by society, declines over time.*

The social discount rate in the economic literature can be explained by the argument that, "A person who lends US$100 this year at 10 per cent is behaving as though he valued US$110 worth of consumption next year as highly as he values US$100 worth this year, putting a factor of 1.0 on this years consumption and 1/1.1 on the next year's consumption." If "r" is the market rate of interest, he places a value of 1/1+r on next year's consumption. By the same logic, discount factor $V_2 \ldots V_T$ associated with consumption in periods 2 to T are the series:

$$\frac{1}{(1+r)^2}, \frac{1}{(1+r)^3}, \ldots \frac{1}{(1+r)^T}$$

---

* Some economists often refer to the social rate of discount as the consumption rate of interest in the economic literature.

Of course, the validity of the arguments in the preceding paragraph depends on the assumptions that the capital market is perfect, that there are no taxes on the returns to expected savings, and that savings assume a rational behavior.[31] However, the assumptions are probably not valid in developing countries or even in developed countries, largely due to monopoly elements. In this case, these elements are lenders who oftentimes receive interest rates much lower than that which borrowers are required to pay. In addition, the returns on savings are generally taxed and the net returns received by savers will be lower than the market rate of interest, thus varying according to the income class of the saver. Furthermore, it may require a considerable length of time for individuals to learn through trial and error how to maximize their welfare and gain experience in this. During the trial and error learning process, decisions about savings may thus not always be as rational as the above assumes.

The preceding argument does indicate, on the other hand, that the market rate of interest--irrespective of the way it is measured--does not always correctly estimate the rate at which the future value of consumption will fall over time or the social rate of discount.[32]

There are still some pessimistic conclusions with respect to the correct value of i. There appears to be no straightforward way to determine its value; at least the economic literature does not appear to be in aggreement on such. This thesis does not presume an answer to this problem because, in the final analysis, the social rate of discount is open to subjectivity and rests on the judgement of economists and policy makers.[33]

### 3.4.2 Skilled and Unskilled Labor

An important aspect of national policy objectives is the incorporation of employment generation mechanisms into investment plans. Such an initiative is essential to the economic development of surplus labor economies. UNIDO states that, "The essence of surplus labor lies in the gap between the market wage in the organized capitalist sectors of the economy and the social value of the marginal product of labor in the rest of the economy...but in the traditional 'rest of the economy' sector, incomes are not in general determined by the rules of perfect competition."[34]

We said at the beginning of this chapter that in assessing costs associated with different production techniques, these costs must be disaggregated in such a way that their true cost to the economy can be estimated.[35] In rural road construction we are concerned with two kinds of labor cost -- skilled and unskilled. In the present study, we are more interested in unskilled "off-seasonal agricultural" labor in the rural areas, because this labor is more subject to unemployment. The question that appears more relevant for skilled labor is regarding the manner in which it is priced in road construction. There was no question as to whether or not it could be absorbed by a shift to labor-intensive production techniques in rural areas.

3.4.2.1 Skilled Labor

Wages paid out to skilled labor generally reflect the cost to society of employing an additional skilled worker to the development project.[36] If the skilled labor market is "perfectly competitive," it follows that the wages should correctly measure the real cost to the society in case of product foregone. Under conditions of imperfect markets, wages to skilled workers may understate or even overstate the true cost of employment on the project.

If employers of skilled labor are monopsonies and possess stronger powers than, for instance, trade union organizations to influence the wage rates, wages to skilled laborers will tend to be lower than the market price under competitive conditions. This situation is said to understate the real cost to society, since opportunities foregone will exceed the actual wage rate. On the other hand, if national governments are successful in setting skilled wage costs higher than their market value, this, by contrast, overstates the real cost to society. Given these two conditions, correction factors (shadow prices) should be applied when evaluating the project to accurately capture the true costs to society.[37] In order to attract skilled labor to rural road projects, special amenities (benefits) -- i.e., subsidized food, rents, or salary increments -- may have to be introduced by the contractor. This means that the wage rate could effectively be higher than the market rate in other sectors of the economy for the same skills.

3.4.2.2 Unskilled Labor*

Unskilled labor is quite an abundant resource in most countries of the developing world and development projects should draw on this resource to facilitate their construction and maintenance activity. In this case, the cost to the economy of employing an additional unskilled worker on a development project is output foregone by alternative employment. In the absence of exogenous factors and monopsonies control of labor opportunities, the wage rate for labor is equal to the marginal product of labor measured at market prices.[38]

In situations where rural labor markets are active, the wage rate is determined by the opportunity cost of employing workers on the project.[39] Under adverse situations where there is visible unemployment ("open unemployment"), hiring additional labor leads to a reduction in unemployment in other sectors of the economy. In the latter case, project labor costs overstate their true cost to the economy.

3.4.3 Foreign Exchange Pricing

Foreign exchange is an important consideration when assessing the substitutability of factor inputs of production with regard to costs. Little and Mirrlees state, "That two of the basic shortages facing the developing world are foreign exchange and savings...foreign exchange is a scarce

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* The term "unskilled labor" refers to laborers whose jobs require little or no formal training and the basic skills required for their employment on a development project can be easily obtained after a few weeks on the project.

resource...."[40]

The gap in foreign exchange comes about when imports exceed exports. When this situation occurs in a country, it is said to have a negative balance of payments or negative value of trade. Experience suggests that the normal response of the national government, given a negative value of trade, is to introduce corrective policies. Often, rather than devalue the national currency, a government will introduce import tariffs and quotas, and offer tax exemptions and subsidies for export items. Such policies are aimed at improving the negative value of trade by restricting imports or stimulating exports. "Free market economists" argue that such policies interfere with trade reaching its own "equilibrium." As a consequence, the rate of foreign exchange under conditions where devaluation has not been used does not capture the losses and gains to the national economy.[41] Hence, the value of a unit of foreign exchange to the economy is greater than that which is indicated by the official foreign exchange rate, causing distortions in the rate of exchange.

### 3.5 Shadow Pricing

The subject of social cost-benefit analysis implies an understanding of a country's national policy objectives and the manner in which these objectives relate to the process of project planning. Bruce of IBRD has indicated that:

> "One of the most important aspects of this process is that both the planning authorities in developing coun-

> tries and external aid agencies should select and design projects to support their respective development objectives. However, too often the authorities get locked into the process of projects simply because 'they are ready' or because of the pressure of special interests and then the bureaucratic pressure of self-interest and the desire to speed the transfer of resources and to ensure that timetables are kept make it difficult, if not impossible, to modify the design of projects and, if necessary, abandon them. Social cost-benefit analysis is a system designed to ensure that all the relevant factors are taken into account in estimating the net benefits, whether this be for the individual, the firm, the public sector organization or the country as a whole."[42]

The preceding paragraphs (Section 3.4) were intended to provide a general rationale for the use of social cost-benefit analysis and to serve as an introduction to the current approach as it relates to the issues under study in this research--the choice of labor-intensive versus capital-intensive production technqiues in rural road construction. The discussion that follows does not attempt in any way to summarize social cost-benefit analysis nor is it a survey of such. Rather, given that the shadow pricing approach is a crucial component of the analysis framework for technology choice, it is useful to provide, in a generalized way, some of the assumptions that are most relevant for shadow pricing.

To begin with, shadow prices are defined in the economic literature as the value of the contribution to a country's basic socio-economic objective made by any marginal change in the availability of commodities or factors of production. Given this, shadow prices are dependent on the country's national objectives and the economic environment in which the marginal changes take place. Such an environment generally would be determined by the physical constraints on resources and the constraints that restrict the government's control over economic development. To the extent that changes in the national objectives or constraints occur, a change in the estimated shadow prices will be necessary.

It may be useful here to make two points clear in regard to shadow prices. When speaking of shadow prices, we are first of all talking about prices that relate to an economic condition in which distortions exist. We are concerned with a situation in which market prices and shadow prices are not equal to each other. The second point is that project planners, when measuring the affect of a project on the national economy, should have a clear understanding of the socio-economic objectives of the national development policy. That is to say, project planners should explicitly consider national policy objectives when evaluating projects to determine how such projects relate to the overall economy.

This thesis assumes that national parameters used for shadow price estimation can be made available to a project planner by the national planning agency or some other governmental department that coordinates overall economic development. In this regard, the preceding discussion was intended only to suggest why cost items in the factors of production should be adjusted to compensate for distortions in their market prices and to indicate in which direction this is likely to take place.

Procedures for actual estimation of adjustment coefficients are beyond the scope of the present work and the reader is directed elsewhere for such.* This is because the exact magnitudes will depend upon local conditions with respect to the relative availability of factor inputs. Generally, a surplus of unskilled labor in a specific region means that the market wage rate will probably overstate the true cost to society by employing this labor. Similarly, a shortage of foreign exchange to the economy means that the nominal (official exchange rate) value of imported goods will understate the true cost to society of their use in public construction projects. The implications of these distortions of factor inputs for the choice of appropriate road construction technologies are:

- The wage rate will tend to be priced higher than what it would be for alternative use, thereby discouraging labor inputs
- The price of equipment will be lower than its actual cost to society, thereby encouraging the use of equipment.

These two conditions will generally favor a capital-intensive approach in road construction because the entrepreneur will receive a higher unit per output under these conditions, thus influencing his choice of technology.

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* For a thorough treatment of the methodology for deriving and applying shadow prices, the reader is referred to the following works: <u>Guidelines for Project Evaluation</u>, Project Formulation and Evaluation Series No. 2 (Vienna: UNIDO, 1972); and <u>Project Appraisal and Planning for Developing Countries</u>, I.M.D. Little and J.A. Mirrlees (London: Heineman, 1974).

As suggested in Chapter 3, there are many difficulties and problems associated with choosing an appropriate discount or interest rate for use in cost-benefit analysis. To a large extent, the selection of a discount rate is a subjective measure and is open to question. As a result, project planners should consider a range of discount rates that reflect private market rates at one extreme and the planners'/economists' judgement about the social rate of discount at the other extreme. In developing countries, the range may vary from 10 to as much as 25 per cent. the project planner should be aware that the appropriate discount rate must approximate as closely as possible the opportunity cost of capital or an interest rate that reflects earnings that will be foregone from other investment if the capital is put to the proposed alternative use. To the extent that the planners choose to discount costs and benefits at something like the nominal interest rate paid on a loan rather than at the (often much higher) social value of the capital to society, this tends to favor higher cost projects and more rapid completion. This tendency in effect favors a capital-intensive technology largely because the expected returns on the investment accrue earlier.

Further discussion of the above issues are to be found in Chapter 4.

The preceding discussion presented a sketch of some of the issues that project planners and engineers must consider when choosing a certain set of factor mixes. We sought to show how each of these issues either singularly or taken together may impinge on the decision making process. The discussion below addresses itself to the issue of project design and the relationship between design and the choice of technology.

### 3.6 Road Design Criteria

In transportation engineering/planning, road design standards are a function of the expected level of traffic, topological features of the terrain and climatic conditions. Generally speaking, the lower the design standards the greater the degree of factor substitution, since higher standard roads (usually of AASHO standards*) require more earthworks and higher standard pavements and sub-grades.

Carnemark of IBRD has suggested that rural roads be designed to correspond to the low traffic volumes, since in developing countries many of the feeder roads have been and continue to be constructed at inappropriately high standards and at excessive costs.[47] He attributes this phenomenon to consulting engineers who are unaccustomed to the designs of secondary and tertiary road systems. Thus, they

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* AASHO standards refers to the American Association of State Highway Officials' standards for rural roads which specify minimum roadway widths, horizontal and vertical clearance, design speed, pavement thickness, sub-grade strength, rate of rise and fall, shoulder width and drainage structures.

are more apt to encourage higher design standards for fear of being associated with road facilities that fail due to environmental factors and/or lack of maintenance, characteristic of so many developing countries.[48]

Soberman indicated that local conditions are an important factor in determining the costs of a transportation facility because the availability, hence costs, of local factor inputs (i.e., building materials and labor) have a direct bearing on the design and the production technique to be applied for pavement thickness and sub-grade strength.[49]

In rural areas of developing countries, reasonable accessibility during the dry season and minimum access during the wet season are the only design criteria that are economically justified, according to Carnemark.[50] Planning agencies and highway authorities who insist on constructing rural roads at such inappropriate standards reduce the range of possible factor substitution in areas where there is a need to absorb surplus agricultural labor. Carnemark suggested that instead of rural roads being improved on an "all or nothing" basis, careful consideration should be given to providing at least an improved earth track, which is better than no access at all.[51] There is always the possibility of improving the road facility at a level corresponding to the volume of traffic increase. Becker argues for a staged construction approach, given the capital resource limitations and the desire to maximize benefits.[52]

He gives the following reasons:

1) "It permits a lower initial investment in a road, thus permitting unused funds to be utilized in other productive endeavors...."

2) "It reduces the initial requirement for other scarce resources such as skilled manpower and equipment and permits the use of these resources on other projects."

3) "In cases where expected traffic increases do not occur, an initial low standard road would entail a lower opportunity loss than would a high standard road because of the small investment....Conversely, if traffic should increase more than anticipated, upgrading would only require moving up the original construction schedule rather than a redesign of the road."[53]

Given these arguments, the lowest possible design standards for rural roads that apply labor-intensive production techniques are justifiable. This is especially true in areas where there is "open employment." It does not appear that capital-intensive techniques could be very relevant under these circumstance.

Since many rural roads, especially earth roads, have initial traffic levels which may not exceed 10 vehicles per day (VPD), the design standards to be applied may effectively mean:

a) a handmade, bulldozed or graded track following the ground profile;

b) the central crown of the road bed surface would be raised using excavated material from drainage ditches;

c) gravel, consisting of locally available materials, would be provided selectively in needed areas;

d) drainage; and

e) the clearing width of the road (horizontal clearance) would be 7 to 10 meters (18 to 25 feet) with a roadway width of 3.5 to 5.0 meters (9 to 13 feet).

This approach and the issue of rural road design standards opens the way for a broader and more comprehensive way of looking at development projects rather than simply in economic terms. That is to say, it allows for national and regional objectives to be explicitly considered in the planning process, especially if these objectives are maximizing social savings and employment generation.

### 3.7 A Summary

Of crucial importance in the choice of production techniques are the factor inputs, e.g., labor and equipment. An analytical framework for a decision regarding production technique was presented in this chapter. The structure of the framework was predicated on three components: first, the theoretical conceptualization of factor substitution that relies on the two factor production function approach; secondly, there are the mostly socio-economic criteria that address the issues of technology choice as it relates to the maximization of social savings and employment generation using the social cost-benefit approach. Thirdly, the criteria upon which the design decisions are based should be broadened to include social criteria.*

This chapter of the thesis showed that there is really no issue of whether labor-capital substitution is possible on engineering grounds because such substitution is technically possible except as influenced by design standards. In the past, biases in favor of capital-intensive techniques were justified using economic arguments which, as this research has shown, were open to inaccurate interpretation of the cost of factor inputs. The application of a social cost-benefit approach and appropriate design criteria taken together demonstrate objectively the strength of the substitutability of labor for capital in rural road construction and removes the inherent biases in the planning process.

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* For a more detailed discussion of this issue, see Chew Keat Soon, Multi-Criteria Framework for Appraisal of Rural Roads in Developing Countries, unpublished M.S. Thesis, MIT, Department of Civil Engineering, June 1978.

# CHAPTER 4

# SELECTING THE OPTIMAL TECHNOLOGY

## 4.1 Introduction

In the preceding chapter we formulated an analytical framework for assessing the substitutability of labor for capital and its optimum utility in rural road construction. In the present chapter we are concerned with demonstrating how the framework can be implemented in the planning process. The methodological aspect of the framework is given in Figure 4.1, in which direct relationships are established between the choice of technology, the design standards, and the size and type of vehicle that will use the facility. During the course of this discussion, it is suggested that the implementation of the framework has implications for other regions of the world and countries concerned with limited resource allocations and employment generation through public projects.

### 4.1.1 Project Level Analysis

The use of a social-cost-benefit approach in project evaluation is carried out to inform decision makers as to the true worth of a project to the national economy. This will necessarily involve the use of shadow prices for all of the factor inputs to enable the project evaluators to correct distortions in their prices at the market level and to reflect their social price.

The analysis presented in this chapter will be conducted at the project level and is intended to demonstrate the application of the analysis framework. In real world situations, a project level analysis of a rural road could be a costly proposition for most developing countries due to the amount of time and costs involved. In addition, rural roads, at least the way in which they are defined in this thesis, are oftentimes not justified on the basis of road user savings due to their low traffic volumes, as would be the case for higher standard roads. When social criteria are included in project evaluation, they play an important role in determining the viability of a rural road project.

## 4.2 The Engineering Aspect of the Analysis Framework

It has already been argued in previous sections that prevailing road construction practices in most developing countries are capital-intensive and some reasons were cited as to why this is so. One of the reasons was identified as a lack of awareness on the part of project engineers and planners of the range of the technical substitution possibilities that may exist. This situation has led to project evaluators unconsciously excluding socially optimum technology from the planning process altogether by producing designs insensitive to local conditions. The present work is focused towards showing the effects of a design decision on the choice of production technique. In addition, some discussion is given to how project engineers may begin to analyze substitution possibilities in the construction process.

When planning rural roads the choice of technology can be represented by the relationships shown in Figure 4.1. These relationships are dynamic in the sense that a variation in any one of the choice parameters -- i.e., design standards, production techniques or economic factors -- can affect the overall cost of construction.

The data necessary to quantify the interactions of these relationships can be summarized as follows:

a) the effect of changes in construction techniques on the costs of constructing a road to given design standards;

b) the effect of varying design standards on total costs of construction and on road maintenance cost given different kinds of terrain;

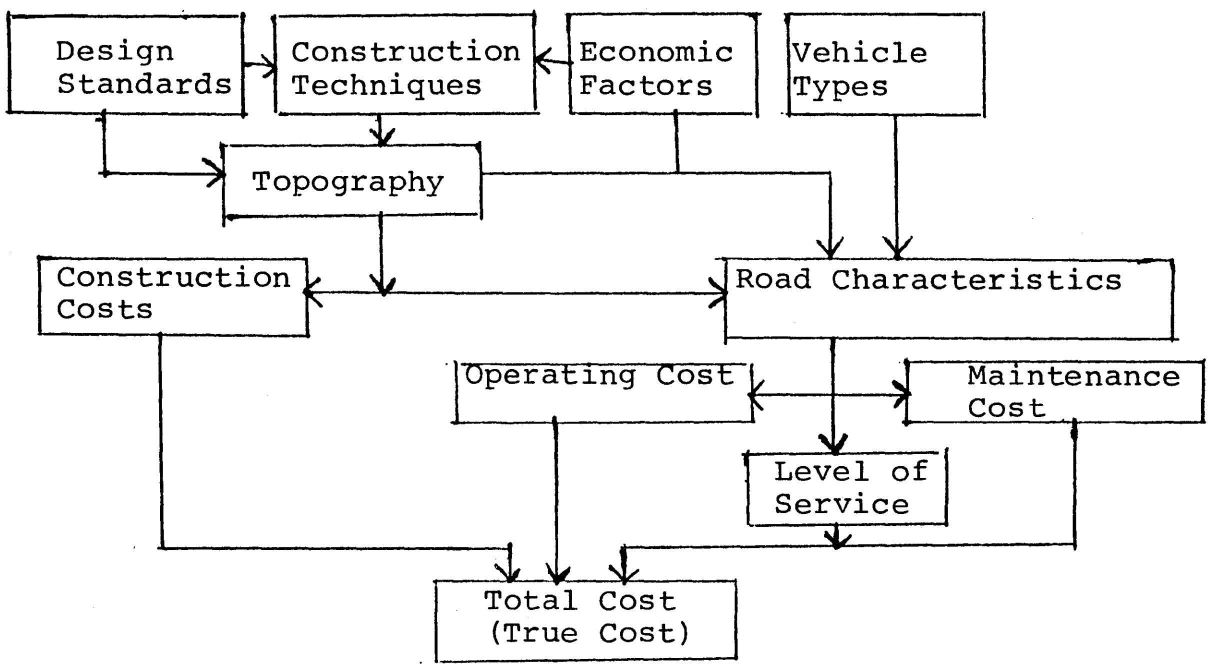
c) the effect of varying design standards in different types of terrain on the quality of the final road given certain geometrics as gradients, horizontal and vertical curvature, and design speed; and

d) the effect of varying vehicle size and type on the operating costs given different design standards and terrain.

For purposes of this research, the most relevant of the above are b and d. This is because changes that are of the most concern here are those that relate to choice of design, hence production techniques and vehicles that would use the road. The former is related to the fixed cost or initial cost of construction the road. The second, however, is

FIGURE 4.1

Inter-Relationships of
Technology Choice Parameters




concerned with the current cost of using the road on the road user costs. These two elements taken together affect the maintenance cost of the road.

The possibilities for labor-capital substitution were discussed in Chapter 3 in terms of an analysis framework. The question now becomes, How can such a framework be implemented such that the optimal factor-combination of labor and capital are chosen? This may mean, in actual planning practice, selecting both the standards to be used in constructing the rural road and the types of vehicles that are to use it.

For our purposes, a particular level of fixed investment can represent a certain type of road and current expenditures can indicate a certain operating procedure. These expenditures can also indicate the extent of the substitution possibilities. Isocost curves can also be used to select that technology or combination of fixed and current cost which are most desirable. In this case, the isocost curve will represent the combinations of annual current expenditures over a period of years and the initial fixed investment is a specified sum of capital in the present. That is to say, the isocost curves identify the alternative ways of investment an amount of capital. In this regard, the entire amount could be set aside to provide for annual operating costs as determined by the prevailing interest and the amortization period. Alternatively, some of the capital could be invested in capital expenditure now, with the remainder being absorbed by current expenditures. As we have indicated in previous sections of this thesis, the point at which the isoproduct curve is tangent to the isocost line is the optimal choice of technology for a given level of factor inputs.

## 4.3 Disaggregating the Construction Process

One approach for assessing the degree of labor-capital substitution in road construction might be to begin with a typical bill of quantities and specifications (see Table 4.1). In doing such, perhaps a common set of bill items could be matched or grouped according to similar activities. However, this approach seems to have limitations in the sense that the design of the facility is fixed while the factor inputs are variable. This in itself imposes a rigid criterion on the factor inputs because the design may be sensitive to changes in the input factors. This is especially so if one is considering pavement thickness and sub-grade strength, and the extent to which tradeoffs are possible.

Given the above consideration, the approach adopted in this study is to view construction as a process made up of different stages. These stages are themselves composed of a series of activities, tasks and methods that interact to produce a certain output. Disaggregating the construction process in this way permits a more detailed estimation of the quantity and quality of input factors -- i.e, materials, equipment and labor -- that are to be expended on the project at the different levels and at different time intervals. The disaggregation would involve the following (also see Table 4.2):

Operation 1: Clearing and Grubbing

Operation 2: Earthworks (Excavation)

Operation 3: Preparation of Sub-grade

Operation 4: Pavement Surfacing

For each stage given in the above, a different range of

Table 4.1

Road Construction Project:
Quantities of Tasks*

| 1 Km. Length | 12 Meters Roadway | 7 Meter Surface | |
|---|---|---|---|
| Excavation for crushed stone | | 4,785 | $m^3$ |
| Watering | | 2,565 | liters |
| Clearing and grubbing | | 45,000 | $m^2$ |
| Compacting base and sub-base | | 28,000 | $m^2$ |
| Stone production | | 7,500 | tons |
| Production of chippings | | 300 | tons |
| Bitumen distribution 10 km. haul | | 17 | liters |
| Compacting surface dressing | | 7,000 | $m^2$ |
| Compacting earthworks | | 120,000 | $m^2$ |
| Excavation for earthworks | | | |
| 25 m. haul | | 11, 925 | $m^3$ |
| 100 m. haul | | 11,925 | $m^3$ |
| Cleaning and brooming | | 7,000 | $m^2$ |
| Hauling and spreading base and sub-base | | 4,785 | $m^3$ |

*The Bill of Quantities for this product conforms closely to the norms established by the government for a road of this standard, and the project can be considered "typical" of this standard in rolling terrain.

Source: IBRD, IDA, Study of the Substitution of Labor for Equipment in Civil Construction, Phase II Final Report, Staff Working Paper No. 172 (Washington, D.C.: January 1974), p. 42.

Table 4.2

Factors Affecting Highway Construction Costs

| Cost Elements | States of Nature | Design Standards |
|---|---|---|
| Site Preparation | topography | design speed<br>width<br>sight distance |
| Earthworks | terrain<br>soil<br>geology | design speed<br>width<br>sight distance<br>maximum gradient<br>maximum curvature |
| Structures | terrain<br>soil<br>geology | width<br>design axle load<br>axle spacing<br>design volume |
| Drainage Structures | terrain<br>soil<br>climate<br>geology | width<br>design axle load<br>axle spacing<br>design volume |
| Pavement | terrain<br>soil<br>geology<br>climate | width<br>design axle load<br>axle spacing<br>design volume |

Source: Soberman, R.M., Transport Technology for Developing Regions: A Study of Road Transportation in Venezuela (Cambridge, Mass.: MIT Press, 1966) p. 39.

Table 4.3

Percentage Distribution of Road Construction Cost Among Various Operations in Asia and the Far East

| Operation | Road Type Feeder | Secondary | Primary |
|---|---|---|---|
| Clearing | 3 | 2 | 2 |
| Excavation of earth with haul 100<m. | 20 | 16 | 14 |
| Excavation of earth with haul 100>m. | 12 | 10 | 9 |
| Compaction and grading | 12 | 11 | 10 |
| Production and hauling of road material other than earth | 30 | 23 | 16 |
| Laying of base course and surfacing | 9 | 18 | 25 |
| Drainage and structures | 14 | 20 | 24 |
| | 100 | 100 | 100 |

Source: Allal, M. et al. Manual on the Planning of Labor-Intensive Road Construction (Geneva: International Labour Office, 1977), p. 45.

factor input substitution is available. That is to say, a different production function can be drawn for each stage in the construction process. Some discussion may now be useful to indicate what activities, methods and tasks are involved in each production stage. The productivity measurement of each stage is given in manhours and machinehours.

### 4.3.1 Clearing and Grubbing

Clearing and grubbing or site clearance, as it is sometimes referred to, is an activity that can be conducted almost entirely by labor-intensive methods. In general, this activity involves clearing trees, brush and other vegetation from the roads' right of way. In some cases, equipment inputs may be necessitated in varying degrees in more mountainous areas.

### 4.3.2 Earthworks (Excavation)

Earthwork activities in rural road construction is normally divided into sections and sub-sections of the road project to reflect the difference in the topological and geological features of the right of way. This activity involves the movement of materials -- i.e., hard clay, topsoil, earth, stones and rocks, etc. The following tasks usually make up this activity: a) excavation; b) loading; c) hauling; d) unloading; and e) spreading.

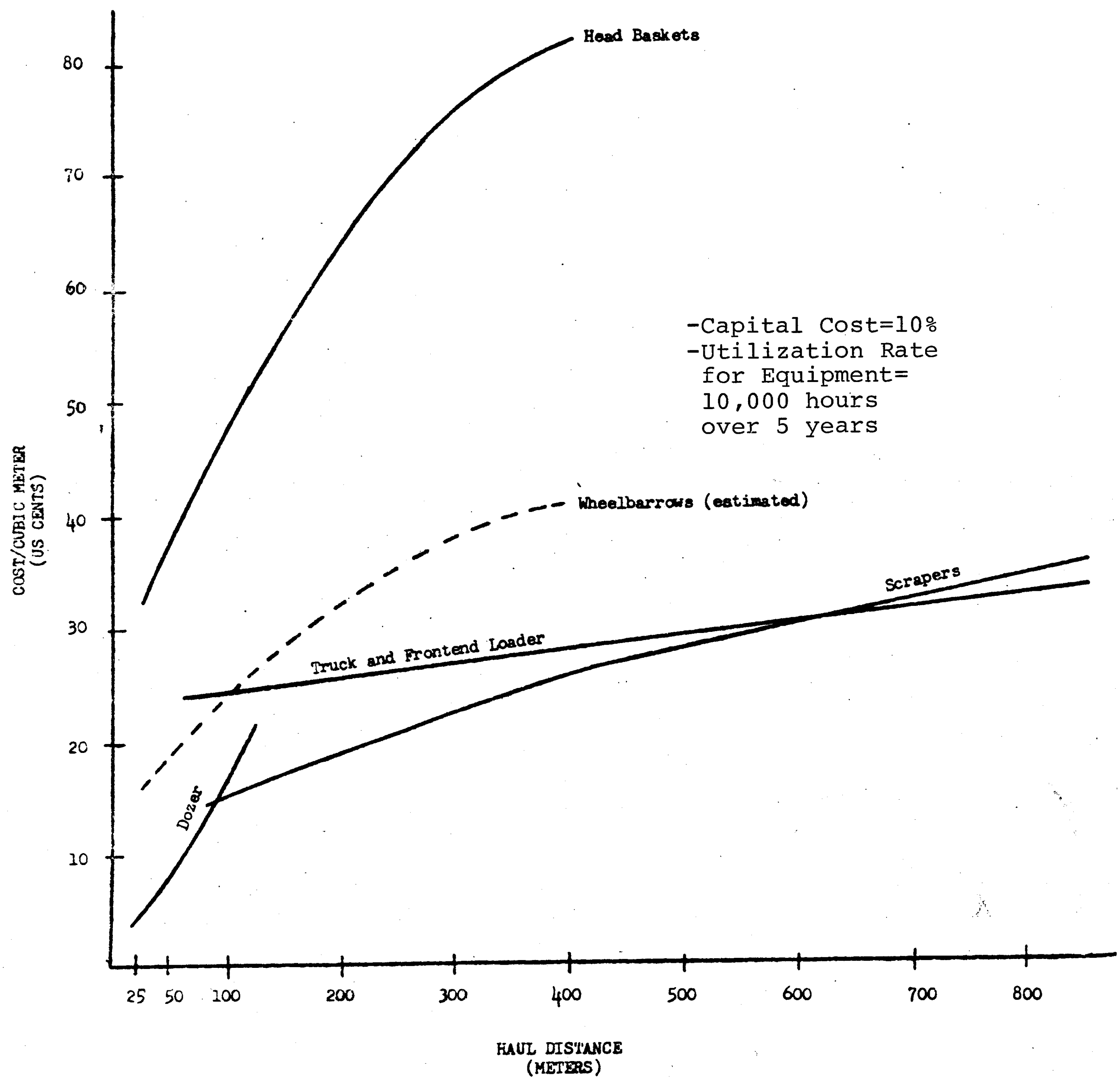
Because of the low-level design of rural roads, particularly earth roads, all of the above tasks are amenable to labor-intensive technology. Earthworks have been found to account for as much as 60 to 80 per cent of the direct cost of road construction.[1] A productivity matrix of different methods of excavation is shown in Table 4.4. The resources required by each method per 1,000 cubic meters covers a range of different factor combinations of labor and equipment based on 15 ways of accomplishing each task.

One of the main considerations in the excavation and movement of earthwork is the haul distance. This is a principle determinant in establishing the cost of earthworks and, as such, is closely related to the design and the execution of construction. Because of the difficulty with excavation and hauling in labor-intensive technology, quantities of cuts and fills are minimized in both design and construction.

In other words, design standards are lowered, taking the natural terrain profile as much as possible -- e.g., no attempt is made to balance cuts and fills, but rather fills are obtained from borrow pits near the spill site to reduce the haul distance.

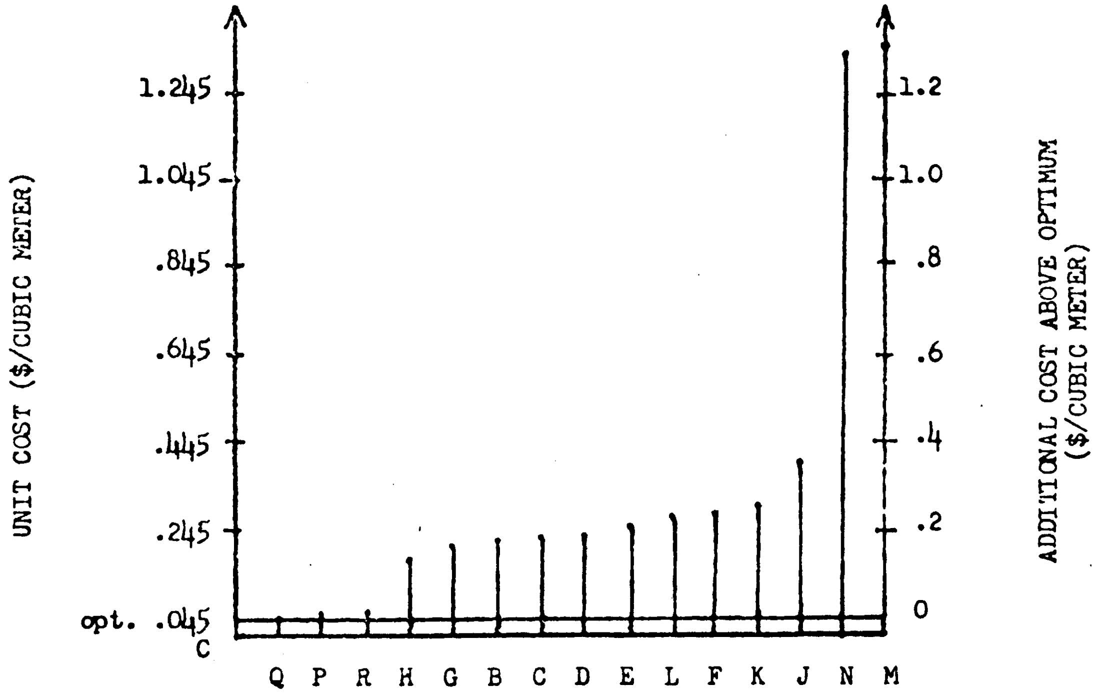
The World Bank has prepared some cost estimates of excavating and hauling earthworks for different haul distances using different methods, as shown in Figures 4.2 and 4.3. It must be noted, however, that the cost for the wheelbarrow was simulated and therefore not observed under actual conditions. It may be that the wheelbarrow could become an effective method of hauling materials at short distances, but further research would be required to test

FIGURE 4.2 UNIT COSTS RELATED TO HAUL DISTANCE OF EXCAVATING, LOADING, HAULING, UNLOADING, AND SPREADING (HARD SOILS) UNSKILLED WAGE = $0.50/day




Source: IBRD, I.D.A., <u>Study of the Substitution of Labour and Equipment in Civil Construction</u>, Phase II Final Report, SWP No. 172 (Washington, D.C.: January 1974).

FIGURE 4.3 RANKING OF CONSTRUCTION METHODS FOR EXCAVATING, LOADING, HAULING, UNLOADING, AND SPREADING TASK BY UNIT COST
25 METER HAUL
LABOR WAGE = $0.50 per day




| | | EXCAVATE | LOAD | HAUL | UNLOAD | SPREAD |
|---|---|---|---|---|---|---|
| Method | B | D6 Dozer | Traxcavator | Truck | Labor | Grader |
| | C | D6 Dozer | Traxcavator | Truck | Labor | Labor |
| | D | D6 Dozer | Traxcavator | Tractor/ Trailer | Tip Trailer | Grader |
| | E | D6 Dozer | Traxcavator | Tractor/ Trailer | Tip Trailer | Labor |
| | F | Labor | Labor | Labor | Labor | Labor |
| | G | Labor | Labor | Wheelbarrow | Tip Wheelbarrow | Labor |
| | H | Labor | Head Baskets | Head Baskets | Labor | Grader |
| | J | Labor | Labor | Bullock Carts | Labor | Labor |
| | K | Labor | Labor | Tractor/ Trailer | Tip Trailer | Labor |
| | L | Labor | Labor | Tractor/ Trailer | Tip Trailer | Grader |
| | M | Labor | Labor | Truck | Labor | Labor |
| | N | Labor | Labor | Truck | Labor | Grader |
| | P | D7 Dozer | D7 Dozer | D7 Dozer | D7 Dozer | D7 Dozer |
| | Q | D8 Dozer | D8 Dozer | D8 Dozer | D8 Dozer | D8 Dozer |
| | R | D6 Dozer | D6 Dozer | D6 Dozer | D6 Dozer | D6 Dozer |

Source: IBRD, Phase II, op cit., p. 37.

Table 4.4

Productivity Matrix for Alternative Methods for Bulk Excavation in Earthworks (1,000 m³)

| Resources \ Methods | D6 Dozer Traxcavator Truck Grader | D6 Dozer Traxcavator Truck | D6 Dozer Traxcavator Tractor-Trailer Grader | D6 Dozer Traxcavator Tractor-Trailer | Labor | Labor Wheelbarrows | Labor Grader Grader | Labor Bullock Carts | Labor Tractor-Trailer | Labor Tractor-Trailer Grader | Labor Truck | Labor Truck Grader | D7 Dozer | D8 Dozer | D6 Dozer |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | B | C | D | E | F | G | H | J | K | L | M | N | P | Q | R |
| 2 Truck - 6m³ | 14.7 * | 14.7 | | | | | | | | | 435.0 | 435.0 | | | |
| 3 Dozer - D8 | | | | | | | | | | | | | | 2.8 | |
| 4 Traxcavator - 941B | | | 20.0 | 20.0 | | | | | | | | | | | |
| 5 Grader | 2.0 | | 2.0 | | | | 2.0 | | | 2.0 | | 2.0 | | | |
| 6 Bullock Cart | | | | | | | | 637.0 | | | | | | | |
| 7 Unskilled Labor | 22.0 | 520.0 | 32.0 | 530.0 | 4424.0 | 3318.0 | 2818.0 | 2889.0 | 2877.0 | 2377.0 | 3061.0 | 2561.0 | 4.3 | 2.8 | 6.7 |
| 8 Operator | 22.0 | 20.0 | 32.0 | 30.0 | | | 2.0 | | | 2.0 | | | 4.3 | 2.8 | 6.7 |
| 9 Truck Driver | 14.7 | 14.7 | | | | | | | | | 435.0 | 435.0 | | | |
| 10 Tractor Driver | | | 26.7 | 26.7 | | | | | 18.9 | 18.9 | | | | | |
| 11 Gas | 548.4 | 511.6 | 737.2 | 700.4 | | | 36.8 | | 182.2 | 219.0 | 101.0 | 137.8 | 124.6 | 108.3 | 118.4 |
| 12 Oil | 10.1 | 9.4 | 18.0 | 17.4 | | | 0.64 | | 4.1 | 4.7 | 1.7 | 2.3 | 2.1 | 1.6 | 2.5 |
| 13 Wheelbarrow | | | | | | 651.0 | | | | | | | | | |
| 14 Trailer | | | 26.7 | 26.7 | | | | | 601.0 | 601.0 | | | | | |
| 15 Tractor | | | 26.7 | 26.7 | | | | | 18.9 | 18.9 | | | | | |
| 16 Bulls & Driver | | | | | | | | 637.0 | | | | | | | |
| 23 Assistant Operator | 22.0 | 20.0 | 32.0 | 30.0 | | | 2.0 | | | 2.0 | | 2.0 | 4.3 | 2.8 | 6.7 |
| 44 Dozer - D6 | 10.0 | 10.0 | 10.0 | 10.0 | | | | | | | | | | | 6.7 |
| 46 Dozer - D7 | | | | | | | | | | | | | 4.3 | | |
| 48 Assistant Foreman | 10.0 | 10.0 | 10.0 | 10.0 | | | | | | | | | 4.3 | 2.8 | 6.7 |
| 49 Traxcavator - 955K | 10.0 | 10.0 | | | | | | | | | | | | | |
| 51 Gangleader | | | | | 148.0 | 111.0 | 94.0 | 96.0 | 96.0 | 79.0 | 102.0 | 85.0 | | | |

* All units are expressed in hours, except for gas and oil, which are expressed in liters.

Source: IBRD, Phase II, op cit., p. 37.

such an hypothesis.

4.3.3 Preparing the Sub-Grade

There are two sub-activities that are associated with preparing the sub-base -- i.e., spreading and mixing. The first sub-activity covers the range of material used in road construction and includes natural soils, bitumen, water, oil, etc. This activity normally uses capital-intensive methods -- i.e., scraper, grader and dozer. Although it can be conducted entirely by labor-intensive techniques, it has been observed that manual methods of spreading have not in the past been very productive and the desired output was not achieved. This may suggest that rather than an abandonment of labor-intensive techniques, further research may be required to determine new innovations in manually-operated equipment inputs for this activity.

The second sub-activity is mixing, which is concerned with stabilizing materials by combining each with either cement, lime or bituminous material. This activity is also adaptable to labor-intensive methods for low-standard roads.

4.3.4 Pavement Surfacing

Since in this research we are only concerned with low-standard rural roads such as gravel and earth roads, this activity is essentially treated in the same manner as preparing the sub-grade. In other words, this activity can be executed in basically the same manner as sub-grade preparation, both of which are amenable to labor-intensive methods except for the compaction task. This task requires equipment to achieve a certain appreciable depth of compaction which cannot be done using manual labor techniques. Higher standard road surfaces are only executable by capital-intensive production techniques because of the level of compaction that is required.

The preceding discussion has suggested areas of labor-capital substitution during different stages of the construction process. It further disaggregated the process into four stages. This was done in order to permit the engineer to estimate the quantities of materials and labor that would be required at each level of the process and for each separate task at any given time in the construction process. Most of the analysis requires technical knowledge of the way in which quantities are estimated, materials selected and the nature and choice of equipment, and as such the work reported here was directed towards project engineers.

## 4.4 The Design of Rural Roads

The standards of road projects imposed during the design phase influence decisions regarding factor inputs of labor, capital (equipment) and the materials required to produce the desired output, and in turn the choice of production techniques. Given this, it is essential that the development planners and engineers be aware of the implications of design decisions during the project design phase. That is to say, if the design is insensitive (fixed) to the changes in the factor input ratio, it reduces the opportunities for labor-capital substitution during the project's construction. Conversely, if the design is treated as variable or as a tradeoff between a design and a construction technique, then increased opportunities for input substitution are possible, given their relative availability.[2] A typical approach that results in limited opportunities for input substitution is to begin by choosing a design or setting design standards without fully taking into consideration the social and the environmental impact of the decision and not relating the design choice to conditions prevailing in the area where the project is to be situated. The alternative to this approach is to start by keeping the design choice flexible enough so that it allows for tradeoffs during the construction phase and future maintenance.

Before discussing the above in any detail, it may be useful to describe some standards that are used in the design of rural roads.

### 4.4.1 Road Design Standards*

In the design of roads, project engineers are principally concerned with achieving a "balance" in the design. This requires that all of the road geometrics be computed to accommodate the same design speed which itself should represent a reasonable approximation of actual operating speeds.

In addition, the surface of the road should be adequate to facilitate the design speed and vice versa. This

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* Geometric standards for rural roads are given in Appendix B.

issue of design speed is important in the context of developing nations because experience suggests a tendency on the part of drivers to drive far in excess of the design speed and safe operating conditions.

### 4.4.2 Design Criteria for Earth Roads

Some suggestions (see Section 3.6) have already been made regarding the criteria that planners and engineers should consider when designing rural roads. The basic notions were that rural roads should be designed to permit good access during the dry season and rather minimum access during the rainy season and that the geometrics should be of the lowest possible design standard. This is just one set of criteria regarding the design of earth roads. Earth roads may offer wider possibilities for labor-capital substitution because of low standard designs, which in some cases has meant a handmade track. Other types of rural roads also offer opportunities for labor-capital substitution, as will be shown below.

### 4.4.3 Design Standards for Gravel and Higher Standard Roads

The acceptable practice for the design of gravel and higher standard rural roads is to set geometric standards for the following:

a) horizontal curvature

b) vertical curvature

c) road widths
   1) lane widths

2) roadbed width
3) shoulder width

d) site distance
   1) passing
   2) non-passing
   3) approaching

e) gradients[3]

Geometric standards for intersection layout are usually specified by engineers. Although we are concerned with rural roads which presume that they will intersect a primary or secondary road, no treatment of layout for intersections are included in this discussion. This is due to the fact that intersection requirements for low-volume roads are generally minimal.

### 4.4.4 The Design Speed

The general philosophy behind the design speed, at least as practiced in the United States, is to set the speed consistent with observed traffic levels and speeds under similar operating conditions. This is done because speed is considered to be a function of the driver's behavior and the performance of the vehicles.[4] However, there are other factors that must likewise be considered. These include a) the difficulty and expense of construction as influenced by topographic and geological conditions; and b) the availability of resources to carry out the work.[5]

Under most circumstances changes in the design speed will be affected by changes in the type of terrain and/or other local conditions. For instance, a road beginning in a valley and crossing a mountain range and then ending in a valley on the other side of the range would be divided into different design sections because of the differences in the characteristics of the road.[6] This will require that individual design sections be of a sufficient length to maintain some consistency in the design speed which may not always be possible if the road is of a short length. Some typical design speeds as practiced in different countries are given in Figure B.1 of Appendix B and in Figure 4.5. The relationship between design speed and construction costs in different terrain is presented.

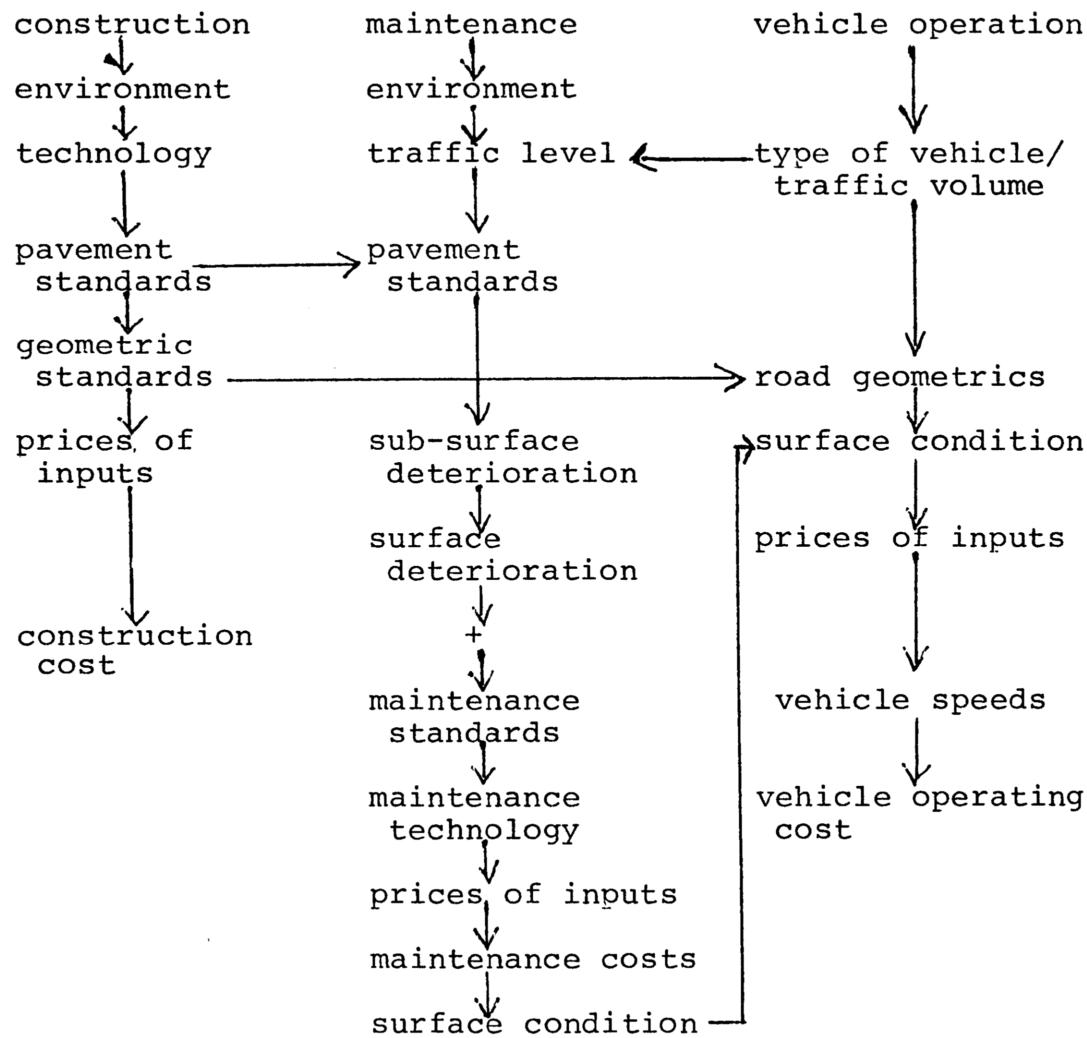
## 4.5 Economic Aspects of the Analysis Framework

In Chapter 3 we suggested that project planners sometimes do not conduct a social-cost benefit analysis to select the optimal mix of production techniques. Oftentimes the planner, when evaluating public projects, will use only market prices of factor inputs which cannot measure the affects of these inputs on the economy, given certain national policy and social objectives. The following treatment sets out an approach for project planners in the evaluation of rural road projects. The section is intended to complement the work of the engineer whose approach to labor-capital substitution was outlined in the preceding section.

Once all of the factor input requirements are quantified according to the approach outlined in Section 4.2, the next precedure is to conduct a social-cost analysis of using these inputs. This procedure will be referred to in this section as the economic analysis.

FIGURE 4.4

Inter-Relationship Among Construction, Maintenance and Vehicle Operating Costs




Source: Harral, C.G. and S.K. Agarwal. "Highway Design Study," paper in Low-Volume Roads, National Academy of Sciences, Special Report 160 (Washington, D.C.: Transport Research Board), p. 20.

In the engineering analysis, we disaggregated the construction process into four separate activities. Given this, the economist would now have to determine the aggregate consumption cost of each individual activity under different assumptions. This will further involve breaking down the cost for each activity into the cost of equipment, skilled and unskilled labor, and materials. These costs are to be measured at their market prices. They are then shadow priced to account for price distortions in the market.

### 4.5.1 Data Inputs

In order to implement the methodology discussed in the preceding chapter, two sets of data are required. The first pertains to changes in the fixed cost as the design standards are varied. The second set of data is concerned with estimating variation in current costs for different classes of vehicles using the road to changes in the design standards.

### 4.5.2 Fixed Costs

The project planner will want to determine the variation in fixed costs to changes in design standards. This can be done by analyzing completed road construction projects in the area of concern,since cost factors may vary from region to region. In particular, this may involve disaggregating the cost in relationship to design standards.

#### 4.5.2.1 Construction Costs

In this section, data for construction costs were obtained from a road feasibility study in Liberia, West Africa. The project was a 38 mile gravel road that was to connect two rural towns. The cost components of the project are itemized below:

Estimated Costs for a 38-Mile Gravel Road

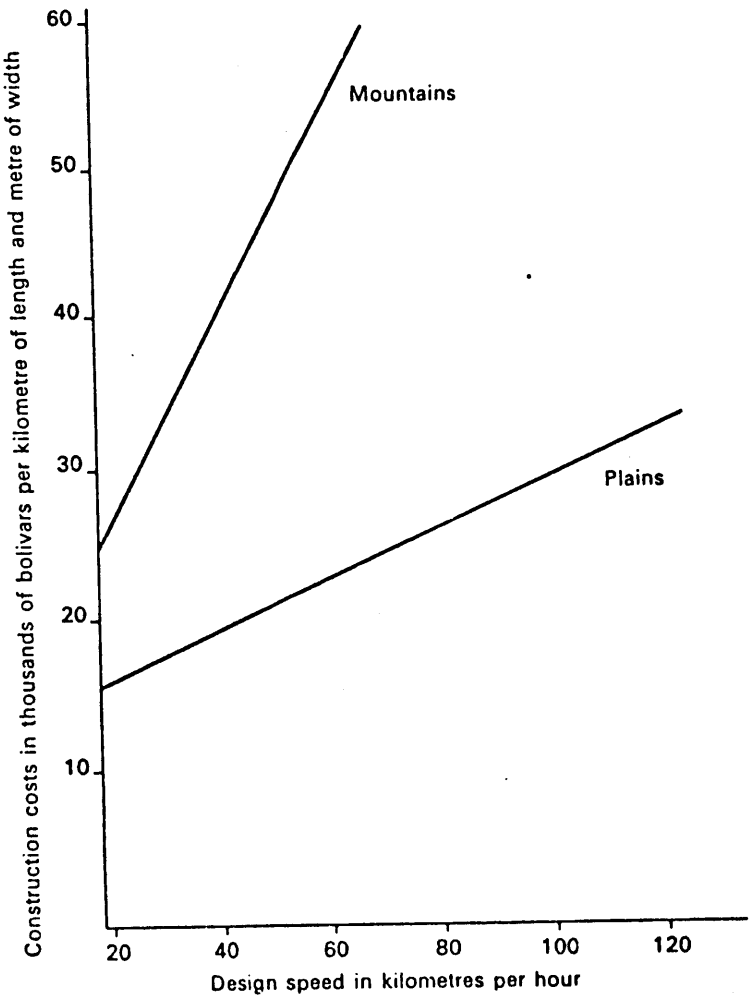
| Cost Component | Cost (in U.S.$'000) |
|---|---|
| Clearing and Grubbing | 180 |
| Unclassified Excavation | 1,714 |
| Selected Burrow Topping | 272 |
| Furrow Ditches | 135 |
| Excavation for Drainage Ditches | 33 |
| Overhaul, Station Yards | 312 |
| Yardmile Overhaul (Selected) | 81 |
| Drainage Structures | 874 |
| Cost of Work | 3,607 |
| Contingencies, 15% | 541 |
| Supervision | 207 |
| Total Project Cost | $4,455 |

The major design variables that should be considered at the planning level are design speed and roadway width, which will be discussed in detail later in this section. It will also be shown that the choice of design speed is associated with other factors that influence road construction cost, such as sight distance and horizontal and vertical curvature, as well as gradient.

The data that are used for construction cost should be based on prevailing road construction practices and completed projects. These data are oftentimes given in a typical bill of quantities as unit prices for materials, which include the contractor's overhead cost and profit. Construction

Figure 4.5

Example of the relationship between design speed and construction cost in different terrains




Source: Soberman, op cit.

costs in addition are given in per mile (per km) cost in engineering-economy studies, which also include the contractor's overhead and profit. A typical bill of quantities is shown in Table 4.2.

4.5.3 Current Costs

Annual maintenance and vehicle operating costs are included in what is known as current cost. The maintenance costs generally include fixed and variable cost components. The fixed components are the results of road surface deterioration and structures due to environmental factors -- i.e., vegetation encroachment and heavy rain. A typical situation in developing countries, at least in tropical climates, is that rainfall is probably the most important environmental factor that influences maintenance costs. Under some circumstances, during the rainy season the cost of maintaining a rural road can become so exorbitant that it may become cheaper to pave the road to a higher standard. This may, in part, account for the general lack of adequate maintenance programs in many developing countries. The variable maintenance component, on the other hand, depends on the traffic levels and loadings. For a given road, the annual maintenance cost can be expressed as:

$$C_m = C \times F_t \times F_w \times L^*$$

where $C_m$ = annual maintenance cost for a road

* The equation referred to here was used in a highway maintenance study of roads in the Republic of Liberia in 1971 for IBRD.

$C$ = cost per mile

$F_t$ = traffic adjustment factor

$F_w$ = width adjustment factor

$L$ = road length in miles

$$F_t = (1 + \frac{T-T_b}{2T_b})$$

where $T_b$ = basic ADT = 100 for laterite roads (ADT is the average daily traffic)

$T$ = ADT on road

$$F_w = \frac{W}{W_b}$$

where $W_b$ = basic width = 20 feet

$W$ = width of proposed road

The width adjustment factor $F_w$ and the traffic adjustment factor $F_t$ were included to account for variations in the design standards for earth and gravel roads. Generally, differences in the design standards do not produce significant differences in the overall pattern of maintenance cost during the project's life. Load applications near the edge of a pavement surface produce more deterioration in pavements and shoulders than those applied towards the center line of the road. Thus, the area to be maintained per mile (per kilometer) increases as road widths increase. The relative frequency of edge applications decrease and normally tend to offset maintenance cost increase. That is to say, total maintenance costs remain the same and the productivity of the maintenance crew is forced to increase or the

Table 4.5

Annual Maintenance Cost* for a Rural Road

| | Proposed Road Length 38 Miles | | | |
|---|---|---|---|---|
| Year | T=ADT | Feet | Maintenance Cost (US$ Million) | Per Mile (US$) |
| 1980 | 225 | 1.62 | 0.108 | 2,800 |
| 1981 | 232 | 1.66 | 0.110 | 2,900 |
| 1982 | 241 | 1.70 | 0.113 | 3,000 |
| 1983 | 253 | 1.76 | 0.117 | 3,100 |
| 1984 | 265 | 1.82 | 0.121 | 3,200 |
| 1985 | 277 | 1.88 | 0.125 | 3,300 |
| 1986 | 292 | 1.96 | 0.130 | 3,400 |
| 1987 | 309 | 2.04 | 0.136 | 3,600 |
| 1988 | 325 | 2.12 | 0.141 | 3,700 |
| 1989 | 338 | 2.19 | 0.146 | 3,800 |
| 1990 | 357 | 2.28 | 0.151 | 3,900 |
| 1991 | 371 | 2.36 | 0.157 | 4,100 |
| 1992 | 383 | 2.42 | 0.161 | 4,200 |
| 1993 | 398 | 2.49 | 0.165 | 4,300 |
| 1994 | 411 | 2.56 | 0.170 | 4,400 |
| 1995 | 425 | 2.62 | 0.174 | 4,500 |
| 1996 | 441 | 2.71 | 0.180 | 4,700 |

*Maintenance costs are calculated at market prices in 1976.

Source: Technical and Economic Feasibility Study of a Rural Road in Liberia, West Africa, 1977.

Table 4.6

Annual Maintenance Cost for a Rural Road in Shadow Prices*

| | Road Length: 38 Miles | | | |
|---|---|---|---|---|
| Year | T=ADT | Feet | Maintenance Cost (US$ Million) | Per Mile (US$) |
| 1980 | 225 | 1.62 | .082 | 2,158 |
| 1981 | 232 | 1.66 | .083 | 2,184 |
| 1982 | 241 | 1.70 | .086 | 2,263 |
| 1983 | 253 | 1.76 | .089 | 2,342 |
| 1984 | 265 | 1.82 | .092 | 2,421 |
| 1985 | 277 | 1.88 | .095 | 2,500 |
| 1986 | 292 | 1.96 | .099 | 2,605 |
| 1987 | 309 | 2.04 | .103 | 2,711 |
| 1988 | 325 | 2.12 | .107 | 2,816 |
| 1989 | 338 | 2.19 | .111 | 2,921 |
| 1990 | 357 | 2.28 | .115 | 3,026 |
| 1991 | 371 | 2.36 | .119 | 3,132 |
| 1992 | 383 | 2.42 | .122 | 3,211 |
| 1993 | 398 | 2.49 | .125 | 3,289 |
| 1994 | 411 | 2.56 | .129 | 3,395 |
| 1995 | 425 | 2.62 | .132 | 3,474 |
| 1996 | 441 | 2.71 | .137 | 3,605 |

*Costs are shadow priced assuming the following: 15% of total annual cost is in foreign exchange, foreign exchange shadow rate=1.75 x nominal rate; 80% of maintenance cost is in wages to unskilled labor, shadow wage rate for unskilled labor=.5 x market wage rate.

Source: Liberia Road Feasibility Study, op cit.

crew size may become larger to increase productivity.

4.5.3.1 Vehicle Operating Costs

Vehicle operating costs are also disaggregated into two categories--fixed costs or costs associated with owning the vehicle that are independent of the vehicle use, and variable costs or costs related to operating the vehicle. Fixed vehicle costs are categorized as depreciation costs, insurance, taxes, licenses and interests.

Variable vehicle costs are the depreciation costs when the vehicle is put in use. These costs are driver's wages and their helpers, tires, fuel, lubricants, repairs and maintenance costs.

In developing countries, changes in road design standards oftentimes affect the fixed cost by significantly increasing the useful life of the vehicle through improved road surfaces, horizontal and vertical alignments, and increased running speeds. Procedures for estimating road user costs were discussed by deWilde of IBRD, and the treatment of this issue is deemed outside the scope of this thesis.*

The vehicle operating costs presented in Tables 4.6-4.9 are based on actual conditions in a West African country. As the tables indicate, operating costs were estimated at market and shadow prices for eight classes of vehicles operating on gravel and earth roads.

The inter-relationships between vehicle operating costs,

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* The reader should refer to the following citation for vehicle operating cost factors: Jan deWilde, Quantification of Road User Savings (Baltimore: Johns Hopkins University Press, 1966).

Table 4.7

Summary of Vehicle Operating Costs on a Gravel Road at Market Prices (in U.S. cent/mi.)

Speed: 30 MPH    Road Length: 60 Miles    Condition: Good

| Vehicle Type / Cost Items | Private Car | Taxi | Small Pick-up | Large Pick-up | Small Bus | Large Bus | 3-4 Ton Truck | 6-8 Ton Truck |
|---|---|---|---|---|---|---|---|---|
| Wages | --- | 2.40 | 3.00 | 4.00 | 3.43 | 3.00 | 8.03 | 7.84 |
| Insurance | 3.13 | 1.40 | 1.75 | 2.33 | 2.91 | 2.88 | 3.40 | 4.56 |
| Interest | 1.59 | 0.40 | 0.55 | 1.39 | 1.21 | 1.19 | 1.48 | 1.85 |
| Taxes | --- | --- | --- | --- | --- | --- | --- | --- |
| Depreciation | 8.51 | 3.22 | 4.32 | 8.97 | 9.84 | 9.67 | 4.83 | 6.04 |
| Fixed Costs | 13.23 | 7.42 | 9.62 | 16.69 | 17.39 | 16.74 | 17.74 | 20.29 |
| Tires | 1.15 | 0.75 | 1.12 | 1.56 | 1.12 | 1.67 | 11.89 | 18.22 |
| Fuel | 3.18 | 3.02 | 3.82 | 4.58 | 4.58 | 5.50 | 7.00 | 8.17 |
| Lubricants | 0.32 | 0.30 | 0.38 | 0.46 | 0.46 | 0.55 | 0.70 | 0.82 |
| Repair & Maint. | 6.91 | 1.94 | 3.00 | 3.99 | 3.40 | 3.36 | 3.97 | 5.32 |
| Variable Costs | 11.56 | 6.43 | 8.32 | 10.59 | 9.56 | 11.08 | 23.56 | 32.53 |
| TOTAL | 24.79 | 13.85 | 17.94 | 27.28 | 26.95 | 27.82 | 41.30 | 52.82 |

Note: Cost items were priced at their market value in 1976.

Source: These data are based on a technical and economic feasibility study of a road project in Liberia, West Africa conducted in 1977.

Table 4.8

Summary of Vehicle Operating Costs on an Earth Road at Market Prices (US ¢/mi.)

Speed: 30 MPH Road Length: 60 Miles Condition: Good

| Vehicle Type / Cost Items | Private Car | Taxi Taxi | Small Pick-up | Large Pick-up | Small Bus | Large Bus | 3-4 Ton Truck | 6-8 Ton Truck |
|---|---|---|---|---|---|---|---|---|
| Wages | --- | 2.11 | 2.64 | 3.52 | 3.02 | 2.64 | 7.07 | 6.91 |
| Insurance | 2.87 | 1.29 | 1.61 | 2.14 | 2.67 | 2.64 | 3.12 | 4.19 |
| Interest | 1.50 | 0.38 | 0.52 | 1.31 | 1.14 | 1.12 | 1.39 | 1.74 |
| Taxes | --- | --- | --- | --- | --- | --- | --- | --- |
| Depreciation | --- | --- | --- | --- | --- | --- | --- | --- |
| Fixed Costs | 4.37 | 3.78 | 4.77 | 6.97 | 6.83 | 6.40 | 11.58 | 11.84 |
| Tires | 1.43 | 0.93 | 1.39 | 1.93 | 1.39 | 2.07 | 14.74 | 22.60 |
| Fuel | 3.53 | 3.35 | 4.24 | 5.08 | 5.08 | 6.11 | 7.77 | 9.07 |
| Lubricants | 0.35 | 0.34 | 0.42 | 0.51 | 0.51 | 0.61 | 0.78 | 0.91 |
| Repair & Maint. | 69.10 | 19.40 | 30.00 | 39.90 | 34.00 | 33.60 | 39.70 | 53.20 |
| Variable Costs | 74.41 | 24.02 | 36.05 | 47.42 | 40.98 | 43.39 | 62.99 | 85.78 |
| TOTAL | 78.78 | 27.80 | 40.82 | 54.39 | 47.81 | 49.79 | 74.57 | 97.62 |

Source: Liberia Road Reasibility Study, 1977, op cit.

Table 4.9

Summary of Vehicle Operating Costs on a Gravel Road at Shadow Prices (in U.S. cent/mi.)

Speed: 30 MPH Length: 60 Miles Condition: Good

| Vehicle Type / Cost Item* | Private Car | Taxi | Small Pick-up | Large Pick-up | Small Bus | Large Bus | 3-4 Ton Truck | 6-8 Ton Truck |
|---|---|---|---|---|---|---|---|---|
| Wages | --- | 2.11 | 2.64 | 3.52 | 3.02 | 2.64 | 7.07 | 6.91 |
| Insurance | 2.87 | 1.29 | 1.61 | 2.14 | 2.67 | 2.64 | 3.12 | 4.19 |
| Interest | 1.50 | 0.38 | 0.52 | 1.31 | 1.14 | 1.12 | 1.39 | 1.74 |
| Taxes | --- | --- | --- | --- | --- | --- | --- | --- |
| Depreciation | 8.02 | 3.03 | 4.07 | 8.45 | 9.27 | 9.11 | 4.55 | 5.69 |
| Fixed Costs | 12.39 | 6.81 | 8.84 | 15.42 | 16.10 | 15.51 | 16.13 | 18.53 |
| Tires | 1.08 | 0.71 | 1.06 | 1.47 | 1.06 | 1.57 | 11.20 | 17.16 |
| Fuel | 3.00 | 2.84 | 3.60 | 4.31 | 4.31 | 5.18 | 6.59 | 7.70 |
| Lubricants | 0.30 | 0.28 | 0.36 | 0.43 | 0.43 | 0.52 | 0.66 | 0.77 |
| Repair & Maint. | 6.34 | 1.78 | 2.75 | 3.66 | 3.12 | 3.08 | 3.64 | 4.88 |
| Variable Costs | 10.72 | 5.61 | 7.77 | 9.87 | 8.92 | 10.35 | 22.09 | 30.41 |
| TOTAL | 23.11 | 12.42 | 16.61 | 25.29 | 24.02 | 25.86 | 38.22 | 48.94 |

Note: All cost items were shadow priced using the following adjustment factors: Wages, skilled = .881; Insurance = .878; Interest = .866; Depreciation = .866; Tires = .866, Fuel and Lubricants = .866; Repairs and Maintenance = .878. These factors were extracted from REF 42 in Chapter 3 and were intended solely to demonstrate changes in the price inputs from market to shadow prices--the prices do not reflect actual conditions.

Source: Derived from Table 4.7.

Table 4.10

Summary of Vehicle Operating Costs on an Earth Road at Shadow Prices
(in U.S. cent/mi.)

Speed: 30 MPH Road Length: 60 Miles Condition: Good

| Vehicle Type / Cost Item | Private Car | Taxi | Small Pick-up | Large Pick-up | Small Bus | Large Bus | 3-4 Ton Truck | 6-8 Ton Truck |
|---|---|---|---|---|---|---|---|---|
| Wages | --- | 1.86 | 2.33 | 3.10 | 2.66 | 2.33 | 6.23 | 6.09 |
| Insurance | 2.63 | 1.18 | 1.48 | 1.96 | 2.45 | 2.42 | 2.86 | 3.85 |
| Interest | 1.41 | 0.36 | 0.49 | 1.23 | 1.07 | 1.06 | 1.31 | 1.64 |
| Taxes | --- | --- | --- | --- | --- | --- | --- | --- |
| Depreciation | --- | --- | --- | --- | --- | --- | --- | --- |
| Fixed Costs | 4.04 | 3.30 | 4.30 | 6.29 | 6.18 | 5.81 | 10.40 | 11.58 |
| Tires | 1.35 | 0.88 | 1.31 | 1.82 | 1.31 | 1.95 | 13.86 | 21.29 |
| Fuel | 3.33 | 3.16 | 3.99 | 4.79 | 4.79 | 5.71 | 7.32 | 8.54 |
| Lubricants | 0.33 | 0.32 | 0.40 | 0.48 | 0.48 | 0.57 | 0.73 | 0.85 |
| Repairs & Maint. | 63.43 | 17.81 | 27.54 | 36.63 | 31.21 | 30.84 | 36.44 | 48.84 |
| Variable Costs | 68.84 | 22.17 | 33.24 | 43.72 | 37.70 | 39.07 | 58.35 | 79.52 |
| TOTAL | 72.48 | 25.47 | 37.54 | 50.01 | 43.97 | 44.88 | 68.75 | 91.10 |

Note: The use of shadow prices here are fictitious and do not reflect the actual conditions in the country where the base data was obtained.

Source: Data werederived from Table 4.8.

maintenance costs and construction costs are given in Figure 4.4.

#### 4.5.4 Combined Fixed and Current Costs

After determining the variation for fixed and current costs in terms of changes in design standards and vehicle size, this information can now be applied to the analytical framework for selecting the optimal technology as discussed earlier. That is to say, estimates of total annual current costs for a rural road in a West African country were calculated for each year from 1980 to 1996. Maintenance costs based on equations previously discussed were computed for the various road types. Construction costs for each road type were estimated given recent construction practices and completed projects. The next procedure was to discount the current cost and future benefits over the useful life of the project. This allows the project planner to describe the substitution possibilities between the current and fixed costs. In order to compare the cost on a coordinate system, the fixed costs have to be amortized at an interest rate (in this case 12%) on an annual basis. This will then show the substitution relationship as it is determined by the point of tangency between the isoproduct curve and the isocost line.

For each of the two designs on the isoproduct curves, the fixed investments are different. This corresponds to a specific set of design choices or standards. The optimal choice is the one having the highest benefit-cost ratio and the ability to meet the intended social objectives.

The economic analysis that follows consists of two rural road projects--a gravel road and an earth road. The two projects were compared to an earth track (road) with respect to their technical and economic feasibility. The original design of both project costs were based on input factors calculated in market prices. This analysis recalculated the input factors in shadow prices and then conducted a sensitivity analysis using a higher discount rate. This was done in order to determine whether opportunities for labor-capital substitution exist.

Tables 4.11 through 4.14 are the result of the economic analysis for each of the two road projects discussed above. The two projects were calculated both in shadow prices and market prices in terms of their fixed and current costs. The decisions maker is thus presented with a group of projects in shadow and market prices, corresponding to two design choices.

As revealed by the economic analysis, the project having the highest benefit-cost ratio was the earth road project computed in market prices (see Table 4.12). This project has a benefit-cost ratio of 1.73 compared to the other projects. The ranking of the projects are given below:

| | B/C Ratio | |
|---|---|---|
| Project | discounted at 12% | discounted at 20% |
| earth road in market prices | 1.73 | 1.21 |
| gravel road in market prices | 1.62 | 1.13 |
| earth road in shadow prices | 1.29 | 0.88 |
| gravel road in shadow prices | 1.17 | 0.80 |

Table 4.11

<u>Economic Analysis for Gravel Road Project in Market Prices</u>
(in U.S.$'000)

| Year | Costs | | | Benefits | Discounted at 12% | | Discounted at 20% | |
|---|---|---|---|---|---|---|---|---|
| | Construction | Maintenance | Total | User Savings* | Costs | Benefits | Costs | Benefits |
| 1978 | 1.100 | | 1.100 | | .982 | | .916 | |
| 1979 | 1.650 | | 1.650 | | 1.315 | | 1.145 | |
| 1980 | 1.650 | .108 | 1.758 | .863 | 1.251 | .614 | 1.107 | .499 |
| 1981 | | .110 | .110 | 1.029 | .070 | .653 | .053 | .496 |
| 1982 | | .113 | .113 | 1.158 | .064 | .657 | .045 | .465 |
| 1983 | | .117 | .117 | 1.106 | .059 | .560 | .039 | .370 |
| 1984 | | .332 | .332 | 1.273 | .150 | .576 | .093 | .355 |
| 1985 | | .125 | .125 | 1.489 | .051 | .480 | .029 | .346 |
| 1986 | | .130 | .130 | .775 | .047 | .280 | .025 | .150 |
| 1987 | | .136 | .136 | 1.617 | .044 | .521 | .022 | .261 |
| 1988 | | .481 | .481 | 1.912 | .138 | .549 | .065 | .257 |
| 1989 | | .146 | .146 | 1.092 | .038 | .280 | .016 | .123 |
| 1990 | | .151 | .151 | 1.251 | .035 | .287 | .014 | .117 |
| 1991 | | .157 | .157 | 2.328 | .032 | .476 | .012 | .181 |
| 1992 | | .520 | .520 | 1.430 | .095 | .261 | .034 | .092 |
| 1993 | | .165 | .165 | 1.622 | .027 | .264 | .009 | .088 |
| 1994 | | .170 | .170 | 1.885 | .024 | .275 | .008 | .085 |
| 1995 | | .174 | .174 | 1.750 | .022 | .228 | .007 | .066 |
| 1996 | | .560 | .560 | 1.986 | .058 | .231 | .018 | .062 |
| | | | | | 4.502 | 7.282 | 3.567 | 4.013 |

Note: Discount Rate=12%; Benefit/Cost Ratio (B/C)=1.62; at 20%, B/C=1.13. Costs are in market prices.

* User savings are the reduced vehicle operating costs from an earth track to a gravel road, using a factor of 2.0.

Source: Liberia Road Feasibility Study, <u>op cit</u>.

Table 4.12

Economic Analysis for Earth Road Project in Market Prices
(in U.S.$'000)

| | Costs | | | Benefits | Discounted at 12% | | Discounted at 20% | |
|---|---|---|---|---|---|---|---|---|
| Year | Construction | Maintenance | Total | User Savings* | Costs | Benefits | Costs | Benefits |
| 1978 | .909 | | .909 | | .812 | | .757 | |
| 1979 | 1.095 | | 1.095 | | .878 | | .760 | |
| 1980 | 1.095 | .075 | 1.170 | .682 | .832 | .485 | .677 | .395 |
| 1981 | | .091 | .091 | .882 | .052 | .560 | .044 | .425 |
| 1982 | | .095 | .095 | .914 | .054 | .519 | .038 | .367 |
| 1983 | | .100 | .100 | .873 | .051 | .442 | .033 | .292 |
| 1984 | | .217 | .217 | 1.005 | .098 | .455 | .061 | .244 |
| 1985 | | .112 | .112 | 1.175 | .045 | .475 | .026 | .273 |
| 1986 | | .118 | .118 | .612 | .043 | .221 | .023 | .119 |
| 1987 | | .125 | .125 | 1.276 | .040 | .411 | .020 | .206 |
| 1988 | | .461 | .461 | 1.509 | .133 | .434 | .062 | .203 |
| 1989 | | .138 | .138 | .862 | .035 | .221 | .015 | .097 |
| 1990 | | .147 | .147 | .988 | .034 | .226 | .014 | .092 |
| 1991 | | .155 | .155 | 1.862 | .032 | .381 | .012 | .145 |
| 1992 | | .561 | .561 | .652 | .103 | .119 | .036 | .042 |
| 1993 | | .165 | .165 | 1.280 | .027 | .208 | .009 | .069 |
| 1994 | | .168 | .168 | 1.488 | .025 | .217 | .008 | .067 |
| 1995 | | .177 | .177 | 1.382 | .023 | .180 | .007 | .052 |
| 1996 | | .634 | .634 | 2.521 | .074 | .292 | .020 | .079 |
| | | | | | 3.389 | 5.846 | 2.622 | 3.167 |

Note: Discount Rate=12%; Benefit/Cost Ratio (B/C)=1.73; at 20%, B/C ratio=1.21.

* User savings are taken as reduced vehicle operating cost from an earth track to an improved earth road and are assumed to be reduced by a factor of .83.

Source: Liberia Road Feasibility Study, op cit.

Table 4.13

<u>Economic Analysis for Gravel Road Project in Shadow Prices</u>
(in U.S.$'000)

| | Costs | | | Benefits | Discounted at 12% | | Discounted at 20% | |
|---|---|---|---|---|---|---|---|---|
| Year | Construction | Maintenance | Total | User Savings* | Costs | Benefits | Costs | Benefits |
| 1978 | 1.210 | | 1.210 | | 1.080 | | 1.008 | |
| 1979 | 1.815 | | 1.815 | | 1.447 | | 1.260 | |
| 1980 | 1.815 | .082 | 1.897 | .655 | 1.350 | .466 | 1.098 | .379 |
| 1981 | | .083 | .083 | .782 | .053 | .497 | .040 | .377 |
| 1982 | | .086 | .086 | .880 | .049 | .499 | .035 | .354 |
| 1983 | | .089 | .089 | .664 | .045 | .336 | .029 | .222 |
| 1984 | | .252 | .252 | .967 | .114 | .437 | .070 | .270 |
| 1985 | | .095 | .095 | 1.132 | .038 | .457 | .022 | .263 |
| 1986 | | .099 | .099 | .589 | .035 | .212 | .019 | .114 |
| 1987 | | .103 | .103 | 1.229 | .037 | .396 | .017 | .199 |
| 1988 | | .366 | .366 | 1.453 | .105 | .418 | .049 | .196 |
| 1989 | | .111 | .111 | .830 | .029 | .213 | .012 | .093 |
| 1990 | | .115 | .115 | .951 | .026 | .218 | .011 | .089 |
| 1991 | | .119 | .119 | 1.770 | .024 | .362 | .009 | .138 |
| 1992 | | .395 | .395 | 1.087 | .072 | .199 | .026 | .071 |
| 1993 | | .125 | .125 | .951 | .020 | .155 | .007 | .051 |
| 1994 | | .129 | .129 | 1.233 | .019 | .180 | .006 | .056 |
| 1995 | | .132 | .132 | 1.433 | .017 | .186 | .005 | .054 |
| 1996 | | .426 | .426 | 1.511 | .050 | .175 | .013 | .047 |
| | | | | | 4.610 | 5.406 | 3.736 | 2.973 |

Note: Costs are shadow priced assuming the following: construction costs--30% in foreign exchange, foreign exchange shadow rate=1.75; 50% in unskilled labor, shadow wage rate=.5. Maintenance costs are shadow priced at 1.75 for foreign exchange, which was 15% of total cost, .5 for unskilled labor, which was 80% of total cost.

* User savings are the reduced vehicle cost from an earth track to a gravel road and are assumed here to be reduced by a factor of 2.0. Discount rate at 12%--B/C ratio =1.17; Discount rate at 20%--B/C ratio=0.80.

Source: Liberia Road Feasibility Study, <u>op cit</u>.

Table 4.14

Economic Analysis for Earth Road Project in Shadow Prices
(in U.S.$'000)

| | Costs | | | Benefits | Discounted at 12% | | Discounted at 20% | |
|---|---|---|---|---|---|---|---|---|
| Year | Construction | Maintenance | Total | User Savings* | Costs | Benefits | Costs | Benefits |
| 1978 | 1.000 | | 1.000 | | .893 | | .833 | |
| 1979 | 1.250 | | 1.250 | | .996 | | .868 | |
| 1980 | 1.250 | .057 | 1.307 | .518 | .889 | .369 | .756 | .300 |
| 1981 | | .069 | .069 | .617 | .044 | .392 | .032 | .298 |
| 1982 | | .072 | .072 | .695 | .041 | .394 | .029 | .279 |
| 1983 | | .076 | .076 | .664 | .039 | .336 | .025 | .222 |
| 1984 | | .165 | .165 | .764 | .067 | .346 | .046 | .213 |
| 1985 | | .085 | .085 | .893 | .031 | .361 | .020 | .208 |
| 1986 | | .090 | .090 | .465 | .033 | .168 | .017 | .090 |
| 1987 | | .095 | .095 | .970 | .031 | .312 | .015 | .157 |
| 1988 | | .350 | .350 | 1.147 | .101 | .330 | .047 | .154 |
| 1989 | | .105 | .105 | .655 | .027 | .168 | .012 | .074 |
| 1990 | | .112 | .112 | .751 | .026 | .172 | .010 | .070 |
| 1991 | | .118 | .118 | 1.415 | .024 | .290 | .009 | .110 |
| 1992 | | .427 | .427 | .858 | .078 | .157 | .028 | .056 |
| 1993 | | .126 | .126 | .973 | .021 | .159 | .007 | .053 |
| 1994 | | .128 | .128 | 1.131 | .017 | .165 | .006 | .051 |
| 1995 | | .135 | .135 | 1.050 | .016 | .137 | .005 | .040 |
| 1996 | | .482 | .482 | 1.916 | .050 | .222 | .017 | .060 |
| | | | | | 3.463 | 4.478 | 2.782 | 2.435 |

Note: Discount rate=12%; Benefit/Cost ratio (B/C)=1.29; at 20% discount rate, B/C=.88. Costs are in shadow prices.

* User savings are the reduced vehicle operating cost from an earth track to an improved earth road and are assumed to be reduced by a factor of .83.

Source: Liberia Road Feasibility Study, op cit.

While the earth road project calculated in market prices is clearly superior economically speaking, this project may not meet the social objectives of the region or the nation. Factor inputs at market prices tend to favor capital-intensive technology because of the lower cost for equipment and higher labor cost. Thus, if the social objective is to increase employment opportunities, then it is not likely to be met under these conditions.

At a discount rate of 12 per cent, which closely approximates the opportunity cost of capital where the original data base was obtained, both of the projects in shadow and market prices were economically feasible. If the decision maker had placed a higher value on meeting social objectives rather than simply on economic justification, further consideration would have been given to the two projects calculate in shadow prices where significant differences exist in their initial investment cost (see Tables 4.13 and 4.14). The earth road project in shadow prices requires an initial capital outlay of 3.5 million dollars and the gravel road project in shadow prices requires some 4.8 million dollars. These initial investment costs are quite significant for low standard roads. If one compares these costs to the cost of the earth project in market prices, whose initial investment was only 3.0 million dollars, there is only a moderate difference between the earth project in shadow prices and market prices, representing a difference of .5 million dollars.

The above clearly suggests that the earth road should be chosen and that if the input factors were shadow priced then a wider opportunity would exist for substituting labor for capital because the cost of equipment would not appear as cheap as it did and, conversely, unskilled labor would not have been so costly as it was. Hence, the optimal technology choice from a social and economic point of view is the earth project at a discount rate of 12 per cent.

A sensitivity analysis was conducted for each project using a discount rate of 20 per cent. The result of this analysis is also contained in Tables 4.11 through 4.14. The analysis revealed that only the projects calculated in market prices were economically justifiable. This may indicate several things:

a) To begin with, the discount rate chosen may be too high and further consideration should be given to discounting the costs and benefits at a lower discount rate.

b) The fixed cost could be spread over four years rather than three.

c) The current cost, particularly the maintenance costs, could be spread over five years rather than three to four years.

d) More consideration could be given to the design standards such that more labor-capital substitution possibilities exist or the project could be redesigned altogether.

The above are only some feedback mechanisms that the project planner should consider when planning a rural road project under the conditions discussed above. The project planner is only charged with presenting the alternative as objectively as possible. In the final analysis, the choice of what technological choice should be chosen rests in the hands of the decision makers, who may not always base their decisions solely on objective factors.

## 4.6 Summary

The present chapter suggested a way in which the analysis framework for labor-capital substitution could be implemented at the project level. The methodology essentially consisted of a social-cost benefit analysis which considered the factor inputs in terms of their social prices. The question of the choice of technology was viewed as being directly dependent upon the design and relative availability of factor inputs (economic factors).

The degree of labor-capital substitution was taken as the tradeoff between current -- i.e., maintenance and vehicle operating costs -- and the initial fixed cost or construction cost between the two standards of roads. These inputs were then summarized where the present worth of the benefits and costs were discounted over the life of the project and expresses as a ratio of $\Delta B/\Delta C$.

# CHAPTER 5

# SUMMARY AND CONCLUSIONS

## 5.1 Limitations of the Study

The conclusions reached in this research are subject to some qualifications and limitations. To begin with, the theoretical formulation of the model is rather conceptual and to some extent is an oversimplification regarding the real world. That is to say, production functions in actual situations may not respond in such a smooth manner along the isoproduct curve. This is oftentimes due to the lack of awareness of the range of technological alternatives on the part of project engineers. Conceivably, there could be two points on the isoproduct curve that may be tangent to the isocost line, which may suggest improperly defined factor-combinations. On the other hand, however, the general theory of the production function is that it is believed to behave in a sort of concave manner in spite of the lack of knowledge of the shape of the curve between different points.

The second issue that warrants some caution is the overenthusiasm of using shadow pricing techniques. There are many practical problems that may be encountered. The first is that of estimation in terms of the heterogeneous nature of the factor inputs and their supply. For instance, different wage rates have been observed in different regions of a given country. This may indicate some difficulty in estimation when less information is known about the wage structure in certain regions. The other aspect of the problem is that of supply. The labor supply in most rural areas is available only in certain off-season periods, which also suggests seasonal variations in the wage rate. This may not be such an easy factor to quantify as may be suspected.

The third, and perhaps most important, qualification of the study relates to the issue of alternative technology and the application of shadow prices. The author does not insist that alternative technologies can be found in all circumstances by correcting market imperfections in the factor inputs of a given technology, because in some cases only one technology is possible. Even with the application of shadow prices, some construction activities have been found to be sub-optimum. However, correction factors can be useful in estimating the real cost to the economy of using a certain input.

The final issue is that of long-term planning for rural roads in developing countries. Road facilities are typically planned using 15 to 20 year time horizons. That is to say, the expected useful life of a road facility is normally taken as between 15 and 20 years or at least the project is expected to realize the return on the initial investment over this period, given an expected level of benefits to be received. It has been observed that rural roads may not always realize expected traffic levels and, as such, the benefits that would accrue from road user savings would not materialize. Given this situation, it is important that project planners and engineers pay careful attention to the design of the facility. In this regard, facilities that are more adaptable to improvements in the road geometrics are those that were originally designed with lower standards. As the traffic level increases, corresponding changes in the road's geometrics could be introduced to facilitate the traffic increase. This procedure is known in engineering as staged construction.

Although this research presented only a cursory treatment of the issue of stage construction, it does have implications for long-range rural road planning. That is to say, stage construction permits limited capital resources to be expended only when it is socially optimum to do so and it can provide a more rational basis for decisions about resource allocations.

## 5.2 Summary

The application of technologies that are insensitive to the development needs of countries of the developing world is increasingly being questioned by national and regional governments and the international community. The issue is one of inappropriate production techniques--i.e., capital-intensive technologies--that are incapable of expanding employment opportunities while at the same time absorbing scarce capital resources. The concerns regarding this matter have taken the form of studies and research conducted or commissioned by international lending and technical assistance agencies focusing on the substitutability of labor for capital in civil works projects -- especially rural road projects. The logic of this approach rests in the fact that civil works projects or road projects in particular offer a wider range of technologies without a trade-off in the quality of the product than does manufacturing or steel or petrochemical production. Thus, opportunities for employment generation are more likely to be available in road construction projects.

Several reasons have been identified as to why some techniques in use in developing countries are unsuitable. These are: a) developing countries have different factor endowments than those of developed countries; b) these technologies are costly and require a social infrastructure which is usually nonexistent; and c) they tend not to be able to absorb surplus labor brought on by seasonal agriculture.

It was subsequently revealed that inappropriate technologies continue to be chosen by project planners and decision makers over more labor-intensive production techniques or alternative technologies because of: a) lack of awareness of alternatives to the present technologies; b) unfamiliarity with national policy objectives and how these can be implemented at the local level; and c) improper criteria for project evaluation. All of these tendencies either singularly or in combinations have been identified as having increasingly led to the adoption of highly capital-intensive production methods in countries that exhibit an abundant supply of labor and capital scarcity.

Given the above conditions, an analytical framework for assessing the degree of labor-capital substitution was formulated on the basis of three components. The first was a theoretical conceptualization of factor substitution that relies on the two-factor production function approach. The second was the social cost-benefit approach aimed at maximizing social savings and employment generation by applying social-cost benefit analysis. The third criteria was design decisions that include social criteria.

Case study material was presented to show how this framework for decision making could be applied in practice and to indicate the global dimensions of such an approach. This involved dissaggregating the production process in a way that would permit the estimation of factor inputs at different levels of the process and their degree of substitution. The inputs were then calculated at shadow prices to measure their true cost to the economy, given their relative availability.

## 5.3 Conclusions

This research has shown that there is no question of the technical feasibility of substituting labor for capital in rural road projects because, in most activities in the construction process, substitution is possible.

The extent to which labor can be substituted for capital in rural road construction in developing countries has been shown to be primarily dependent upon the following factors:

- The relative availability of factor inputs--i.e. labor and capital (equipment)
- The distortions of factor prices with regard to the rate of foreign exchange, interest rates and labor (skilled and unskilled)
- The institutional constraints imposed by the national government with respect to setting wage rates, interest rates, and in the rate of foreign exchange
- The specific environmental conditions where the project is to be located--i.e., topographical, climatic, and geological conditions
- The criteria upon which decisions about design standards are based

All of the above interact in a dynamic manner to produce a decision about the quantity and quality of factor combinations (labor and capital) and how and in what way these inputs combine to influence the choice of technology.

The tendencies on the part of project planners and engineers to select inappropriate or capital-intensive production techniques can be attributed to improper methods or project evaluation where market prices, usually distorted, are used in the evaluation procedures and the lack of awareness of alternatives to the technologies that they are accustomed to using and are trained in. At market prices labor-intensive methods are not competitive with capital-intensive methods, as has been shown in the thesis text.

The social cost-benefit approach argues for an alternative or intermediate set of labor-capital mixes that would be socially optimal and would be capable of responding to the employment needs of rural areas. If this approach were to be applied in the planning and design phase of rural projects, labor-intensive production technqiues would not always appear sub-optimal, at least in all activities of the construction process.

Finally, criteria used in the design phase of rural roads should be sensitive to the social objectives of the nation and the regions to the extent that these criteria enhance the social objective at the local level--particularly if one of the national objectives is creating employment opportunities or the redistribution of incomes.

## 5.4 Recommendations

The analytical framework presented in this thesis is conceptual and represents at best one approach to an understanding of what factors influence decisions with regards to the choice of a technology. Some case study materials illustrated how this framework could be implemented. There remains a need to conduct more research and studies into the possibility of planning on a multi-sector basis. That is to say, public works projects in rural areas should be planned to correspond to off-seasonal agricultural periods. At least some construction activities should be planned during this period. This will serve as a mechanism to ensure that off-seasonal agricultural labor is being absorbed. This is the first recommendation for future research.

Although some measures have been adopted by international lending and technical assistance agencies to promote the use of appropriate technology through the preparation of manuals and reports, the results have been far from satisfactory. Some research is required to determine if institutions -- either international, national or regional -- could be established to serve as clearing houses and to coordinate information on different techniques of production; provide training for project managers, engineers and planners; and to disseminate information to government planning agencies and set up demonstration projects, as well.

These two areas of research will require nothing short of a sincere and conscious effort on the part of the international community and national governments if adequate policy measures are to be adopted and implemented to support the application of appropriate technologies.

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APPENDIX A

Figure A.1
Use of head baskets to carry excavated material (India)

I.L.O.Photo

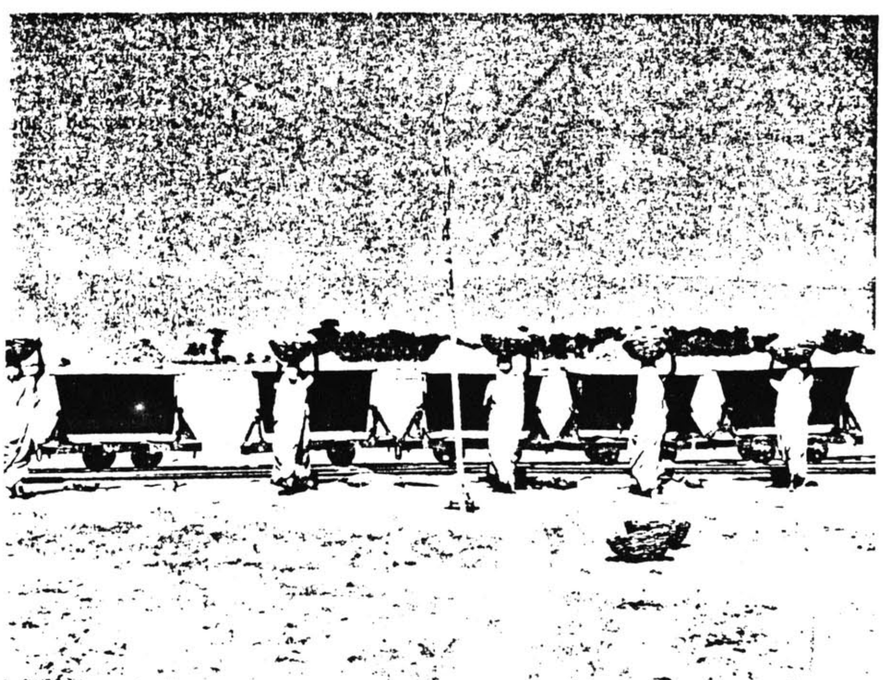
Figure A.2

Carrying excavated material on stretchers (Philippines)

I.L.O Photo

Figure A.3

Loading tipping trucks from head baskets (India)



I.L.O Photo

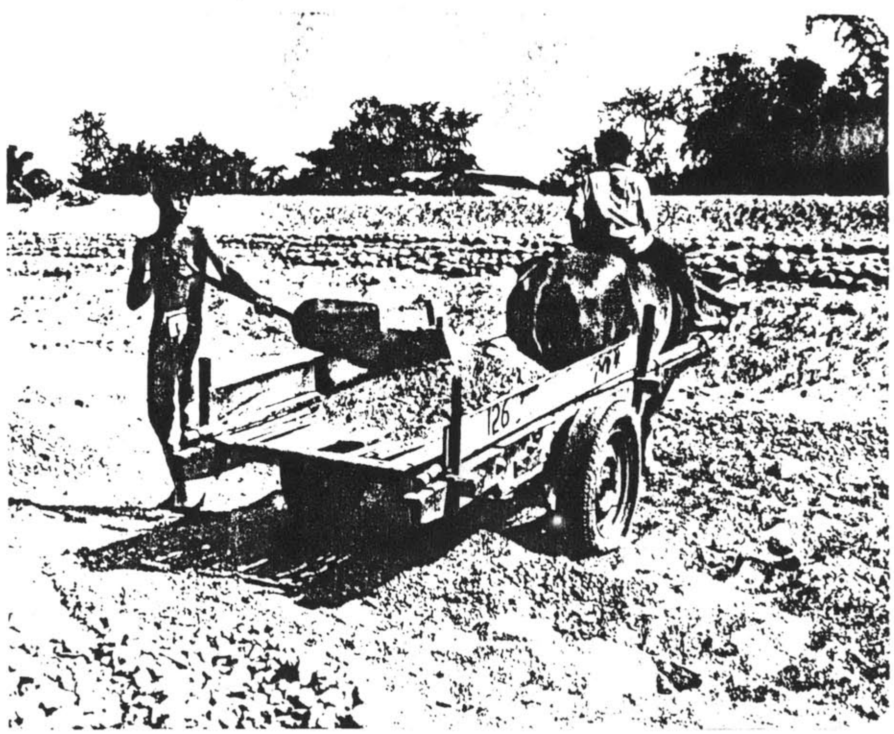
Figure A.4

Donkeys carrying soil (Pakistan)

I.L.O. Photo

Figure A.5

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



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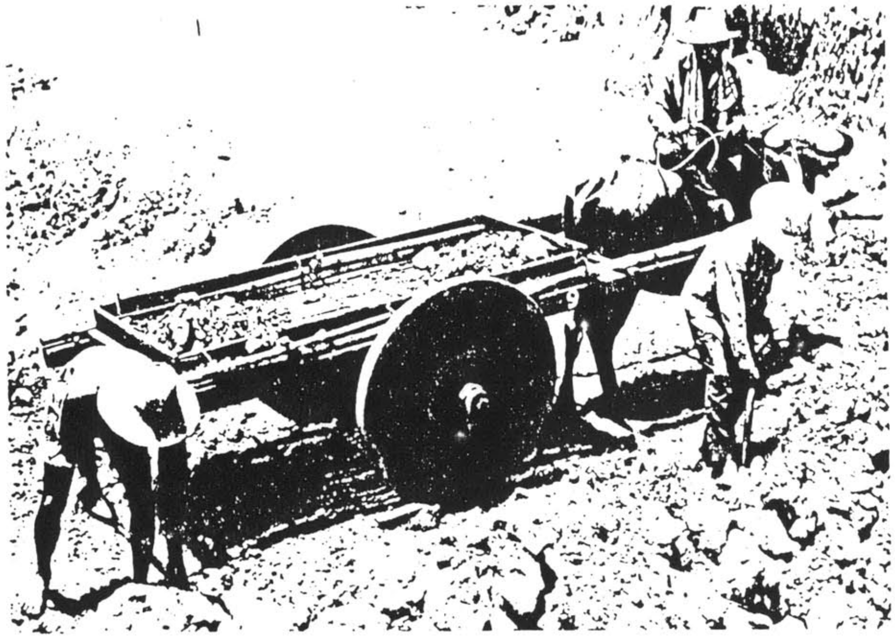


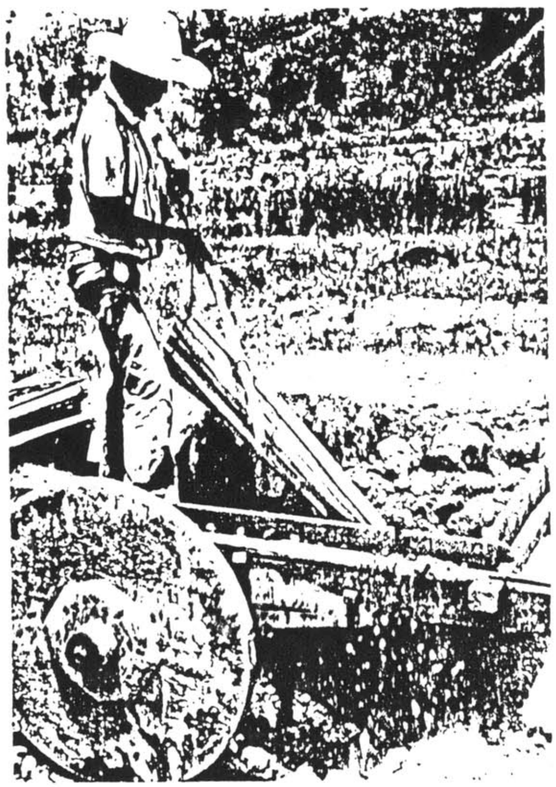


Figure A.6

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

I.L.O. Photo

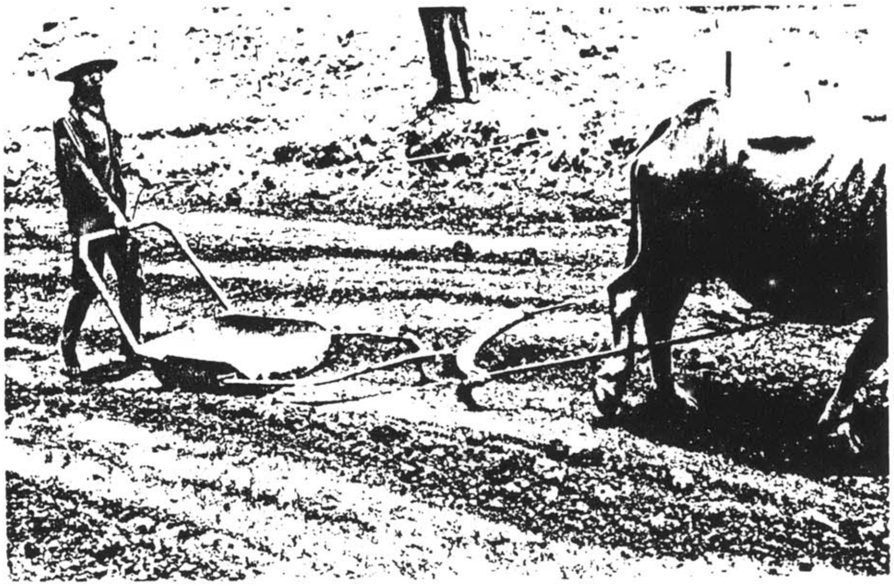
Figure A.7

Bamboo scraper (Philippines)

I.L.O. Photo

Figure A.8

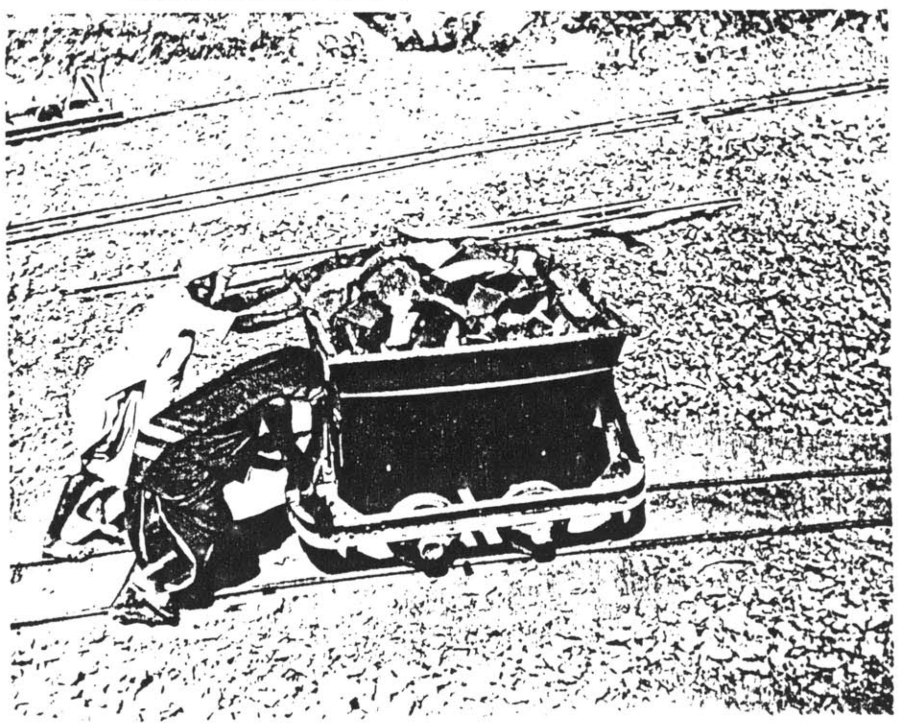
Animal-drawn steel scraper (Philippines)



I.L.O. Photo

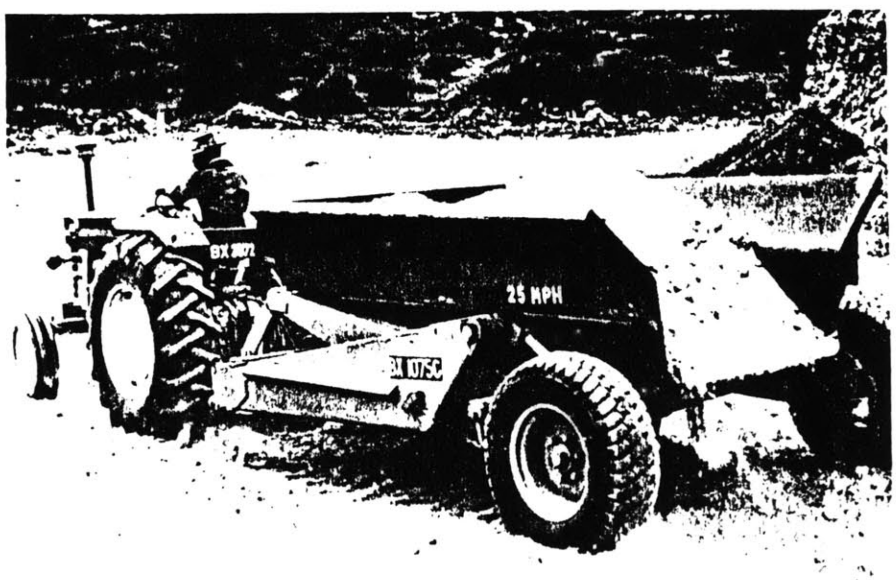
Figure A.9

Tipping truck on rails (India)



I.L.O Photo

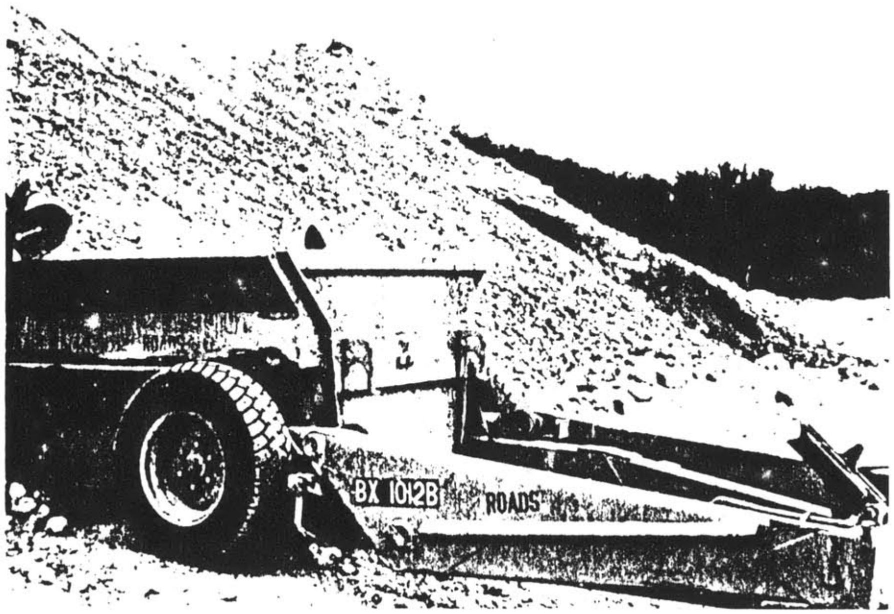
Figure A.10
Small dump truck combination consisting of small tractor, towed chassis and hauling container (Southern Africa)




I.L.O. Photo

Figure A.11

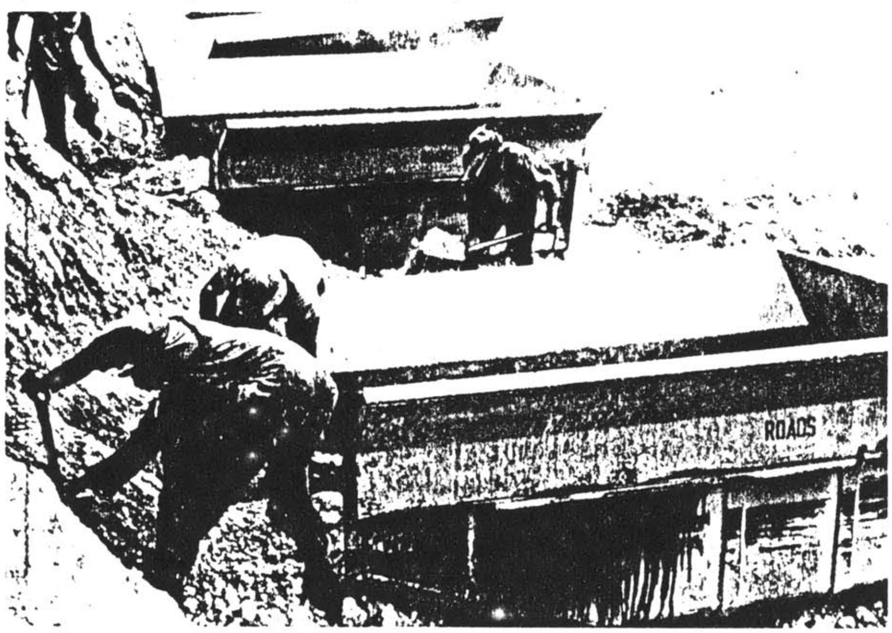
Hauling container on its towed chassis




I.L.O. Photo

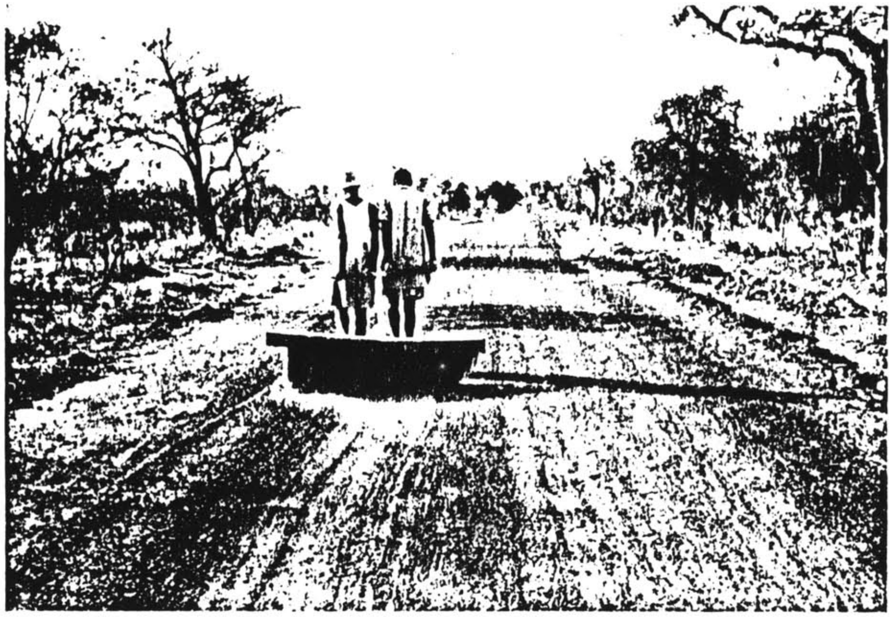
Figure A.12

Hauling container being loaded by hand




I.L.O. Photo

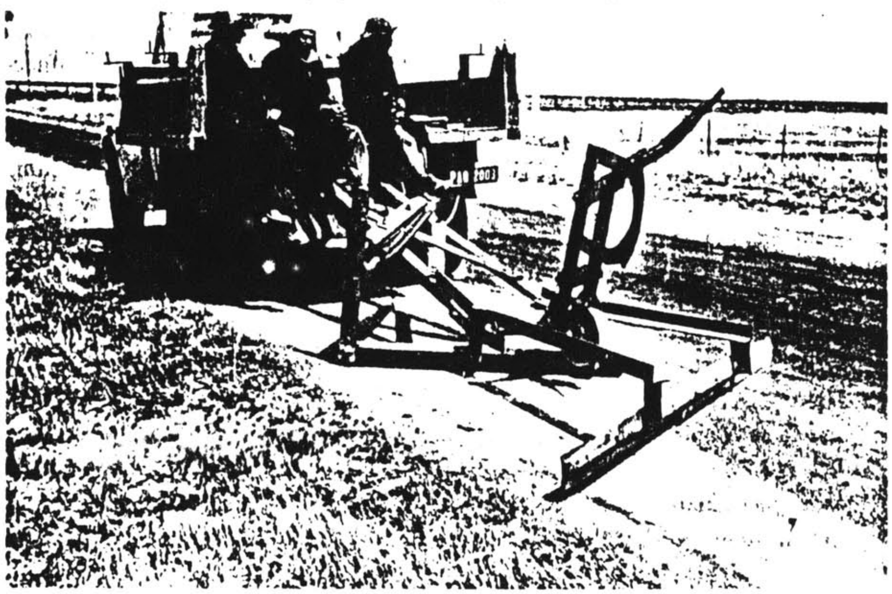
Figure A.13
Broom used to finish a road surface(East Africa)



I.L.O. Photo

Figure A.14

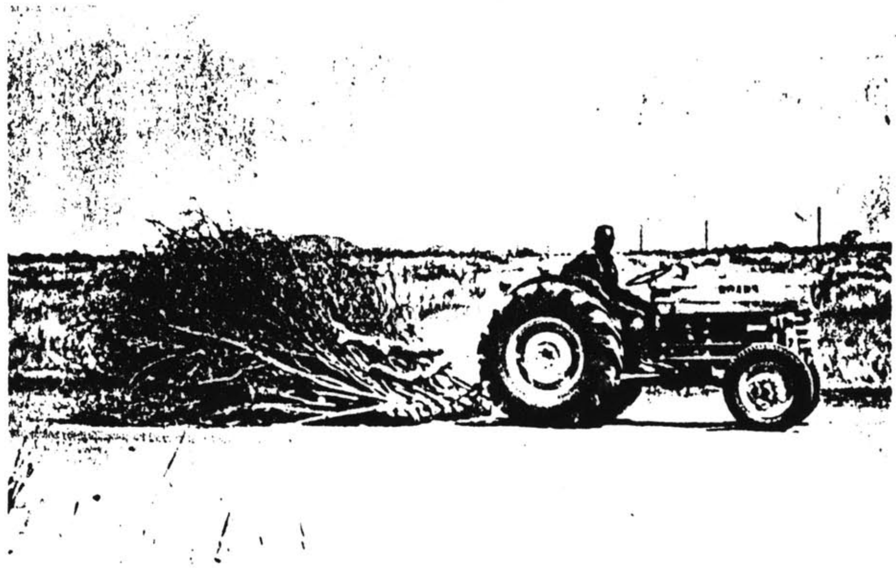
Drag used for shaping road surface (East Africa)




I.L.O. Photo

Figure A.15

Towing of brooms for spreading (East Africa)



I.L.O. Photo

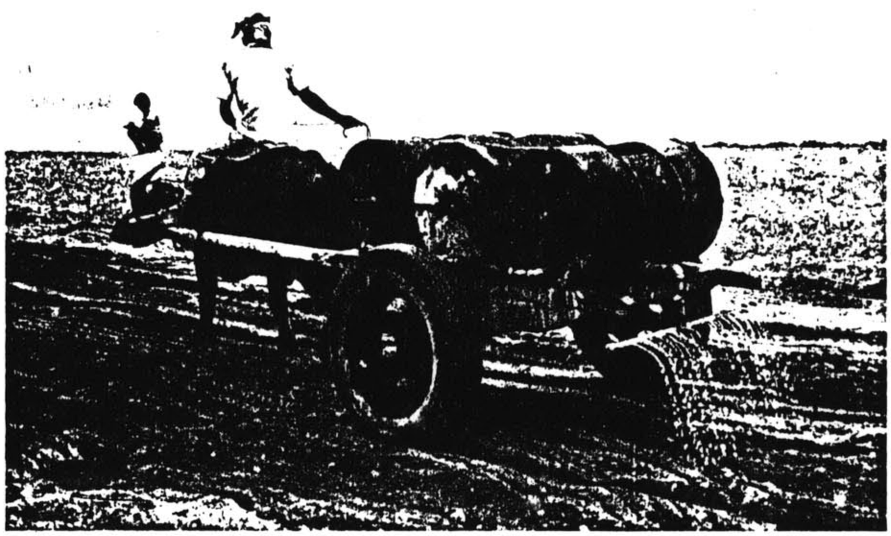


Figure A.16

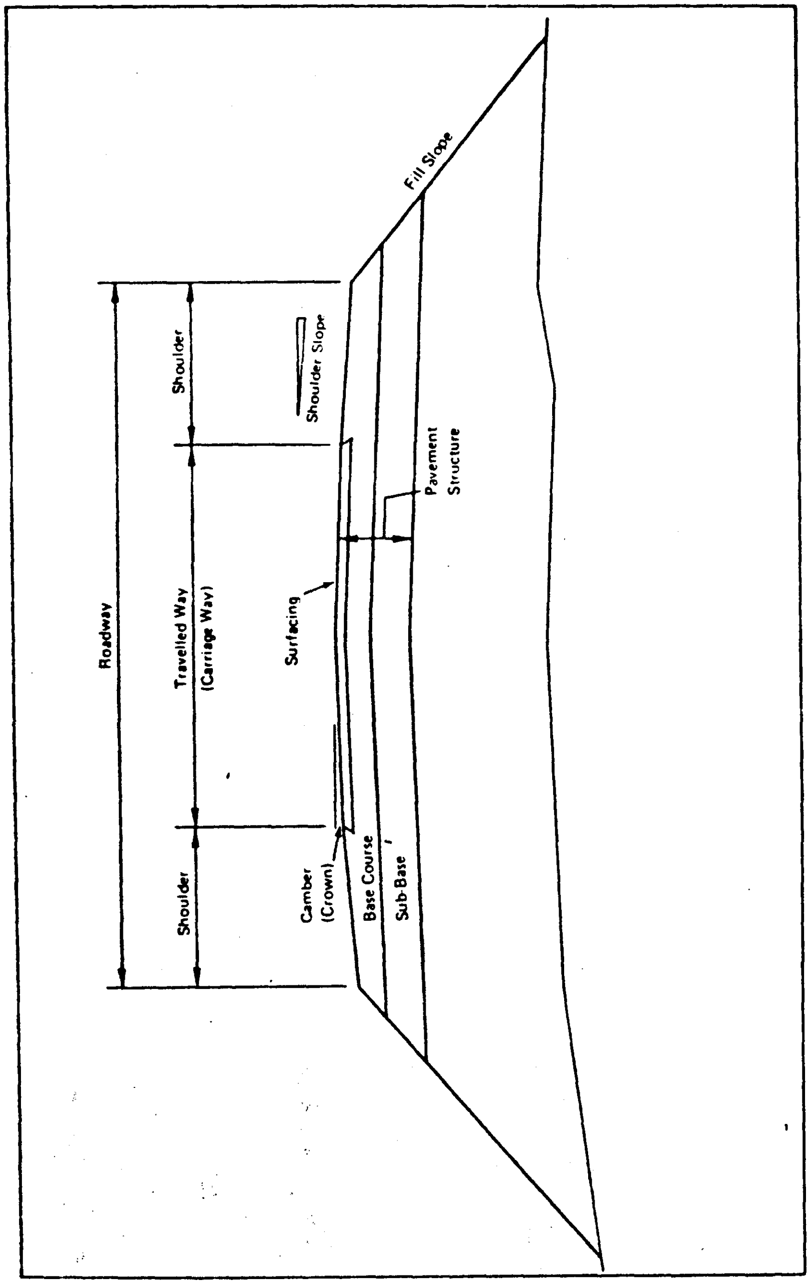
Animal drawn water bowser (Philippines)

I.L.O. Photo

# APPENDIX B

FIGURE B.1

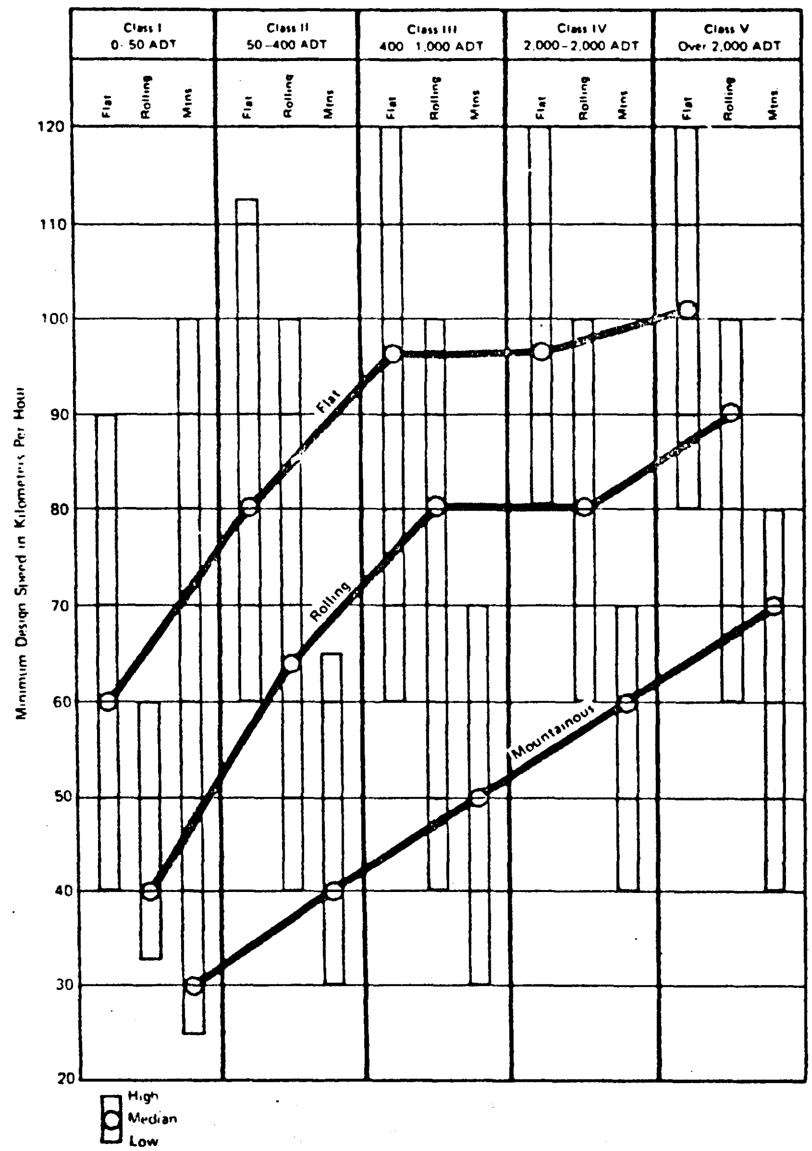
**HIGHWAY TERMS**




Source: Transport Research Board. "Geometric Design Standards for Low-Volume Roads," Compendium I (Washington, D.C.: National Academy of Sciences, 1978), pp. 21-38

FIGURE B.2

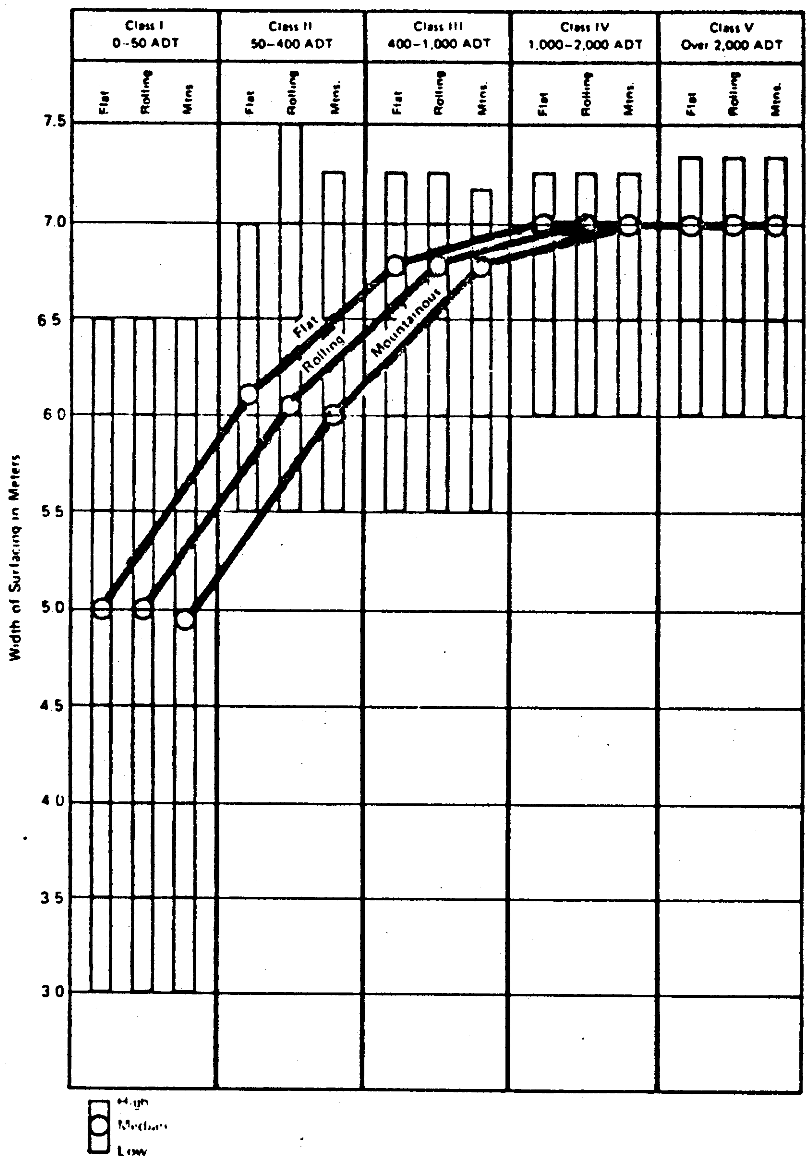
**Standards for Design Speed in 55 Countries**




Source: TRB, op cit.

FIGURE B.3

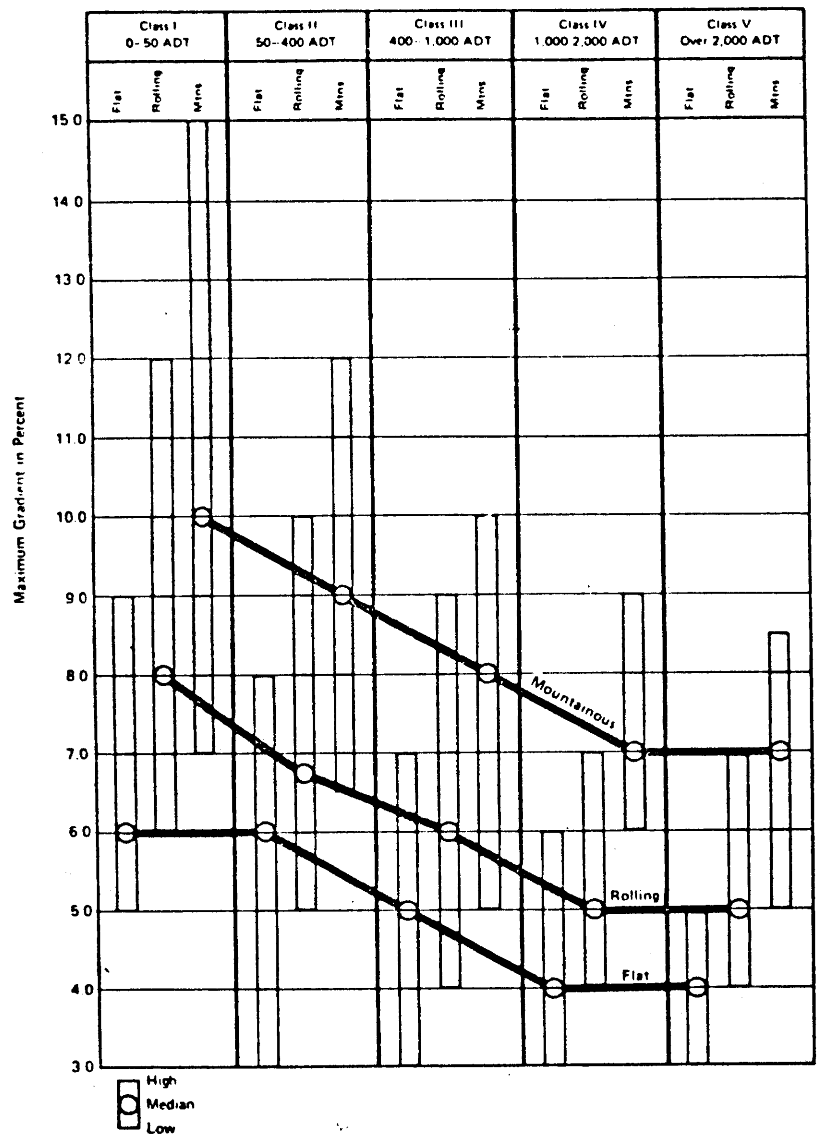
**Standards for Width of Surfacing in 56 Countries**




Source: TRB, <u>op cit</u>.

FIGURE B.4

**Standards for Maximum Gradient in 52 Countries**




Source: TRB, op cit.

Table B.1

**High, Median and Low Values for Design Elements of Tertiary and Special Purpose Roads (Traffic generally less than 100 ADT)**

| Terrain | Flat | Rolling | Mountainous |
|---|---|---|---|
| | | km.p.h. | |
| *Design Speed* (13 Countries) | | | |
| High value | 80 | 80 | 63 |
| Median value | 60 | 40 | 40 |
| Low value | 40 | 30 | 20 |
| *Maximum Gradient* (14 Countries) | | | |
| | | Percent | |
| High value | 12.0 | 12.0 | 16.0 |
| Median value | 7.5 | 9.0 | 10.0 |
| Low value | 6.0 | 8.0 | 7.0 |
| *Width of Surfacing* * (15 Countries) | | | |
| High value | 7.00 m. (without regard to terrain) | | |
| Median value | 5.00 m. (without regard to terrain) | | |
| Low value | 2.63 m. (without regard to terrain) | | |
| *Width of One Shoulder* * (15 Countries) | | | |
| High value | 2.44 m. (without regard to terrain) | | |
| Median value | 1.00 m. (without regard to terrain) | | |
| Low value | 0.50 m. (without regard to terrain) | | |
| *Width of Roadway (Surfacing plus Shoulders)* * (15 Countries) | | | |
| High value | 10.96 m. (without regard to terrain) | | |
| Median value | 7.00 m. (without regard to terrain) | | |
| Low value | 4.00 m. (without regard to terrain) | | |
| *Design Loading for Bridges* (7 Countries) | | | |
| AASHO—H20-S16 | 2 Countries | | |
| AASHO—H15-S12 | 2 Countries | | |
| AASHO—H15 | 1 Country | | |
| NAASRA—H20-S16 | 1 Country | | |
| British Standard 153, Two Thirds of HA Loading | 1 Country | | |
| Single-Lane bridges are built initially on low traffic roads in at least 2 countries. | | | |
| *Right of way* (4 Countries) | | | |
| Desirable minimum, 50 m. | 2 Countries | | |
| Desirable minimum, 20 m. | 2 Countries | | |

* For some projects the width of the roadway and the width of surfacing were the same; that is the road had no shoulder. In these cases 0.5 meter of the surface on each side was arbitrarily designated as "shoulder."

Source: TRB, op cit.