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ISAD(G) Reference Code: WB IBRD/IDA 03 EXC-10-4483S

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INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT

INTERNATIONAL DEVELOPMENT ASSOCIATION

Study of the Substitution of Labor for Equipment in Road Construction

Phase I: Final Report

October, 1971

The objectives of the Phase I study were, first to survey the relevant engineering and economic literature to determine the state of existing knowledge concerning the substitutability of labor and equipment in road construction, including the nature and extent of available empirical evidence, and second, to prepare detailed recommendations for further studies as required.

The preliminary findings of the consulting team are that the substitution of labor for equipment is technically feasible for a wide range of construction activities for roads of various qualities, but that almost all existing engineering data are inappropriately structured or too poorly defined with respect to specific environmental conditions to permit a quantitative analysis of the substitution possibilities. Therefore a major part of the Phase I study has focused on development of an appropriate disaggregation of construction activities and delineation of the principal parameters which must be observed in subsequent field studies in order to explain variations in productivity rates.

The only general conclusion that can be ventured at this stage of the study is that specific environmental factors are so important that a case by case analysis of substitution possibilities may be required. Formulation of an appropriate computer model, utilizing existing programming routines, has been initiated in the IBRD Economics Department and should permit removing a number of restrictive assumptions that were employed in the Phase I analyses to ease the computational burden. The model will be used initially to further define the data to be collected in the Phase II studies. Arrangements have been made to commence Phase II field studies in India in November, 1971.

This study has been prepared jointly by a team from the IBRD Economics Department Transportation and Public Utilities Division and four consulting firms which was first under the direction of Jan de Weille and subsequently of Clell G. Harral.

The pressure of time deadlines has not permitted clearance of this draft with the consulting firms so that they should not be held responsible for the analyses and conclusions given herein. Summary and Conclusions follow the Table of Contents.

Prepared by: C. G. Harral, B.P.M. Mitchell and E.P. Holland (IBRD); K.C.W. James and J.J. Gandy (Scott Wilson Kirkpatrick and Partners, Ltd.); P. Lombard and M. Testet (Bureau Centrale d'Etudes pour les Equipements d'Outre-Mer); M.Chervel and P. Trocme (Societe d'Etudes pour le Developpement Economique et Social); J.W. Knowles and R.E.G. Smith (Economist Intelligence Unit, Ltd.); H. Latimer (Editorial Consultant).

SUBSTITUTION OF LABOR

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INTERNATIONAL BANK FOR RECONSTRUCTION AND DEVELOPMENT

Study of the Substitution of Labour for Equipment in Road Construction

SUMMARY AND CONCLUSIONS - PHASE I

1. A review of the existing engineering literature has revealed an extraordinary variation in the limited amount of data that is available concerning productivity rates in road construction. Even productivity rates quoted for equipment show a marked variation, though significantly less so than for labor. An evaluation of alternative sources of further data (including international and local contractors, supervisory consulting engineers and public works departments) has led to the conclusion that little useful information can be expected from these sources and that the only way to obtain reliable information sufficiently detailed to permit study of the substitution problem is through direct field observations of ongoing construction projects (supplemented by a limited interviewing program and further literature search).

2. A major part of the study has therefore focused on development of an appropriate disaggregation of construction activities and delineation of the principal parameters which must be observed in subsequent field studies in order to explain variation in productivity rates. The parameters which were found to have a major effect on productivity rates and the substitutability of labor encompass:

(i) the physical environment (geology, climate, vegetation, length of hauls, height of lifts);

(ii) the size or scale of the project, and the time available to complete it;

(iii) the construction quality standard specified;

(iv) the social and institutional environment, including the prevailing attitude toward manual labor, the organization of the work (particularly as it affects the incentives for productivity), and the health and nutritional standards of the labor force.

3. Despite the extremely wide variation in available data, a series of preliminary analyses of substitution possibilities have been attempted in order to derive such conclusions as may be possible and to formulate an initial analytical approach to the problem. In each of two parallel analyses substitution possibilities were examined for a set of hypothetical road projects in different terrains for three typical types of paved roads. The two analyses differed in their sources of data (one using English, the other French sources) and in the differing judgements of the two engineering consultants (SWKP and BCEOM). Production function isoquants were determined for each group

of road construction operations (earthworks, subbase, base and surface treatment) and the optimal combination of methods for each operation (for an assumed wage rate for unskilled labor of US$1.00 per day) was determined and compared with the equipment intensive and labor intensive extremes of the production function. The following conclusions emerge from these examples:

(a) It is technically feasible to substitute labor for equipment for all but about 10 to 20 percent of total road construction costs for the higher quality construction standards considered here, while relaxation of standards 1/ to an intermediate quality permits labor substitution for only an additional 5 to 8 percent of costs (i.e. for all but about 2 to 15 percent of total costs).

(b) The economic feasibility of labor substitution will depend, inter alia, on the productivity rates of equipment and labor and the wage assigned to unskilled labor (assuming a fixed set of prices for equipment, materials and fuel). For example, parallel estimates for one road type in rolling terrain utilizing identical assumptions concerning wages and prices, but employing the differing data and assumptions concerning productivity rates given by SWKP and BCEOM, yield markedly different conclusions concerning the economic feasibility of substitution. At a wage of $1.00 per day the optimal combination of methods would involve about 28 and 37 percent labor costs for the high and intermediate quality cases, respectively, in the SWKP estimates and only about 6 percent in either case for the BCEOM analyses. The institutional framework is a major factor in explaining these differences: the BCEOM estimates reflect productivity rates weighted toward experience derived in public "makework" projects, such as the National Promotion in Morocco, where there is little incentive to achieve efficient utilization of labor, whereas the SWKP estimates are weighted more by experience derived from dam projects in South India which were oriented to achieve maximum labor productivity.

(c) The feasibility of using intermediate technologies involving a mixture of modern equipment and manual methods appears promising and should be further investigated. For example, according to the SWKP estimates handloading of detachable low slung trailers pulled by tractors may be optimal for moving earthworks and materials over certain haulage distances when wage rates for

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unskilled labor are in the range of US$3.50 per day or less. However, handloading of trucks would never appear sensible (except in isolated instances), since the cost of detaining the truck longer while loading it greatly exceeds the savings in loading costs according to any estimate.

4. At this stage of the study no general conclusions can be drawn in the form of simple criteria for determining the optimal combination of equipment and labor intensive methods of construction. The only conclusion that can be ventured is that specific physical, economic and social environmental factors are so important that a case by case analysis may be required. While it is hoped that subsequent studies including generation of an improved data base will permit some simplification of the problem, the scope of the analyses still required for each project will remain substantial. In the examples analyzed in this report, restrictive simplifying assumptions were made to reduce the computational burden of the analyses and simplify the presentation. More adequate analyses must distinguish intermediate inputs, separately account for local and foreign exchange components and incorporate time phasing and other interdependencies among the different activities. Thus, computationally efficient analytical methods should be developed for project by project analysis, and formulation of a computer model of the choice of technology problem using existing linear programming routines is already underway in the Bank. The model will be used initially to further define the necessary data for the Phase II field studies.

5. Inasmuch as the number of environmental parameters and combinations of parameters which have a major influence on productivity rates is very great, it will not be possible to collect information for more than a limited sample of the total spectrum in the Phase II field study. However, this study should help to further define the most important parameters, thus narrowing subsequent research, and will initiate a data bank which should be continuously extended as additional information becomes available from various sources. The establishment of a regular system for collecting this type of information from all future IBRD highway projects is one possibility that should be considered seriously.

6. Where labor substitution is not financially profitable, substitution may still be socially desirable where unemployment or underemployment exceeds the "frictional" minimum. In these cases the "inefficiency costs" of substituting successively more labor intensive methods for equipment can be calculated. This cost may be viewed as the price of the additional jobs created, or the subsidy that would be required to compensate private contractors for creating these jobs. Analyses of this nature were undertaken for road construction based on the SWKP and BCEOM data, which indicate that the average cost per additional man-day of employment in road construction may range from about US$0.49 to 0.62. At this stage these figures can only be considered as educated guesses; they may well vary by orders of magnitude in specific cases. An attempt was made to find comparable estimates for industries other than road construction, but the literature search revealed no information of this nature.

7. An evaluation of the employment creation potential of the road construction industry revealed that while employment in road construction could be expanded to a great extent, particularly if appropriate policy instruments (e.g. subsidies for labor or taxes on equipment) were vigorously pursued, the additional employment created would constitute only a minor fraction of that needed according to all available forecasts of labor force and employment growth in the foreseeable future. For example, in the case of Morocco it is estimated that maximum labor absorption in road construction will provide at most about 3 percent of the jobs necessary to maintain the current ratio of unemployment over the next seven years let alone reduce it. However, many of the results of these analyses for road construction may be applicable to other civil construction activities which can provide additional employment opportunities.

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CHAPTER I. The Employment Problem and Choice of Construction Technology

A. Introduction

1. It is a truism that less developed countries are characterized by a chronic underutilization of human resources. In order to provide improved standards of living for a rising population, all resources available should be utilized as fully as possible. If, however, technology is inflexible and resources are not available in appropriate proportions, some factors may remain underutilized. When the surplus factor is labour, those without work consider themselves denied an equitable share in the product and are likely to become dissatisfied with the political, economic, and social structures of their countries. Thus, despite growth in per capita income and rising productivity levels in most countries, concern with what is now called the employment problem has been increasing greatly. Many people now believe employment to be the major challenge of development policy.

2. Despite the availability of abundant surplus labour in many less developed countries much of the construction and manufacturing in these economies is highly mechanized. Some of the reasons for this preference for capital intensive methods can be summed up in terms of (a) nonavailability, or lack of knowledge of, suitable labour intensive technology; and (b) distortions in prices which tend to overstate the cost of labour and understate the cost of equipment thus leading to a divergence between social profitability and private profitability, which guides private firms' choice of technique.

3. This equipment bias can be detected in various industries. The present report is concerned with the road construction industry and the possibilities of substituting labour for equipment in that field; in addition, some of the results of these analyses may be applicable to other civil construction. We first examine many alternative methods to determine the economically efficient method (or combination of methods) to build a given road of specified quality. We then consider the increase in economic costs that would be required to employ successively more and more labour to the point of displacing virtually all equipment for the sake of job creation. The findings depend, of course, on what prices and wage rates are assumed; hence the effects of alternative wage ratesare explored.

4. The technical feasibility and problems of substituting labour for equipment are examined in Chapters II and III, while Chapter IV considers the problems of mobilizing and managing large labour forces and related issues. Chapter V examines the extent of job creation that can be expected from the road construction industry and calculates the costs thereof in

terms of the subsidies that would be required to compensate for the resulting inefficiencies. In addition, the experience of Morocco where the "National Promotion" constitutes an important example of road construction being used as a vehicle for employment creation is reviewed. Finally, Chapter VI provides recommendations for further studies.

B. The Choice of Socially Optimal Construction Technology

5. The forces of competition will theoretically result in an efficient choice of technology in those industries where reasonably competitive conditions exist. Those producers, or contractors, who utilize the most efficient technology will survive and those who do not will ultimately fail. If the cost of labour is low then contractors can be expected to take advantage of the lower cost by using techniques that employ more labour and less equipment. Yet the assertion is repeatedly heard that road contractors in developing countries with large and persistent labour surpluses are employing highly equipment intensive techniques. At least two explanations for this seeming contradiction are plausible: First, construction technology may be so rigidly fixed that optimal methods are still highly equipment intensive despite the presence of abundant cheap labour. Second, distortions in market prices, the causes of which are discussed below, may tend to overstate the true cost (i.e. scarcity value) of labour in the labour surplus economy, thus leading private contractors (and very possibly many public agencies as well) to employ less labour than they would if the prices they confronted reflected true social costs. Let us consider these issues in turn.

1. Inflexibility of Available Road Construction Technology

6. The major developments of modern road construction technology have taken place primarily in the United States and Western Europe in the last 30 to 40 years. In these economies labour costs are high relative to capital so that the major thrust of technological development has been to reduce the labour component by substituting machinery, much of which is complicated and requires large capital investments, but has high overall productivity and particularly low labour input coefficients per unit of output. Development of such equipment, of course, has constituted a very favorable development for the labour-scarce developed economies permitting great reductions in the costs of civil construction and lessening the "toil of man" in some very onerous physical work. However, this labour economizing technology is not necessarily appropriate to the labour abundant economy - although it may be financially profitable if the improvement in overall productivity is great enough, as it certainly is in some road construction operations.

7. It is particularly unfortunate that there has been no major thrust in world technological development toward a technology more suited to the labour abundant economy. An "intermediate" technology offering improvement in efficiency over fully manual methods but more flexibility to accommodate higher labour inputs would be highly desirable. Lacking

an appropriate intermediate technology, the equipment intensive, labour minimizing technologies current in the western countries, which have limited flexibility for adaptation to labour abundant situations, have frequently been exported to developing countries even where labour is in fact relatively abundant.1/

2. Price Distortions and the Divergence between Market and Social Profitabilities

8. Private (or financial) costs are the costs ordinarily incurred in meeting the capital and operating costs of any organization or undertaking. These are costs as a businessman or (often) government corporation would compute them, including taxes, tariffs, local currency value of any foreign exchange components at official rates, interest charges on capital investments, and the market price (plus taxes and social security contributions) paid for labour. It is a basic tenet of the competitive economy that relative prices of various factors in financial cost terms should approximate relative social (or economic opportunity) costs so that decisions based on them yield an efficient allocation of resources which maximizes social welfare as defined in economic theory.

9. However, it is widely acknowledged that there are many instances in developed as well as developing countries in which financial costs of production inputs may diverge from their social opportunity costs and the use of financial costs in economic planning in general and the choice of construction technology in particular would result in a non optimal use of resources.2/ In developing countries important examples include the prices of skilled and unskilled labor, capital, inputs which utilize foreign exchange, and inputs upon which sales and other taxes are imposed. For the efficient allocation of the country's scarce resources, these inputs should be valued ("shadow priced") at their social opportunity costs, as distinct from financial costs. The social opportunity cost of any input factor in a given use is the value of the output of the factor in its next-best use which is forgone because that resource is employed in one use rather than the other.3/

1/ The preliminary engineering analyses for the hypothetical road projects given below suggests that the technical feasibility of mixing labour intensive and equipment intensive methods in various activities should be investigated further.

2/ See Jan Tinbergen, The Design of Development, Economic Development Institute of the International Bank for Reconstruction and Development (Baltimore: Johns Hopkins University Press, 1958): A. Qayum, The Theory and Policy of Accounting Prices (Amsterdam: North Holland Publishing Co., 1960); and in the more recent literature, I.M.D. Little and J.A. Mirrlees, Manual of Project Analysis in Developing Countries, Vol. II (Paris: OECD, 1969); and A.C.Harberger, "On Measuring the Social Opportunity Cost of Labour," International Labour Review (June 1971).

3/ Harberger, ibid., and others have argued that the supply price of marginal units of labour for given jobs in given labour market areas is a better measure of social opportunity cost than the forgone product. This distinction is suggested partly because of conceptual deficiencies in national income accounts and partly because of practical problems in estimating forgone product.

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10. The market price of labour does not reflect its true social opportunity cost in many developing countries. There are three principal reasons why this is so. First, government policies such as minimum wage legislation and social security taxes, intended to benefit the labour force, tend to overstate the scarcity value of labour. Second, trade unions, where present and potent, have essentially the same effect on the price of labour. Third, extended family institutions in many countries dictate that the householder take in and care for a broad range of relatives regardless of what their contribution may be to the family farm or household industry. In these cases the marginal product of the additional family members may fall below the going market wage or even approach zero. If the marginal labour were removed, output would remain constant or be reduced only marginally, and the social opportunity cost might be considerably less than the market wage.

11. For equipment, the market price will often tend to understate the social opportunity costs. This is because road construction equipment is quite typically an imported item and the local currency is overvalued by the official foreign exchange rate. This problem may be accentuated in many cases by the availability of foreign loans for equipment at concessionary rates of interest provided by bilateral and international lending agencies.

12. Private contractors and many government agencies base their decision concerning the choice of technology on market prices. Thus where the market price overstates the true cost of labour and understates the true cost of equipment, the result must be choice of a more equipment-intensive technology than is economically efficient or socially desirable.

13. If in fact subsequent studies provide proof that more labour intensive technologies would be efficient, or socially desirable even if inefficient, various policy measures may be considered in order to guide the choice of technology along desired lines. These include, inter alia, taxes on the purchase of equipment, subsidies on labour employed, and direct force account work by public agencies employing labour intensive techniques. These policy instruments are not treated in the present report but will be considered in subsequent studies.

Chapter II. Engineering Analyses of the Substitution of Labor for Equipment

A. Introduction

1. The basic inputs in road construction are labour, equipment and materials. Over recent years, the general trend has been to reduce the labour input by increasing the use of equipment and hence, in view of the higher productivity of the latter, to reduce the time needed for and the cost (in financial terms) of construction. The increasing use of equipment has led to a rise in the quality of the finished product since in many of the construction processes closer tolerances can be achieved than with hand labour. It has also encouraged the development of designs and methods which are particularly suited to equipment-intensive operations.

2. The principal question which the engineering studies are required to answer is:

> "What, from a purely technical point of view, is the scope for substituting labour for equipment in road construction, taking into account a variety of physical (and economic) environments."

Before the advent of civil engineering equipment, there was no alternative but to build roads by hand labour assisted by simple hand tools. Hence, from a purely technical aspect, roads undoubtedly can be built by hand labour, but not necessarily to the same design or to the same standards of quality as can be achieved by equipment.

3. Some of the older forms of road pavement construction, such as pitching and stone setting, are clearly not suited to mechanical construction. Waterbound macadam bases were originally devised for construction entirely by hand labour; however, while it is technically possible to manufacture and lay waterbound macadam by equipment, such bases have been largely replaced in the developed countries by graded stone ('crusher-run') bases which can be produced more easily by mechanical crushers. On the other hand, some modern forms of construction necessitate the use of equipment; for example, an asphaltic concrete pavement can be laid normally only by machine.

4. Even with the most modern forms of construction, there are a few activities which have to be undertaken by hand labour. Furthermore, it is technically possible to carry out many activities associated with equipment-intensive methods (such as production of local materials and their handling and transport) without reducing the overall standards of workmanship and quality. Hence, while the scope for labour substitution may be restricted by the design, it still exists to some degree even with the most modern equipment-orientated designs and techniques. This study attempts to measure the extent to which such substitution is possible for roads of various standards.

5. The quality of a finished road is dependent upon its geometric design, its riding performance and the period of time over which the latter is maintained. For a given design, the riding performance and durability are mainly governed by the standards achieved in construction where such activities as compaction and surface finishing are important. Other activities, such as haulage of materials, have no effect whatsoever on the quality of the finished road. In considering the scope for labour substitution, account needs to be taken of the quality levels reasonably attainable by labour/equipment in these critical activities. Three levels of quality have been considered - high, intermediate and low - and have been defined in technical terms for each of the critical activities. It should be noted that equipment intensive techniques do not necessarily imply a high quality factor; in certain activities (e.g. selection of excavated materials) hand labour can often do better than equipment.

6. The general approach to the engineering side of the study has been to break down the road construction process into basic activities, and to assess the technical feasibility of labour substitution within each activity in relation to quality and environment. The relative importance of labour and equipment in road construction and the theoretical scope for labour substitution have been analysed without taking account of the constraints which would limit the extent to which this could be done in practice. 1/ Productivity data for both labour and equipment have been abstracted and reviewed. The effects of the environment on the substitution problem have been analysed and the associated engineering problems have been evaluated.

Definitions of The Basic Inputs in Road Construction

7. The study is concerned with assessing the possibility and practicability of varying the mix of two of the basic inputs, labour and equipment, in road construction. For the results to be meaningful, it is essential that account be taken of any consequential changes in the third input, materials. The substitution of labour for equipment necessarily entails the replacement of the skilled personnel engaged in equipment operation and maintenance by other (mainly unskilled or semi-skilled) labour; the latter also save the materials consumed in operating the equipment.

8. In the context of this study, the meanings of the terms "equipment", "labour" and "materials" have been widened to take account of these factors in such a way as to simplify the computational burden of the analyses and presentation of the results. These simplifications are not essential and would be relaxed for more advanced analyses than the examples given in the present report.

1/ These constraints are described in Chapters III and IV.

9. "Equipment" is taken to mean essentially powered machines that replace rather than aid unskilled labour. It includes the trained operators, operators' assistants, maintenance mechanics and facilities, spare parts and other consumable materials such as fuel, greases, tyres, etc., required for its operation.

10. With the exception of the operators and mechanics referred to in paragraph 8, "labour" consists of all categories of skilled, semi-skilled and unskilled labour. It also includes the hand tools required to carry out the work together with elementary unpowered equipment such as wheel barrows, hand-operated winches, pumps, handcarts, etc., whose main purpose is essentially to increase the productivity or improve the quality of the work carried out by unskilled labour rather than to replace it. It includes animal-drawn carts.

11. With the exception of the consumables required for equipment operation (which are defined as forming part of "equipment") materials are divided into the following categories:

(i) "Manufactured" - those materials which are not produced as part of the road construction operation and the labour/equipment input in their manufacture is beyond the control of the road construction authorities. Examples of materials in this category are cement, bitumen and steel. In general, the quantities required for a given operation are independent of the manner in which the operations is carried out; there are exceptions, such as the possible need to use a higher proportion of cement to achieve a specified concrete strength when mixing by hand. An essential requirement of these materials is that they cannot be substituted for, either in part or in whole, by labour.

(ii) "Local" - those materials which can be produced as part of the construction work. Common examples are crushed rock products, bricks and pre-cast concrete units. These materials can be produced with varying combinations of labour and equipment and they are therefore treated as part of the construction process.

12. It will be noted that there are materials which under different circumstances could be categorised as manufactured or local. For example, in certain areas timber for bridging, formwork, etc., could be produced, by hand or by machine, as part of the road construction and hence it would be categorised as a local material; on the other hand, it might be purchased as a manufactured product. Similar considerations could apply to other materials such as lime for stabilisation, crushed rock products, pre-cast concrete units,etc.

13. One material which falls into neither of the two categories is the explosive for blasting. This is manufactured but can be replaced entirely by hand labour. To avoid having a further category, explosive material is considered to be part of "equipment" and dealt with in the same way as the consumables required for plant operation.

14. Although the study is primarily concerned with the substitution of unskilled labour for equipment, it is clear that account must also be taken of the corresponding substitution of unskilled for skilled labour and the replacement of materials by labour.

B. Disaggregation of Construction Activities

1. List of Basic Activities

15. The first approach to defining the basic construction activities centred on an analysis of a typical specification and bill of quantities for road construction. Many of the basic activities were found to be common to several "bill items" and it was considered that a better approach would be to define the basic activities, grouping similar items together, and to build-up the "bill items" or processes from them. Varying degrees of disaggregation were considered. To permit the full analysis of labour substitution possibilities, it was concluded that complete disaggregation was required to the state where an activity could be carried out either solely by labour or solely by equipment with no possibility of a mixture of the two inputs.

16. An attempt has been made to minimize the number of basic activities by grouping reasonably similar activities together; for instance, loading such items as soils, crushed rock and stabilised materials has been considered to be the same activity since the productivity rates and hence the trade-off between labour and equipment would differ only marginally.

17. Sub-division of activities has been necessary to allow for differing qualities of workmanship where these would affect the quality of the finished road. However, in many of the activities this has not been necessary, since either there is no significant difference between the standards obtainable by labour and equipment-intensive methods or the quality of the basic activity has a negligible effect on the quality of the finished road.

18. Further sub-division of activities has been necessary to allow for inherent variations in productivity rates due to environmental factors, since the optimum trade-off between labour and equipment could vary. This applies in the case of clearing and grubbing where allowance has been made for the density of vegetation; in excavation where the nature and condition of the soil has a pronounced effect on productivity; and in haulage where the distance involved is paramount in determining the technology.

19. While the scale of the work and the time available will, in practice, limit the extent to which labour substitution can be implemented, they have not generally been taken into account in identifying the basic activities since these factors can best be dealt with during the aggregation process. An exception is the case of earthworks where a distinction has been made between excavating in small quantities and excavating in bulk, since the former is more suited to the use of labour.

20. In drawing up the list of basic construction activities certain works have been excluded. The most notable omission has been bridgeworks, which have been specifically excluded from the study (though culverts have been included). Other excluded works are fencing, pavement markings, signposting and other minor items which would have little significance in the overall aspects of labour substitution.

21. The basic construction activities are listed immediately following this section. Each activity has been categorised in the following terms:

(1) "E" denotes an activity which is essentially equipment-intensive and labour substitution is not technically feasible.

(2) "L" denotes an activity which is essentially labour-intensive and equipment substitution is not technically feasible.

(3) "EL" denotes an activity which can be carried out by either equipment or labour.

22. The main criterion applied in assessing these categories has been that of technical feasibility as distinct from that of technical possibility. While it could be argued, for instance, that crusher-run base material (Activity 11.8 could be produced by hand labour, it is doubtful whether this would ever be done, since waterbound macadam would be better suited to a labour-intensive project.

23. The categorisation of activities indicates solely whether it is technically feasible to substitute labour for equipment. Apart from the practical constraints of scale, timing, availability of labour, etc., that might apply in relation to a specific project, the effect on costs consequent on labour substitution must also be taken into account.

24. If the substitution process leads to increases in equipment costs for a particular activity, then there is clearly no benefit to be gained by so doing, irrespective of the wage rate for labour - this particularly applies in the loading activity wherein any savings in replacing loading equipment by hand labour could be more than off-set by additional equipment charges for the increased waiting time of the vehicle being loaded. Labour substitution is considered impracticable in such cases.

25. While the level of disaggregation has to some extent been governed by the need to allow for differing productivity rates due to environmental and other factors, this has been limited to those cases where productivity is dependent primarily on the nature of the work. Disaggregation has not been based on:

(i) Differing types of equipment which could be used for a particular activity and which would have differing productivity rates, unless the nature of the activity is essentially of a different character (e.g., mixing stabilised materials "in situ" or "not in situ").

(ii) Differences in the relative rates of productivity of equipment and labour due to environmental and other factors (for example, a particular environment may lead to high productivity for equipment but low for labour).

26. These general principles have been applied to varying degrees in isolating the basic activities. The degree of disaggregation has been greatest in those cases where substitution of labour for equipment appears to have the best possibility technically.

27. In certain construction processes, disaggregation to such a detailed level is not meaningful. This particularly applies to earthmoving operations carried out by equipment. For example, a scraper operation combines the basic activities of excavating, loading, transporting, unloading, spreading and part compacting; excavating by shovels is invariably combined with the loading operation, and numerous other examples could be quoted. Similarly, with labour-intensive methods, the excavating and loading activities, and the unloading and spreading activities, are often carried out simultaneously. It is therefore clear that in addition to considering each basic activity on its own, it will be necessary to take into account combinations of certain associated activities.

28. There is a further interaction between some sequential activities and this particularly applies in the loading, hauling, unloading and spreading activities. The method of haul, be it by head basket, wheel barrow, animal cart, tractor/trailer, truck or scraper, gives rise to differing loading heights and corresponding loading rates. Similarly, the method of unloading influences the effort required for spreading. These factors have not been taken into account in drawing up the list of basic activities at this stage, but it is clear that further sub-division of the basic list will eventually be required. Further reference is made to this aspect in Section .

29. The trade-off between labour and equipment varies from activity to activity and is dependent on the relative costs (and productivities) of the alternatives. Labour substitution could lead to increases in cost and, in practice, there would clearly be a limit to which this would be acceptable. For the purposes of this study, labour substitution has been deemed to be impracticable if the cost of carrying out an activity by equipment (at the assumed rates) is less than that of carrying it out by unskilled labour at a daily wage rate of US$0.20.

30. While the list of activities is thought to be comprehensive, further additions and greater disaggregation may become desirable as productivity data becomes available during the subsequent stages of the study. The areas in which this is most likely to occur are referred to in the next section of this Chapter.

Table II.1. List of Basic Construction Activities

			Category
1.	Site Preparation		
	1.1.	Clearing and grubbing	
		(1) light vegetation	EL
		(2) medium vegetation	EL
		(3) dense vegetation	EL
	1.2	Stripping topsoil	EL
2.	Excavating Small Quantities		
	2.1	In soft material	EL
	2.2	In hard material	EL
	2.3	In rock	EL
3.	Excavating in Bulk		
	3.1	In soft material	EL
	3.2	In hard material	EL
	3.3	In rock	EL
4.	Loading		
	4.1	Homogenous loose materials (e.g. soil, crushed rock, stabilised materials, asphaltic concrete, etc.)	EL
	4.2	Other solid and packaged materials (e.g. bagged cement, drummed bitumen and petrol, lump rock, reinforcement, etc.)	EL
	4.3	Water	EL
	4.4	Other bulk liquids (e.g. bulk bitumen, fuel oil, petrol, etc.)	EL
5.	Hauling		
	5.1	Up to 300 m	EL
	5.2	300 m - 2 km	EL
	5.3	Over 2 km	E

Table II.1 (continued)

6.	Unloading		
	6.1	Homogenous loose materials	EL
	6.2	Other solid and packaged materials	EL
	6.3	Water	EL
	6.4	Other bulk liquids	EL
7.	Spreading		
	7.1	Natural soils (for earthworks)	EL
	7.2	Unstabilised base and sub-base materials, quality factor	
		(1) high	E
		(2) intermediate	EL
		(3) low	EL
	7.3	Stabilised base and sub-base materials, quality factor	
		(1) high	E
		(2) intermediate	EL
	7.4	Bitumen macadam and asphaltic concrete, quality factor	
		(1) high	E
		(2) intermediate	EL
	7.5	P.C. concrete for pavements, quality factor	
		(1) high	E
		(2) intermediate	EL
	7.6	Cement/lime for stabilised bases, quality factor	
		(1) high	E
		(2) intermediate	EL
	7.7	Bitumen for surface dressing, penetration macadam, etc., quality factor	
		(1) high	E
		(2) intermediate	EL
	7.8	Gravel/sand for surface dressing, penetration macadam	EL
	7.9	Water (for compaction and curing, limewater for stabilisation)	EL

Table II.1 (continued)

8. Mixing

8.1	Natural soils in situ (for mechanical stabilisation, aeration, etc.), quality factor	
	(1) high	E
	(2) intermediate	EL
	(3) low	EL
8.2	Cement/lime with soils in situ, quality factor	
	(1) high	E
	(2) intermediate	EL
	(3) low	EL
8.3	Cement/lime with soils not in situ, quality factor	
	(1) high	E
	(2) intermediate	EL
8.4	Cold bitumen with soils in situ, quality factor	
	(1) high	E
	(2) intermediate	EL
8.5	Cold bitumen with soils not in situ, quality factor	
	(1) high	E
	(2) intermediate	EL
8.6	Hot bitumen with soils not in situ, quality factor	
	(1) high	E
	(2) intermediate	EL
8.7	Bitumen macadam, quality factor	
	(1) high	E
	(2) intermediate	EL
8.8	Asphaltic concrete	E
8.9	P.C. concrete, quality factor	
	(1) high	E
	(2) intermediate	EL
	(3) low	EL

9. Compacting and Finishing

9.1	Bulk materials in earthworks, quality factor	
	(1) high	E
	(2) intermediate	EL
	(3) low	EL

Table II.1 (continued)

	9.2	Unstablised bases and sub-bases, quality factor	
		(1) high	E
		(2) intermediate	EL
		(3) low	EL
	9.3	Stabilised bases and sub-bases, quality factor	
		(1) high	E
		(2) intermediate	EL
	9.4	Bitumen macadam, quality factor	
		(1) high	E
		(2) intermediate	EL
	9.5	Asphaltic concrete	E
	9.6	Surface dressings, quality factor	
		(1) high	E
		(2) intermediate	EL
	9.7	P.C. concrete for pavements, quality factor	
		(1) high	E
		(2) intermediate	EL
10.	Laying		
	10.1	Stone pitching	L
	10.2	Brick soling	L
	10.3	P.C. concrete linings (including compacting and finishing)	L
	10.4	Masonry walling	L
	10.5	Brick walling	L
	10.6	Precast concrete products	EL
	10.7	Steel pipe culverts	EL
	10.8	P.C. concrete in foundations, headwalls, etc., (including compacting and finishing quality factor	
		(1) high	EL
		(2) intermediate	EL
		(3) low	EL
11.	Production of Local Materials		
	11.1	Rock for pitching/masonry	EL
	11.2	Coarse aggregate for waterbound macadam	EL
	11.3	Crushed rock for bases and sub-bases (i.e. Crusher run)	E
	11.4	Coarse aggregate for bitumen macadam	EL

Table II.1 (continued)

11.5	Coarse aggregate for P.C. concrete asphaltic concrete	E
11.6	Coarse aggregate for quality factor	
	(1) high	E
	(2) intermediate	EL
	(3) low	EL
11.7	Coarse aggregate (chippings) for surface dressing	EL
11.8	Fine aggregate, quality factor	
	(1) high	E
	(2) intermediate	EL
	(3) low	EL
11.9	Making bricks	EL
11.10	Breaking bricks	EL
11.11	Precast concrete units, quality factor	
	(1) high	E
	(2) intermediate	EL

12. Miscellaneous

12.1	Cutting, bending and fixing reinforcement	L
12.2	Formwork (including stripping) quality factor	
	(1) high (wrought)	EL
	(2) intermediate (rough)	EL
12.3	Laying, trimming and compacting topsoil	EL
12.4	Sprigging with grass, etc.	L
12.5	Seeding with grass, etc.	EL
12.6	Brooming and cleaning surfaces	EL

13. Management and Other

13.1	Site overheads, logistic support, etc.	
13.2	Head office overheads and profit	
13.3	Administration	
13.4	Mobilisation, including transport to site offices	

Further Consideration of Basic Construction Activities

Site Preparation

31. Clearing and grubbing have been treated as a single activity though the two are occasionally carried out as separate operations. Productivity depends on the thickness of vegetation and this has been allowed for by sub-division of the activity into three levels - light, medium and dense vegetation. No separate activities have been provided for demolition of buildings, structures, etc., which are seldom of significance in under-developed countries.

32. The activity for removing topsoil is confined to this operation alone. Loading, transporting, unloading, etc., when replacing topsoil is provided for under other activities.

Excavating in Small Quantities

Excavating in Bulk

33. These two groups of activities are confined to the actual digging operation. The first group applies to the excavation of small quantities in ditches, trenches, foundations, etc., and it differs from the second group in that the excavation is invariably to precise lines and levels and hence it is more suited to hand labour. The second group includes bulk excavation in cuttings and borrow pits where tolerances are not so strict and are of less significance in relation to the quantity of material moved.

34. In both groups sub-divisions of the activity have been made to allow for the effect on productivity of the nature of the ground. The sub-divisions are defined:-

(1) "Soft" - capable of being excavated by a spade or similar hand tool; or capable of being loaded by a tracked scraper without push assistance but becoming uneconomic to do so; or capable of being loaded by a wheeled scraper with push assistance.

(2) "Hard" - requiring to be loosened by a pickaxe or crowbar before excavation by spade, etc., can take place; or capable of being loaded by scrapers with pre-ripping and push assistance.

(3) "Rock" - requiring the use of drills, plugs, feathers or wedges if excavated by hand, or unrippable by earthmoving machines and requiring the use of pneumatic tools and/or blasting.

35. These are the broad contract definitions but they are clearly not adequate for precise identification of all materials. It is considered that, as the study proceeds, there will be such a wide range of productivity rates dependent upon this factor that further sub-divisions will become essential.

Loading

36. To allow for the wide difference in rates of loading by hand labour and equipment and since transporting equipment is not productively employed during loading, this activity is defined as including the waiting time during the loading activity of any equipment for transport. Four sub-divisions of the activity are envisaged, depending on the nature of the materials being loaded.

37. No provision has been made for variations in the height through which materials are moved during the loading activity. This can have a marked effect on productivity, particularly when loading materials by hand labour, and may need to be taken into account during later stages of the study.

Hauling

38. Three sub-divisions of this activity have been provided, depending on the length of the haul, viz:

(1) up to 300 m - the practical limit of hand labour (though greater distances could be achieved using a relay system of carriers)

(2) up to 2 km - the practical limit of haulage by scrapers and animal-drawn carts

(3) over 2 km - essentially a truck or tractor/trailer operation

These arbitrary sub-divisions might need to be amended in the light of further experience.

39. No differentiation has been made between loaded and unloaded trips since the former necessarily entails the latter and they can both be taken into account by averaging. The height to be gained or lost during haulage significantly affects the productivity of hand labour but that of equipment to a lesser extent; some further disaggregation of this activity might be shown to be desirable to allow for this factor. Similarly, the condition of haul routes would particularly affect equipment productivity but this can be allowed for as an environmental factor.

Unloading

40. As with the loading activity, the waiting time of any equipment used for hauling is included. The same sub-division (by nature of the materials unloaded) of the activity has been adopted. It seems unlikely that further disaggregation to allow for variation in unloading height will be required since this has little effect on productivity. However, account will probably need to be taken of the haulage method since, for example, the use of self-tipping vehicles would preclude the use of labour for unloading. (See also paragraph 43)

Spreading

41. The quality of workmanship in many of the activities in this group can have a pronounced effect on the quality of the finished road and it has been necessary to allow for this factor in the disaggregation process. As previously stated, three general levels of quality have been chosen; these can be defined in terms of the degree of control exercised over the activity, permitted tolerances in the thickness of layer (or rate of spread) and permitted tolerances in the upper surface of the layer. Many of the activities are concerned with spreading high-cost materials such as bitumen and cement mixtures; it would not be appropriate to utilise low standards of quality with these materials (though this doubtless occurs at times) and hence the lower levels of quality have been omitted in these cases.

42. The quality factors are defined as:

(1) For bases and sub-bases (Activities 7.2, 7.3, 7.4 and 7.5)

High - Courses laid to precise levels with a substantial degree of compaction incorporated in the spreading process. Tight control of thickness of layer on basis of direct measurement after compaction. Surfaces true to line and level with little or no reshaping required during or after compaction.

Intermediate - As above but no pre-compaction required during the spreading process and reshaping permitted during and after compaction.

Low - Thickness of layers controlled by average rates of spread of loose materials (e.g. measured by truck load). Surface tolerances achieved primarily by shaping during the compaction process.

(2) Cement, Lime and Bitumen (Activities 7.6 and 7.7)

High - Precise control of rates and uniformity of spread by regular direct measurement (by tray tests) and frequent checking and calibration of spreading devices. Accurate control of bitumen temperatures.

Intermediate - Precise control of rate of spread by checking quantities in relation to areas covered but control of uniformity of spread by visual inspection only. Fairly wide margins on bitumen temperatures.

43. Some further disaggregation may be necessary to take account of the way in which materials to be spread are unloaded. For instance, materials carried by head basket can be unloaded so that little spreading is required whereas those dumped from a truck would entail much more effort to spread.

Mixing

44. As in the previous group of activities, it has been necessary to take into account the quality of workmanship. Again, although three general levels of quality are used, the lowest quality has been deemed not to be appropriate with high-cost materials. In the case of asphaltic concrete it is considered that only the highest quality would apply.

45. The quality factors are defined:-

(1) Natural Soils in Situ (Activity 8.1)

High - Involving pulverisation and intimate, uniform mixing of the soils and uniform moisture content; high degree of control by frequent testing of gradation and moisture contents.

Intermediate - As above but without pulverisation of the soils; a high degree of control but slightly lower standards of uniformity acceptable.

Low - A blending or "turning over" of soils rather than mixing; control exercised mainly by visual inspection. (Aeration of soils would fall into this category.)

(2) Cement/Lime with Soils (Activities 8.2 and 8.3)

High - Involving pulverisation and intimate, uniform mixing of the cement/lime with the soil and uniform moisture content; weigh batching for "not in situ" process; high degree of control by frequent testing for cement/lime and water content.

Intermediate - As above but without pulverisation of the soils; volumetric batching for "not in situ" process; a high degree of control but slightly lower standards of uniformity acceptable.

Low - Blending of the cement/lime with the soil by "turning over" rather than mixing; control exercised mainly by visual inspection.

(3) Cold Bitumen with Soils (Activities 8.4 and 8.5)

High - Involving pulverisation and intimate, uniform mixing of the bitumen with the soil; weigh batching for "not in situ" process; high degree of control by frequent testing for bitumen content.

Intermediate - As above without pulverisation of the soil; volumetric batching for "not in situ" process; a high degree of control but slightly lower standards of uniformity acceptable.

(4) Hot Bitumen with Soils (Activity 8.6)

As (3) but with additional requirements for control of bitumen temperatures.

(5) Bitumen Macadam (Activity 8.7)

High - Involving intimate and uniform mixing with weigh batching of ingredients; precise control of temperature of ingredients and final mixture; high degree of control by frequent testing for gradation and bitumen content.

Intermediate - Slightly lower standards of uniformity acceptable and volumetric batching of ingredients; no precise temperature control; control mainly by visual inspection.

(6) P.C. concrete (Activity 8.9)

High - Weigh batching of all ingredients with precise control of moisture content of aggregates, proportions of ingredients, mixing time, workability and strength; normally required to produce high strength (above 30 MN/m^2) concrete.

Intermediate - Volumetric batching of all ingredients with slightly lower standards of control; to produce concrete strengths within the range 15-30MN/m^2.

Low - Volumetric batching of solid ingredients with control of workability, water content and workability mainly by visual inspection; low concrete strengths (less than 15 MN/m^2).

NOTE: Wherever weigh batching is specified, calibrated adjustable volumetric devices providing the same standards of accuracy would be acceptable for continuous mixing processes.

Compacting and Finishing

46. Although compacting and finishing are separate activities, requiring differing types of hand tools or equipment, they are essentially undertaken as a joint operation. Experience may show that they should be dealt with separately, but it is believed that full disaggregation is not necessary in this case.

47. Disaggregation of the individual activities has again been based on quality following a similar procedure adopted to that in the spreading and mixing groups. In the case of earthworks, some further disaggregation by soil type will certainly be required since the effort required to meet a given level of compaction varies between wide extremes depending on the soil type; the desirable range of compaction is similarly dependent on the type of soil/material.

48. The quality factors are defined below:-

(1) Bulk Materials in Earthworks

High - Greater than 95% B.S. (Proctor) compaction with a high degree of control of moisture content and final density by frequent testing.

Intermediate - Between 90 and 95% B.S. (Proctor) compaction with a moderate degree of control possibly by a method specification (e.g. by a certain number of passes of a specified type and size of roller at a specified moisture content).

Low - Between 85 and 90% B.S. (Proctor) compaction with control mainly by visual inspection and moisture content testing.

(2) Unstabilised Bases and Sub-bases

High - Greater than 98% B.S. (Proctor) compaction with a high degree of control of moisture content and final density by frequent testing.

Intermediate - Between 95 and 98% B.S. (Proctor) compaction with a moderate degree of control, possibly by a method specification.

Low - Between 90 and 95% B.S. (Proctor) compaction, control mainly by visual inspection and moisture content testing.

(3) Stabilised Bases and Sub-bases

High - Greater than 97% B.S. (Proctor) compaction with a high degree of control by frequent density testing.

Intermediate - Between 94 and 97% B.S. (Proctor) compaction with a moderate degree of control, possibly by a method specification and (where applicable) moisture content testing.

(4) Bitumen Macadam

High - Bulk density greater than 95% of the maximum density for the material when compacted in a suitable mould using unlimited compactive effort.

Intermediate - Bulk density between 90 and 95% of the above maximum density.

(5) Surface Dressings

High - Rolling by heavy pneumatic-tyred rollers which facilitates the penetration of the chipping into the underlying material without crushing.

Intermediate - Rolling by other equipment which causes some crushing of the chippings and/or lack of penetration into the underlying material.

(6) P.C. concrete for Pavements

High - Compacted by mechanically operated vibrating beams.

Intermediate - Compacted by hand tamping supplemented by vibrators.

49. The foregoing principles define the quality standards relating to the state of compaction. They are coupled to requirements for surface finish which are given below in terms of maximum tolerances:-

High - Within 10 mm of required levels; when tested with a 3 m straight edge placed at right angles or parallel to the carriageway, no depression to exceed 10 mm.

Intermediate - Within 20 mm of required levels when tested with a 3 m straight edge placed at right angles or parallel to the carriageway, no depression to exceed 20 mm.

Low - No precise requirement relating to required levels; when tested with a 3 m straight edge placed at right angles or parallel to the carriageway, no depression to exceed 30 mm.

While it would be possible to combine differing levels of quality for compaction with those for finishing, the same levels are, in general, compatible with each other.

Laying

50. Further additions to this group of activities may be required to cover construction techniques peculiar to specific countries, together with some further disaggregation (e.g. differentiation between dry-stone masonry and that laid in mortar).

51. In the items for concrete linings and concrete in foundations, headwalls, etc., the separate basic activities of placing, compacting and finishing have been aggregated since these activities form such a small part of the construction operation and are carried out essentially as part of the same operation. The quality factors for concrete in foundations, etc., are:-

High - Thin reinforced concrete sections requiring close tolerances of finish and trowelled/floated surfaces.

Intermediate - Mass concrete sections requiring close tolerances of finish and trowelled/floated surfaces.

Low - Mass concrete with screeded surfaces.

Production of Local Materials

52. The activities in this group relate only to the actual production processes and other activities, previously defined, are required to cover the full operation of producing a local material. The intention is that the processes required for the production of local materials should be fully disaggregated. Examples are:-

(1) The activities for producing coarse aggregates (11.2 through 11.7) cover only the crushing operation. Supplementary activities that might be required to cover the full processes are excavating in rock, loading, transporting, unloading, etc.

(2) Activity 11.8, fine aggregate, covers the crushing, washing, blending and grading operations only. Supplementary activities would include the excavation of the sand, loading, etc., and the supply of water for washing.

(3) Activity 11.9, making bricks, covers only the forming and burning of the bricks. Supplementary activities that might be required to cover the full process are excavation of brick clay, loading, transporting, unloading, etc.

(4) Activity 11.11 precast concrete units, includes erection and stripping of moulds and the placing, compacting and finishing of the concrete. Local materials for and the mixing of the concrete would be covered under other activities.

53. The quality factors are defined:

(1) Coarse Aggregate for R.C. concrete (Activity 11.6)

High - A homogeneous precisely graded clean mixture achieved by blending fractions of different sizes together; washed if necessary.

Intermediate - A well graded mixture with wider tolerances than above, achievable by modern crushing plant without blending.

Low - A stone mixture with unspecified grading except for limitations on the maximum stone size.

(2) Fine Aggregate (Activity 1.8)

High - Washed, with precisely defined grading characteristics which may require blending of two or more materials or other processing.

Intermediate - Washed, but with no grading requirements.

Low - Unwashed, with no grading requirements.

NOTE: The lowest level of quality seldom applies since such aggregate can normally be obtained by the excavating activity alone. However, it is included here since in some sand-deficient areas fine aggregate is produced by crushing rock

(3) Precast Concrete Units (Activity 11.11)

High - Spun or hydraulically pressed units.

Intermediate - With concrete compacted by tamping or vibration.

Miscellaneous

54. Again, the intention is that activities within this group should be fully disaggregated. Other associated activities required for the full processes would be considered separately.

Management and Other

55. These items have been listed separately since they form an integral part of any road construction project. They are not (in the true sense) activities and labour substitution can apply in only a few isolated instances (such as partly in the erection of construction camps). However, it is essential that they be distinguished from the construction activities and their proportion of the total cost of a project be recognised. They are related, in one way or another, to the feasibility of labour substitution and the trade-off between labour and equipment. For instance, in some areas, it may be less costly to mobilise labour than equipment; a larger site staff may be required to supervise labour-intensive projects; it may be argued that a labour-intensive project involves greater risk to a contractor, owing to the possible incidence of strikes, difficulties of enforcing discipline, and greater management problems, etc. and hence higher profits might be justified.

C. Review of Available Engineering Data and Evaluation of Alternative Sources

56. This section describes the sources of engineering data found in the survey of existing literature, and evaluates the adequacy of these data and the problems in collecting more adequate information.

1. Review of Available Data

57. Data recording the productivity of equipment and labor has been extracted during a study of the literature described in Appendix A and referenced in the engineering bibliography. The data sources have taken three main forms - records of projects and experiments, interviews with contractors, and estimating handbooks. An attempt has been made to assess the adequacy of the data as either good or poor and it can only be concluded that the available data are highly inadequate and insufficiently detailed to permit study of the substitution problem. The two main reasons for this assessment are:

(1) Lack of disaggregation of basic activities to the level required for the study.

(2) While precise output figures have been recorded, the conditions and environment under which these outputs have been achieved (or are possible) have seldom been described.

A notable exception to the foregoing is the 1963 ILO publication, "Men Who Move Mountains".

58. A review of the data reveals an extraordinarily wide range of productivity rates, particularly of labour, in differing environments. While certain of the published figures could be relied upon to be representative of "average" conditions, it would be impossible to quantify the effect of environment (in its widest sense) on productivity by any simple rating system.

59. An important example of the extremely wide variation in labour productivity rates is given in Table II.2 for the case of bulk excavation. Where applicable, the source figures have been modified to correspond with the working day of 8 hours assumed for the analyses.

60. The data given in Table II.2 are drawn from a wide range of environments and they range for a single soil categorization ("ordinary") from 0.13 to 8.00, or a variation of more than six thousand per cent. At least two factors may be offered to explain this extraordinary variation. First, a more specific geotechnical identification of soil types will be required; moisture content is only one important parameter which has been left undefined.

Table II.2 Labour Intensive Methods Input Coefficients

Excavating in Bulk and Loading Into Wheelbarrows

	Source, Year (Reference No.)	Soil Type	Labour Hours per m^3
1.	ECAFE early 1960's (SW 1), Philippines	ordinary	0.13
2.	ECAFE early 1960's (SW 1), Japan	ordinary	0.20
3.	ECAFE early 1960's (SW 1), Burma	ordinary	0.22
4.	ECAFE early 1960's (SW 1), India	ordinary	0.60
5.	Boon "Economic Choice of Human and Physical Factors," 1964 (BC 20)	ordinary	0.60
6.	ILO "Men Who Move Mountains," (SW 2), India-Maliabari	ordinary	0.62
7.	British Army (SW 4)	ordinary	0.83
8.	Cameroon 1945 (BC contractor's documents)	sandy	1.00
9.	Price Davies, 1932 (SW 40)	ordinary	1.05
10.	ILO, 1963 (BC 2), India other than Maliabari	ordinary	1.12
11.	Bigolet R.A.L.L., 1970 (BC 5)	sandy	1.28
12.	Cameroon, 1945 (BC contractor's documents)	clayey	1.33
13.	Spence Geddes, 1948 (SW 16)	ordinary	1.44
14.	Galabru "Equipement General" (BC 8)	sandy	1.50
15.	Analysis of Poitiers Crossing, 1850 (BC 3)	sandy	1.55
16.	Bigolet R.A.L.L., 1970 (BC 5)	clayey	1.70
17.	French Army Handbooks (BC 6 and 7)	sandy	2.00
18.	Galabru "Equipement General" (BC 8)	ordinary	2.00
19.	ILO, 1963 (BC 2, p. 53), Ceylon	ordinary	2.25
20.	France, 1961 (BC contractor's documents)	unspecified	2.50
21.	Madagascar Estimating Handbook, 1930 (BC 4)	sandy	2.50
22.	Analysis of Poitiers Crossing, 1850 (BC 3)	hard	2.66
23.	Cameroon 1945 (BC contractor's documents)	hard	2.66
24.	Galabru "Equipement General" (BC 8)	clayey	3.00
25.	Madagascar Estimating Handbook, 1930 (BC 4)	ordinary	3.50
26.	Madagascar Estimating Handbook, 1930 (BC 4)	clayey	3.75
27.	French Army Handbooks (BC 6 and 7)	ordinary	4.00
28.	French Army Handbooks (BC 6 and 7)	clayey	8.00
29.	Abidjan, 1952 (BC contractor's documents)	ordinary	8.00

Reference number preceded by BC refers to BCEOM engineering bibliography; SW refers to SWKP engineering bibliography.

Second, these coefficients were observed in physical, economic and social environments as different, for example, as France in 1850 and India in the 1960's and a whole host of environmental parameters which bear importantly on the productivity rates are unspecified. Possibly among the most important are the social acceptability of and individual attitudes toward manual labor and the institutional and managerial frameworks in which manual labor takes place.

61. All of these factors, which are elaborated upon in Chapter III, will bear importantly upon the choice of construction technology in any given situation.

2. Evaluation of Alternative Sources of Information

62. International contractors. In an attempt to locate sources of reliable productivity data, discussions were held with several civil engineering contractors having experience of working in underdeveloped countries. Such records are maintained by these organisations but invariably in financial terms and essentially for the purpose of financial control. The contractors seldom attempt to make use of these records in preparing tenders since the full environmental conditions are not recorded and, even if they were, it would be difficult to properly compare the varying effects of differing environments.

63. It is considered that little useful information could be obtained from a study of contractors' records of past projects since:

a. Operations are seldom disaggregated into basic activities.

b. Records are related to the costs of items listed in the Bills of Quantities which, however, do not represent the actual work carried out but rather define the financial basis of payment.

c. Contractors might not be willing to disclose the full extent of the information required, particularly the elements of overheads and profit.

d. It is unlikely that there would be adequate knowledge or detailed descriptions of the conditions under which the work was performed.

e. The personnel who were actually engaged on the construction of the project and who could supplement the recorded data by personal knowledge are unlikely to be available to assist in the research. This aspect is particularly pertinent since contractors would probably be less willing to disclose full particulars of the more recently completed projects.

f. Data obtained from less recent projects might not be applicable to current construction techniques, particularly equipment operations.

g. In recent years very few labour-intensive projects have been carried out by large contractors and such data as might be available would be largely confined to equipment-orientated techniques and methods.

Certain of these disadvantages could be overcome by enlisting the active support of contractors (and supervisory personnel) on current projects.

64. Local contractors. The foregoing applies mainly to the large "international" type contractor. The smaller "petty" contractor common to most developing countries is unlikely to maintain records of this type. However, it is felt that much useful information relating to the performance of labour could be obtained by interviewing small contractors and works department personnel (at the overseer level) engaged on road maintenance operations by force account methods.

65. Supervising agencies. Further possible sources of productivity data include the agencies responsible for and consulting engineers engaged in supervising highway construction. No approach has been made to highway authorities to ascertain whether their records could provide fully documented productivity data. However, the experience of engineers who have worked on highway construction and maintenance as government employees in many of the former British colonies in Africa and the Far East indicates that such information would be totally lacking. Nevertheless, it is believed that there is scope for drawing on the knowledge and experience of personnel engaged in directly supervising force account work in the developing countries by an interviewing procedure.

66. The records maintained by international consulting engineers supervising highway construction contracts are not designed to record productivity data in the form required for the study and while an examination of records of past projects in combination with those of the contractor might produce some data, it is unlikely that the necessary degree of disaggregation would exist and the accuracy would be open to doubt. However, as previously stated, the active support of such consultants on current projects would provide a useful source of information.

67. The UK Road Research Laboratory is currently collecting equipment productivity data on two road construction contracts in Uganda and on a further contract in Liberia. The data is in raw form but it is understood that it could be made available to the study at some future date.

3. Conclusions Concerning Available Engineering Data

68. Unfortunately at this stage of the study there appear to be few easy generalizations which would permit formulation of simple criteria for the determination of road construction technology. The available data permit few conclusions except, perhaps, that physical, economic and social environmental factors may be so important in each instance that a case by case approach will be required.1/ It is hoped that further study involving field generation of new data will to some extent relax this finding, permitting some generalization and simplification of the problem.

69. It has been concluded from the review of available data that the data needed in order to determine the production functions and to relate productivity rates to the environment must be obtained primarily by direct field observation of current projects, supplemented by an interviewing programme with personnel engaged in directly supervising construction work. Nevertheless, it is believed that further studies of existing literature and documentation could provide some additional information of value.

70. Some thought has been given to the possibility of collecting productivity data by postal questionnaire. Although it is likely that data so collected would be sketchy, unreliable and slow to arrive, a method which couples the completion of questionnaires with a visit might overcome these objections.

71. Many of the basic activities in road construction are common to other fields of civil engineering (e.g. dam construction and irrigation work) and future field work will be arranged to observe these activities to the extent that time permits.

1/ The reader should bear this in mind in considering the example analyses given in the remainder of this Chapter and Chapter V. The opposed conclusions of SWKP and BCEOM may each be valid in appropriate circumstances.

D. Comparative Analyses of the Substitutability of Labor in Road Construction Activities Based on Alternative Data Sources

72. Despite the extremely wide range of data available in the literature, a series of analyses of road construction activities have been prepared separately by the two engineering consultants, SWKP and BCEOM, in order to gain some measure of the technical scope for the substitution of labor for equipment in road construction. Four series of analyses have been undertaken:

i. the calculation of the trade off between labor and equipment at the level of the basic construction activities expressed in terms of breakeven wage rates;

ii. the aggregation of certain basic activities which are interdependent at the level of a production function isoquant for a specified group of activities (e.g. excavation of 1000 m^3 of soft earth, loading, hauling a specified distance, unloading and spreading);

and in section E below for a series of hypothetical road projects:

iii. the aggregation of groups of similar operations (earthworks, sub-base, base, and pavement) in the quantities required for the construction of one kilometre of hypothetical roadworks according to various designs and terrain.

iv. analyses of the costs required in the complete construction of one kilometer of the hypothetical roadworks by equipment intensive methods, by labour intensive methods and by an optimal combination of methods.

73. In these analyses the construction operations have been disaggregated into basic construction activities. Estimates of the time required to carry out each activity have been prepared based on data contained in estimating handbooks and other sources (as documented in Appendices A and B) first for the optimal combination of methods (for an assumed wage rate for unskilled labour of US$1.00 per day) and then for the equipment intensive and labour intensive extremes of the production functions. These estimates have been converted into monetary terms using

the same set of prices for equipment and labour in both the SWKP and BCEOM analyses, so that differences between the two estimates reflect differences in the productivity coefficients adopted.

74. Construction standards for a given geometric design have been varied between high and intermediate qualities as defined in section II.B above. The geometric standards have been kept the same though, in practice, some changes would be made to accommodate labour-intensive methods.

75. It is noteworthy that the productivity coefficients judged most applicable by the two engineering consultants differ by extraordinarily wide margins, reflecting presumably different experience and different engineering judgment as well as the inadequacy of existing data sources. Whenever available the estimates of the two consultants have been juxtaposed and the basis and source for each given.

1. Analysis of Basic Activities

76. The results of the first series of analyses are presented in Table II.3 in the form of the break-even wage rates. Equipment and material prices and productivity rates on which these analyses are based are given in Appendices A and B, respectively. For the interdependent group of activities excavating, loading, hauling, unloading, and spreading, SWKP arbitrarily divided the time of the road scraper and bulldozer into the individual activities based on the time cycle of the operation. BCEOM eschewed such calculations, so that corresponding coefficients are not available in Table II.3 for these separate activities.

77. The break-even daily wage rate, W, is defined for a given set of equipment prices as that wage rate (for unskilled labour) at which the cost of carrying out an activity by labour is identical with that of equipment. It is equal to the marginal rate of substitution under these assumptions. Its value is given by the following expression:

$$W = \frac{E_1 - E_2}{l_2 - l_1}$$

where E_1 and E_2 represent the equipment costs for equipment-intensive and labour-intensive methods, respectively, and l_1 and l_2 are the unskilled labour input in days for the equipment and labour-intensive methods, respectively. The greater the value of W, the more advantageous is substitution. A negative value indicates that more equipment is required for the labour-intensive method and substitution is therefore impracticable. For the purpose of this study, substitution is also deemed to be impracticable if the break-even daily wage rate is less than U.S.$0.20 (See para. 29).

TABLE II.3: Break-Even Wage Rates (W) by Basic Activity

(W in US $ per man day)

No.	Activity Description	Equipment Intensive Method	Labour Intensive Method	W BCEOM	W SWKP
	Site Preparation				
1.1.2	Clearing and grubbing medium vegetation	D8	Hand	0.66	3.56
1.2.1	Stripping topsoil 10 cm thick	D8	Hand	0.72	0.33
	Excavating in Small Quantities				
2.1.1	Ditches in soft material	Grader	Hand	0.51	1.17
	Grass roots for sprigging	Grader	Hand	NAV	0.73
2.3.1	Ditches in rock	Compressor, drills and explosives	Hand	0.06	1.87
	Excavating in Bulk				
3.1.1	Earthworks in soft material	D8	Hand	NAV	3.82
3.1.2	Gravel for sub-base	D8	Hand	NAV	3.82
3.1.3	Gravel for base	D8	Hand	NAV	3.82
3.3.1	Rock in earthworks	Compressor, drills and explosives	Hand	NAV	0.90
3.3.2	Rock for bases	Compressor, drills and explosives	Hand	NAV	0.34
3.3.3	Rock for chippings	Compressor, drills and explosives	Hand	NAV	0.50
	Loading				
4.1	Homogeneous loose materials	Traxcavator into truck	Hand into truck	-0.01	-0.24
4.1	Homogeneous loose materials	Traxcavator into truck	Hand into trailer	0.00	5.48
4.1	Homogeneous loose materials	Traxcavator into truck	Hand into bullock cart	NAV	4.90

NAV = Not available

TABLE II.3 continued

				W BCEOM	W SWKP
	Loading (continued)				
4.1	Homogeneous loose materials	Traxcavator into truck	Hand into wheelbarrow	NAV	7.56
4.1	Homogeneous loose materials	Traxcavator into truck	Hand into basket	NAV	11.04
4.1	Homogeneous loose materials	Traxcavator into trailer	Hand into trailer	NAV	4.06
4.1	Homogeneous loose materials	Traxcavator into trailer	Hand into bullock cart	NAV	3.72
4.1	Homogeneous loose materials	Traxcavator into trailer	Hand into wheelbarrow	NAV	5.72
4.1	Homogeneous loose materials	Traxcavator into trailer	Hand into basket	NAV	8.36
4.2	Rock from earthworks	Traxcavator into truck	Hand into truck	NAV	1.68
4.2	Rock from earthworks	Traxcavator into truck	Hand into trailer	NAV	7.46
4.2	Rock from earthworks	Traxcavator into truck	Hand into bullock cart	NAV	6.54
4.2	Rock from earthworks	Traxcavator into truck	Hand into wheelbarrow	NAV	10.10
4.2	Rock from earthworks	Traxcavator into truck	Hand into basket	NAV	14.72
4.2	Rock from earthworks	Traxcavator into trailer	Hand into trailer	NAV	5.54
4.2	Rock from earhhworks	Traxcavator into trailer	Hand into bullock cart	NAV	4.96
4.2	Rock from earthworks	Traxcavator into trailer	Hand into wheelbarrow	NAV	7.66
4.2	Rock from earthworks	Traxcavator into trailer	Hand into basket	NAV	11.16
4.3	Water	Pump into bowser	Hand into trailer	NAV	-0.10
4.3	Water	Pump into bowser	Hand into bullock cart	NAV	0.25

NAV = not available

TABLE II.3 continued

				W BCEOM	W SWKP
	Hauling				
5.1.1	Excavated soil 100 m	Truck	Wheelbarrow	NAV	0.22
5.1.1	Excavated soil 100 m	Truck	Baskets	NAV	0.14
5.1.1	Excavated soil 100 m	Tractor and trailer	Wheelbarrow	NAV	0.50
5.1.1	Excavated soil 100 m	Tractor and trailer	Baskets	NAV	0.30
5.1.2	Excavated soil 200 m	Truck	Bullock cart	NAV	0.24
5.1.2	Excavated soil 200 m	Truck	Wheelbarrow	NAV	0.12
5.1.2	Excavated soil 200 m	Truck	Basket	NAV	0.10
5.1.2	Excavated soil 200 m	Tractor and trailer	Bullock cart	NAV	0.44
5.1.2	Excavated soil 200 m	Tractor and trailer	Wheelbarrow	NAV	0.24
5.1.2	Excavated soil 200 m	Tractor and trailer	Basket	NAV	0.20
5.2.1	Excavated soil 400 m	Truck	Bullock cart	NAV	0.19
5.2.1	Excavated soil 400 m	Tractor and trailer	Bullock cart	NAV	0.44
5.2.3	Gravel 1 km	Truck	Bullock cart	NAV	0.15
5.2.3	Gravel 1 km	Tractor and trailer	Bullock cart	NAV	0.27
5.2.4	Gravel 2 km	Truck	Bullock cart	NAV	0.12
5.2.4	Gravel 2 km	Tractor and trailer	Bullock cart	NAV	0.24
5.2.5	Water 2 km	Bowser	Bullock cart	NAV	0.04
5.2.5	Water 2 km	Tractor and trailer	Bullock cart	NAV	0.21
5.3	Loose materials 10 km	Truck	Bullock cart	NAV	0.10
5.3	Loose materials 10 km	Tractor and trailer	Bullock cart	NAV	0.22

TABLE II.3 continued

				W BCEOM	W SWKP
	Unloading				
6.1	Homogeneous loose materials	Tipping truck	Hand from trailer	NAV	17.24
6.1	Homogeneous loose materials	Tipping truck	Hand from bullock cart	NAV	0.90
6.1	Homogeneous loose materials	Tipping truck	Hand from wheelbarrow	NAV	6.30
6.1	Homogeneous loose materials	Tipping truck	Hand from baskets	NAV	8.46
6.2	Rock from earthworks	Tipping truck	Hand from trailer	NAV	17.18
	Spreading				
7.1	Natural soils	Grader from truck/ trailer	Hand from truck/ trailer	0.16	0.50
7.1	Natural soils	Grader from truck/ trailer	Hand from bullock cart	0.16	20.56
7.1	Natural soils	Grader from truck/ trailer	Hand from wheelbarrow	0.81	0.91
7.1	Natural soils	Grader from truck/ trailer	Hand from basket	NAV	20.56
7.1	Natural soils	Grader from wheelbarrow	Hand from tractor/ trailer	0.16	0.24
7.1	Natural soils	Grader from wheelbarrow	Hand from bullock cart	0.16	10.28
7.1	Natural soils	Grader from wheelbarrow	Hand from wheelbarrow	0.81	0.46
7.1	Natural soils	Grader from wheelbarrow	Hand from basket	NAV	10.28
7.2.2	Gravel bases and sub-bases intermediate quality	D8 with spreader box	Hand from truck/ trailer	NAV	6.96
7.2.2	Gravel bases and sub-bases intermediate quality	D8 with spreader box	Hand from bullock cart	NAV	278.80

NAV = Not available

Table II.3 continued

				W BCEOM	W SWKP
	Spreading (continued)				
7.8	Chippings for surface dressing	Truck with chipping spreader	Hand from truck/ trailer	0.13	1.11
7.9	Water	Bowser	Hand from trailer/ cart	NAV	3.05
	Compacting and Finishing				
9.1.1	Natural soils intermediate quality	Grader and roller	Hand	0.22	0.24
9.2.1	Gravel bases and sub-bases intermediate quality	Grader and roller	Hand	2.25	1.06
9.2.3	Macadam and crushed rock base, intermediate quality	Grader and roller	Hand	8.65*	1.07
9.6.1	Surface dressing, intermediate quality	Roller and broom	Hand	-296.8	1.58
	Production of local Materials				
11.?.1	Coarse aggregate for macadam	Crusher	Hand	0.57	0.52
11.7.1	Chippings for surface dressing	Granulator	Hand	NAV	1.26
11.7.2	Chippings for macadam dressing	Granulator	Hand	0.57	1.56
	Miscellaneous				
12.3.1	Laying, trimming and compacting topsoil	Roller	Hand	3.53	0.64
12.6.1	Brooming and cleaning surfaces	Tractor with broom	Hand	1.21	1.78

* The BCEOM coefficient for compacting and finishing gravel base has been calculated from pp. 15, 90 of the Appendix to the BCEOM Report, but is in disagreement with the W coefficient, 0.15, given on p. 28 of their Report.

Source: SWKP Report, pp. 29-33.
BCEOM Report, pp. 26-30 and Appendix.

78. The list of activities given in Table II.3 has excluded the following:

(1) Activities in categories 'E' and 'L' since, by definition, substitution by labour and equipment, respectively, is not possible.

(2) Operations which essentially combine several activities together (e.g., earthmoving by scraper). These activities are treated in paras. 93 ff. below.

Furthermore, these break-even wage rates would not necessarily apply to all the activities in road projects. For example, the output from equipment excavating rock in a quarry would be greater than when excavating it piecemeal within roadway excavation. While such factors are excluded here, they have been taken into account in the subsequent analyses.

79. The wide range in values of the substitution coefficients and break-even wage rates given in Table II.3 will be noted from a few with negative values to quite large values for some of the spreading operations. There is a wide variety of activities for which substitution would be financially advantageous at a daily wage rate of U.S.$2.00. These include activities in the excavating, loading, unloading and spreading groups of operations but not in the hauling group. Loading homogeneous loose materials into trucks and water into bowsers by hand give negative values and indicate that these substitution possibilities should possibly be rejected from further consideration as being impracticable.

80. Activities for which the break-even wage rate is between zero and $0.20 per day are confined to the haulage group of operations. In themselves, the figures indicate that the following methods of haulage would be impracticable:

(1) By basket for distances of 100 m. or more.
(2) By wheelbarrow for distances of 200 m. or more.
(3) By bullock cart for distances of 400 m. or more.

However, the haulage method cannot be considered on its own, but only in combination with other related activities.

81. Many of the basic activities are inter-dependent in that the method adopted for one activity can affect that preceding and that following it. This is particularly so in the excavating, loading, hauling, unloading and spreading groups of sequential activities.

To determine the most advantageous combinations of the various possible ways of carrying out these interdependent activities, the corresponding substitution coefficients (and break-even wage rates) cannot be added or averaged and it is necessary to aggregate the equipment and labour contents of each possible combination of the basic activities. The concept of production function isoquants has been used in the aggregation process and the procedure is explained in the following section.

2. Analyses of Interdependent Activities

a. An Introduction to Production Functions

82. In the subsequent analyses production functions are presented graphically in the form of two dimensional isoquants. For those unfamiliar with production function concepts, this section constitutes an introduction to the graphical representation and interpretation of isoquants. Those readers familiar with production functions may proceed directly to the analyses which commence in section b.

83. A relation between the quantity of output produced from any activity and the associated inputs of equipment and labour can be plotted in two dimensional space. The vertical axis represents, in some unit, the equipment input for a specific activity or operation while the (unskilled) labour input is shown horizontally. For a given output, a series of points may be plotted defining the equipment/labour function, or isoquant. This relationship will have as parameters the specific environment, the scale of the undertaking, length of construction period and the quality level to be achieved.

84. Production relations for some activities in road construction, such as excavation, are not affected by quality considerations, while others, such as compacting and finishing, are heavily dependent on the level of quality specified. It should be noted that a given isoquant depicts alternative combinations of inputs which can produce a given quantity of output of identical quality. A given quality may be achieved by different methods and design e.g. a square meter of pavement with a specified bearing strength and longevity index might be achieved by such alternative designs as penetration macadam of one thickness or single surface treatment over base and subbase courses of different materials and thicknesses, etc. Just as for a given quality, other quantity (or output) levels would result in further isoquants, for a given quantity different levels of quality would often require different isoquants of inputs. In the analyses below we explicitly consider the effect on the required inputs of varying the quality level specified for various road construction activities.

85. Some common unit of measuring differing types of equipment and labour is required so that differing types can be combined together for a two dimensional graphical representation. There are various possibilities:

(1) Equipment could be measured in terms of its horsepower; while this would take some account of the materials consumed in operating the equipment, the skilled and semi-skilled labour involved in its operation could not be so measured.

(2) Labour could be measured in terms of time units with appropriate weighting between the various categories.

(3) Labour, equipment and materials could be measured in monetary terms.

For various reasons monetary cost (excluding mobilisation, overheads, profit, idle time, etc.) has been taken as the unit for equipment and time for labour in the following presentation.

86. For a basic construction activity of category 'E', the production function would theoretically consist of a single point on the vertical axis, representing the cost of carrying out that activity. Similarly, a category 'L' activity would be represented by a single point on the labour axis and a category 'EL' activity would be defined by two points one on each axis. In the latter case, it is assumed (though this may not be strictly accurate) the two points could be joined by a straight line since any part of the work could be carried out either by equipment or labour. The effect of some unskilled labour content in an equipment-intensive activity or of some equipment content in a labour-intensive 'EL' category activity would be to offset these points from the axes, but in the same way they could still be joined by a straight line.

87. With equipment costs measured in U.S.$ and labour time in days, the slope of such a basic production function is equal to W, the break-even wage rate defined in the previous section. The greater the value of W and hence the steeper the slope of the line, the greater is the scope for substitution. Where the slope of the line is greater than the assumed wage rate for unskilled labour, there is financial advantage in substituting. The limit of practicable substitution has been taken as the line represented by a daily wage rate of $0.20 per day.

88. In drawing up the production functions for individual or groups of allied operations, it is assumed that substitution would take place in the order of cost advantage. To take a simple example, consider an operation consisting of three basic activities which can be carried out either solely by equipment or labour with the inputs given below:-

Activity	E_1	l_2	W
	US$	days	$/day
1	50	50	1.0
2	100	50	2.0
3	50	100	0.5
	200	200	1.0

The production function would be defined by straight lines connecting the following sequential points:-

(1) A wholly equipment-intensive operation with co-ordinates E = 200, l = 0.
(2) The substitution for activity 2, co-ordinates E = 100, l = 50.
(3) The further substitution for activity 1, co-ordinates E = 50, l = 100.
(4) The further substitution for activity 3, co-ordinates E = 0, l = 200.

89. Mathematically, if there are 'n' basic activities making up an operation, each of which can be carried out in one of two ways, the number of possible combinations is two raised to the power of 'n'. For example, an operation requiring the excavation of soil from cuttings and its placing and compaction in embankments would require the following activities:-

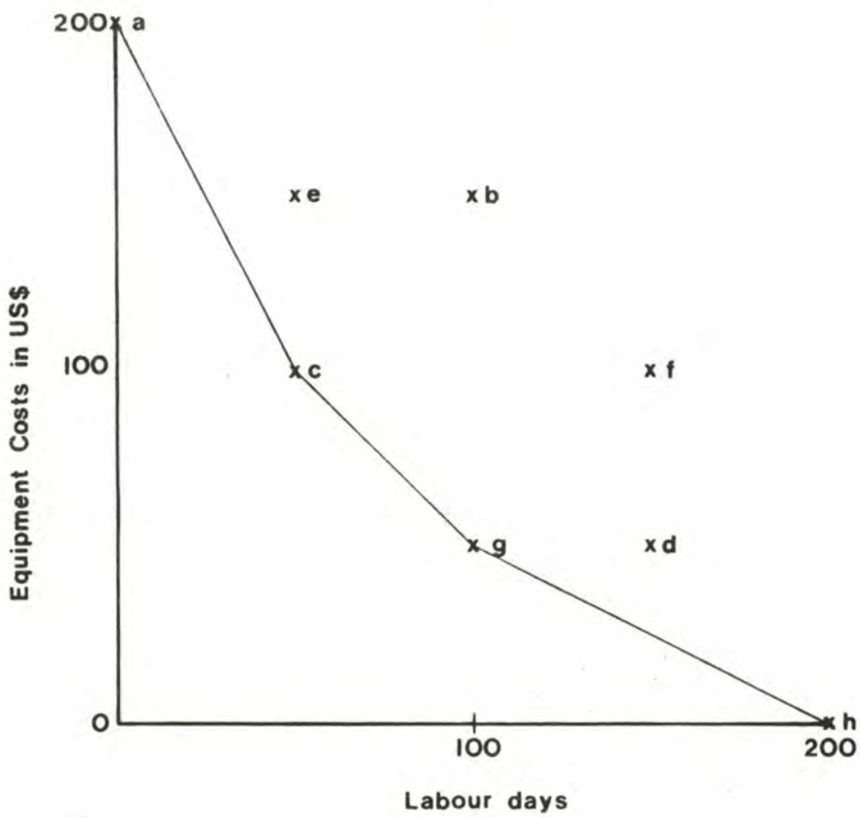
Excavating
Loading
Hauling
Unloading
Spreading
Compacting and finishing

and this list excludes the additional activities required for the adjustment of the natural moisture content to the level appropriate for compaction.

90. Excluding any sub-division of the activities to allow for type of material being excavated, differing loading rates and costs due to variations in the type of haulage vehicle being loaded, the type of haulage vehicle, differing unloading rates due to vehicle type, and differing levels of quality for spreading and compacting and finishing, the theoretical number of possible combinations of the basic activities is 64. In practice, this number can be reduced. For example, it would not be logical to load a scraper by hand nor to load head baskets by machine.

91. Reverting to the simple example of para. 88 it has been assumed that labour substitution can take place in any activity, independently of the others. The production function is defined by 4 points whereas there are eight possible combinations. The production function is illustrated in Figure II.1 and is defined by the line a-c-g-h. The other points, b,d,e, and f, are possible combinations of equipment and labour but represent less efficient ways of carrying out the substitution process.

92. This procedure has been followed in aggregating the various sequences of interdependent activities to establish the most advantageous ways of combining the respective basic construction activities so that the optimum trade-off functions between labour and equipment could be established.



Point	Activity by		E	L
	Equipment	Labour	US$	days
a	1+2+3	—	200	—
b	1+2	3	150	100
c	1+3	2	100	50
d	1	2+3	50	150
e	2+3	1	150	50
f	2	1+3	100	150
g	3	1+2	50	100
h	—	1+2+3	—	200

FIGURE II.1: AN EXAMPLE OF A SIMPLE PRODUCTION FUNCTION

b. Production Functions for Road Construction Activities

93. The complete grouping of interdependent sequential activities into production functions is:

(1) Bulk Excavation in Roadworks: excavating in bulk in soft material, loading, hauling (various distances), unloading and spreading.
(2) Rock Excavation in Roadworks: excavating in bulk in rock, loading, hauling (various distances) and unloading.
(3) Rock Excavation in Quarry (for crushing): excavating in bulk in rock, loading, hauling and unloading.
(4) Gravel Sub-base: excavating in bulk in hard material, loading, hauling, unloading and spreading (at two levels of quality).
(5) Gravel Base: as above
(6) Macadam Base (from crusher to site): loading, hauling, unloading and spreading (at two levels of quality).
(7) Crushed Rock Base (from crusher to site): loading, hauling, unloading and spreading.
(8) Water Distribution: loading, hauling, unloading and spreading.
(9) Chippings for Surface Dressings (from crusher to site): loading, hauling, unloading and spreading.
(10) Bitumen Distribution: loading, hauling, unloading and spreading (including heating).

94. For purposes of illustration and because of its importance we examine the case of bulk excavation in roadworks in the following section for both the SWKP and BCEOM data. Production functions for the other activities at unit levels of output are given in Appendix A; while production functions for various activities at the quantity levels required for one kilometre of various hypothetical roadways are given in section E below. The data from which the production functions have been plotted are contained in Appendix A.

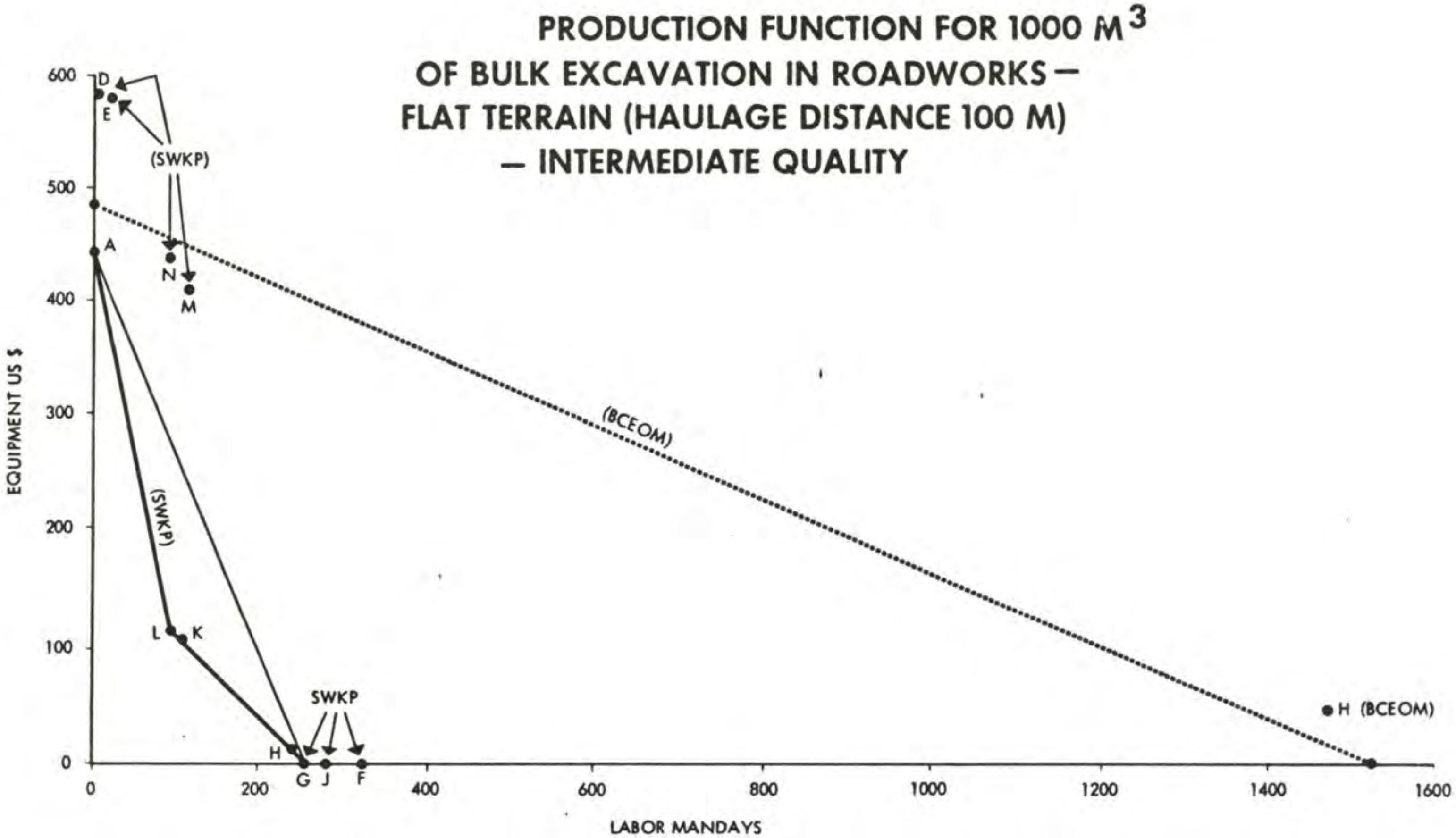
(1) Bulk Excavation in Roadworks

95. Table II.4 shows the various combinations of methods considered for carrying out each activity. The list does not cover all technically possible combinations and for simplicity it has been assumed that the excavating and loading operations would be carried out either both by equipment or both by labour.

96. Figure II.2 shows the corresponding equipment and labour inputs for these various methods of carrying out 1000 m^3 of bulk earthworks in flat terrain where the average length of haul is assumed to be 100 m. The heavy black dots represent the estimates of SWKP while the crosses represent the estimates by BCEOM.

Table II.4 Construction Methods for Bulk Excavation in Roadworks

Operation Method	Construction Method for Activity				
	Excavating	Loading	Hauling	Unloading	Spreading
A	Scraper	Scraper	Scraper	Scraper	Scraper
B	D8 dozer	Shovel into truck	Truck	Tipped from truck	Grader
C	D8 dozer	Shovel into truck	Truck	Tipped from truck	Labour
D	D8 dozer	Shovel into trailer	Tractor and trailer	Tipped from trailer	Grader
E	D8 dozer	Shovel into trailer	Tractor and trailer	Tipped from trailer	Labour
F	Labour	Labour into basket	Basket	Tipped from basket	Labour
G	Labour	Labour into wheelbarrow	Wheelbarrow	Tipped from wheelbarrow	Labour
H	Labour	Labour into wheelbarrow	Wheelbarrow	Tipped from wheelbarrow	Grader
J	Labour	Labour into bullock cart	Bullock cart	Labour	Labour
K	Labour	Labour into trailer	Tractor and trailer	Tipped from trailer	Labour
L	Labour	Labour into trailer	Tractor and trailer	Tipped from trailer	Grader
M	Labour	Labour into truck	Truck	Tipped from truck	Labour
N	Labour	Labour into truck	Truck	Tipped from truck	Grader



IBRD - 6215

Figure II.2

97. SWKP estimates: The scraper operation, identified as point A, is the most efficient way of carrying out the operation wholly by equipment. Of the labour-intensive methods, point G is the most efficient, with haulage by wheelbarrow. However, the straight line A-G does not represent the production function for this operation since some of the other points lie beneath this line. Point L which represents excavating and loading by labour, hauling by tractor/trailer and spreading by grader, is an intermediate substitution possibility and it must lie on the production function which follows the line A-L-H-G. Hence, while the slope of the line A-G gives the break-even wage rate ($1.70) for the whole operation, substitution along the slope A-L would be more advantageous with a break-even wage rate of $3.35 but along L-H-G the overall slope would drop to $0.73. With an actual wage rate between these two figures, substitution would be advantageous only up to point L. BCEOM estimates: Estimates only for methods A, G, and H are available from the BCEOM report, and they depict radically different input requirements for labour intensive methods. Between methods A, G and H, A is efficient at unskilled wage rates above $0.30 per day, method G is the efficient method at wage rates below $0.30 per day, and method H would never be used, i.e. it lies off the production function.

98. Figure II.3 depicts a similar production function for earthworks in hilly terrain where the average length of haul is assumed to be 200 m. SWKP estimates: In this case Method J, hauling by bullock cart, is the most efficient of the labour-intensive methods. Points L and K, both utilizing tractor/trailer units for hauling, are intermediate substitution possibilities, and the production function follows the line A-L-K-J. The break-even daily wage rate for the overall operation is $1.12 while the slopes of A-L and L-K-J are 3.80 and 0.49 respectively. BCEOM estimates: Estimates only for methods A, G and H are available for the 200 m. haul and the conclusions are quite similar to the case of the 100 m. haul: method A is the efficient method at a wage above $0.25 per day, method G is efficient at a lower wage rate, and method H lies off the production function.

99. In rolling terrain the average length of haul has been taken as 400 m and this condition is represented in Figure II.4. SWKP estimates: Methods F, G and H (hauling by basket and wheelbarrow) have been excluded in view of the length of haul. Again, the production function follows the line A-L-K-J. The average substitution slope for the overall operation is $0.92 per day while the slopes for A-L and L-K-J are 3.27 and 0.47 respectively. BCEOM estimates: For the 400 m. haul estimates are available from the BCEOM report for methods A, J, K, L, M, N. However, only two points A and J lie on the production function, all other points being grossly inefficient, with methods M and N having negative breakeven wage rates. The substitution slope or breakeven wage between methods A and J is $0.39 per day; at a higher wage per day method A would be efficient and at a lower wage method J would be efficient.

100. SWKP conclusions: These three examples demonstrate that the most efficient equipment-intensive method for bulk earthworks is by scraper but substitution for more than half of the equipment input is financially advantageous with wage rates less than about $3.25 per day by using tractor/trailer units for hauling and carrying out the other activities by hand.

PRODUCTION FUNCTION FOR 1000 M 3
OF BULK EXCAVATION IN ROADWORKS —
HILLY TERRAIN (HAULAGE DISTANCE 200 M)
— INTERMEDIATE QUALITY

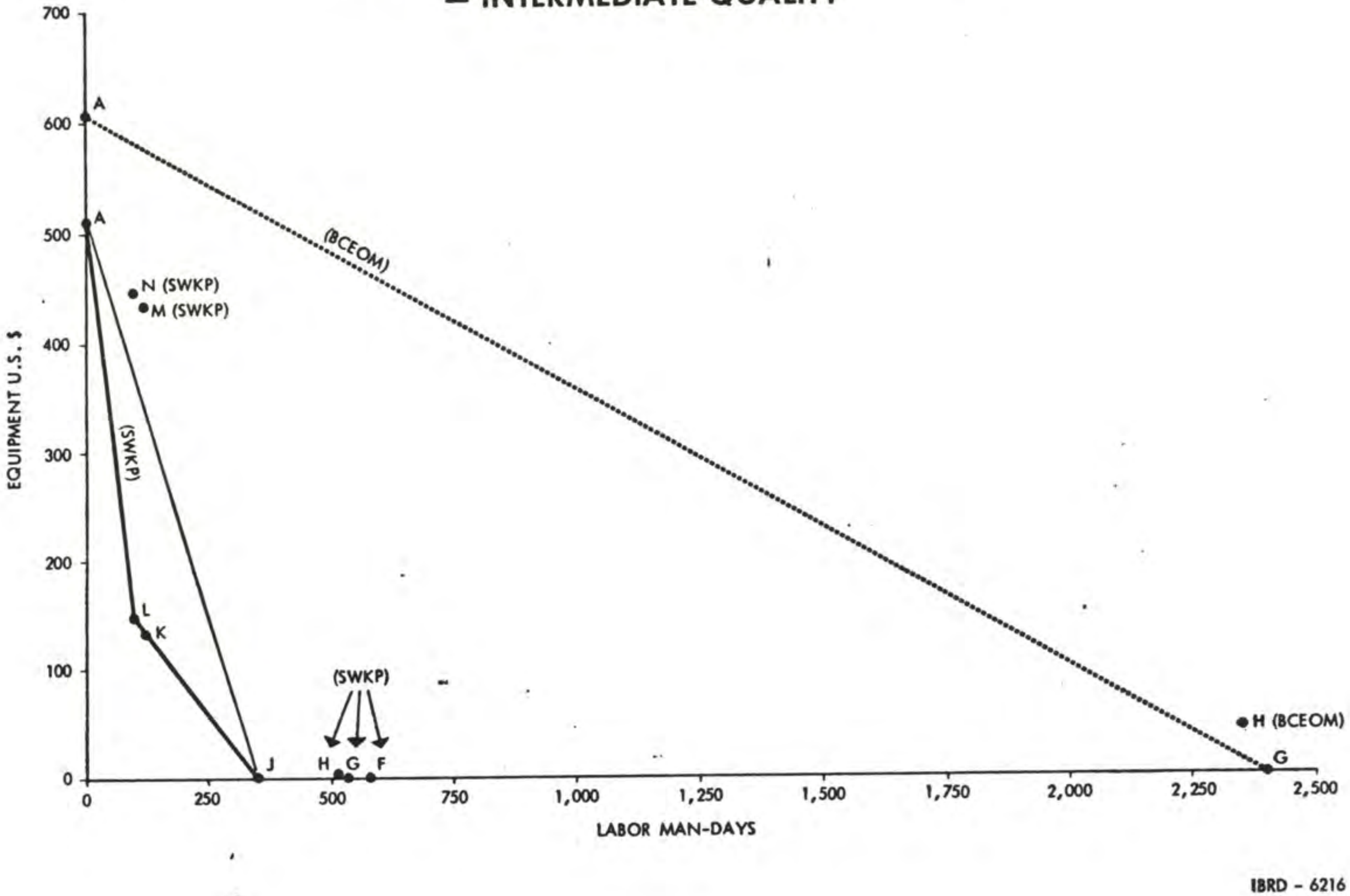


Figure II.3

PRODUCTION FUNCTION FOR 1000 M^3 OF BULK EXCAVATION IN ROADWORKS — ROLLING TERRAIN (HAULAGE DISTANCE 400M) — INTERMEDIATE QUALITY

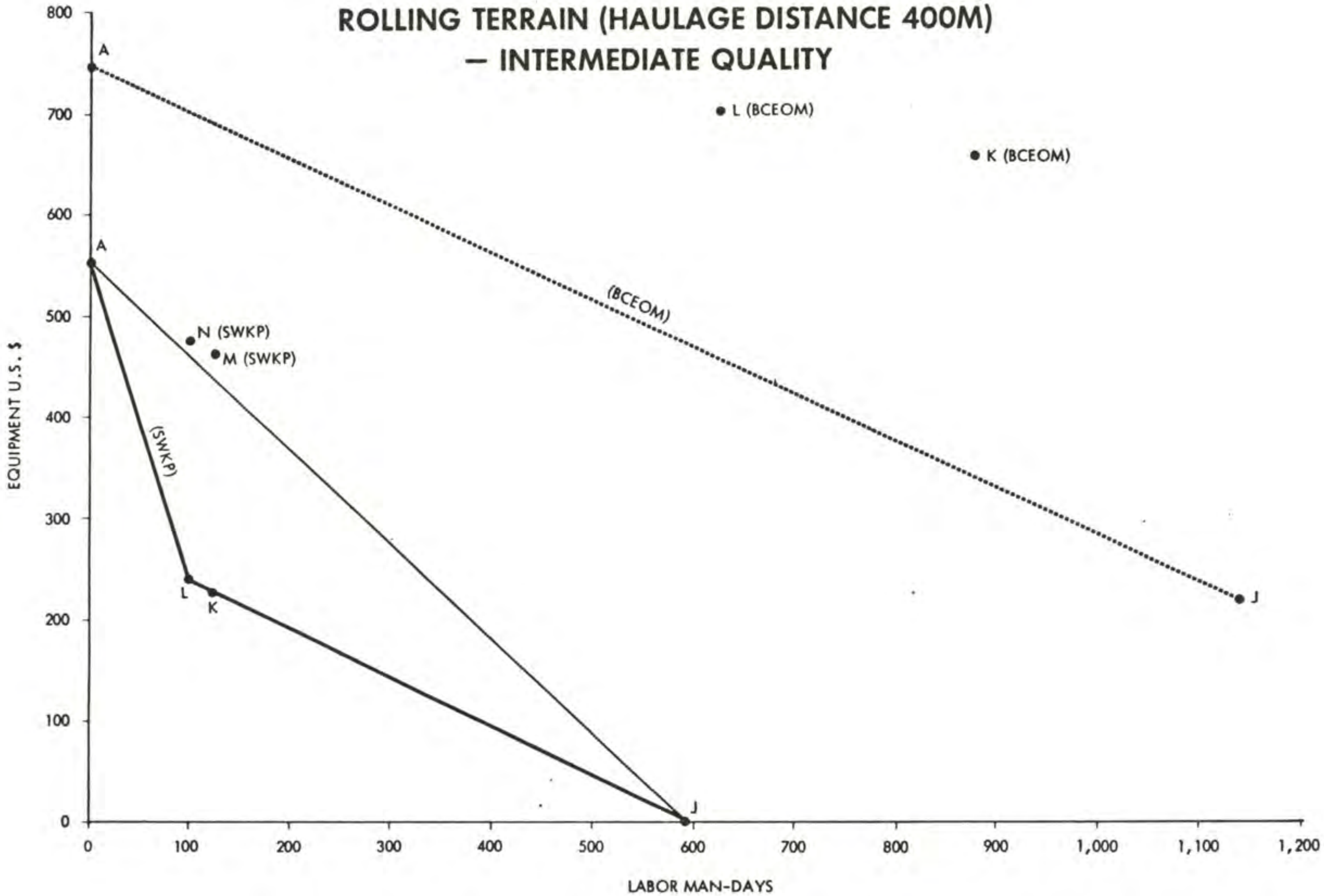


Figure II.4

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<u>BCEOM conclusions</u>: The scraper operation is the most efficient for all cases at wages above about $0.45 per day. Hauling by tractor trailer units is not a feasible method at any set of prices, and only if wages drop below $0.45 per day would manual excavation with hauling by bullock carts or wheelbarrows become feasible. Thus according to the BCEOM analyses the elasticity of substitution of labor for equipment in earthworks would appear to be quite low.

E. Analyses of Hypothetical Road Projects

101. To gain further measure of the technical scope for the substitution of labour for equipment in road construction and the extent of employment generated thereby, a series of hypothetical road projects has been considered. The basic specification is given below:

i.	Width of surfacing	- 7.00m.
ii.	Width of upper surface of base	- 7.50m.
iii.	Width of shoulders	- 1.25m.
iv.	Width of formation	- 10.00m.
v.	Side slopes	- 1:2
vi.	Thickness of sub-base	- 15cm.
vii.	Thickness of base	- 15cm.

102. For simplicity, construction work has been assumed to be limited to the following operations:

i. Clearing and grubbing
ii. Stripping and stacking topsoil
iii. Drainage excavation
iv. Roadway and borrow excavation
v. Embankments
vi. Sub-bases and bases
vii. Bituminous surfacing
viii. Topsoiling and grassing

(The only major operation excluded from this list is culverting.)

103. Flat, rolling and hilly terrains have been simulated by varying the quantities of excavation, filling, soiling and grassing, and the proportion of rock in excavation. Average haul distances for excavated materials have also been varied according to topography. These variations assume differing geometric designs to accommodate the topography, but no variation in design to accommodate differing construction methods (as would undoubtedly be done in actual practice).

104. Three types of road pavement, to simulate differing geological conditions, have been considered:

Type A: Gravel sub-base, gravel base, single surface dressing.
Type B: Gravel sub-base, penetration macadam base.
Type C: Gravel sub-base, crushed rock base, single surface dressing.

Haulage distances and quantities of water required for compaction have been varied in relation to the nature of the pavement material.

105. Full details of the methods of analysis are contained in Appendix A.

1. Analyses of Production Functions for one Kilometre of Hypothetical Roadworks

106. The basic construction activities have been aggregated in the quantities required for the construction of one kilometre of hypothetical roadworks according to the following groups:

a. Earthworks (flat, rolling and hilly terrains)
b. Sub-bases (gravel) and bases (gravel, crushed rock, macadam)
c. Surface dressings (on different bases).

107. For individual independent activities the construction methods assumed are as listed in Table II.3, whereas for the groups of interdependent activities those shown to lie on the production functions have been adopted. For interdependent activities, the two consultants, SWKP and BCEOM, adopted slightly different approaches, varying primarily in the number of alternative methods considered. BCEOM derived production functions (isoquants) from a less extensive range of alternative construction methods (often just two - an equipment intensive and labour intensive alternative) which limited the extent of intermediate (mixed labour and equipment) substitution possibilities. SWKP considered a wide range of alternative methods in developing the production functions introduced in section D (and elaborated in Appendix A) to examine the scope for various combinations of labour and equipment. In the following sections a, b, and c both the SWKP and BCEOM analyses are treated concurrently, except that isoquant relations for earthworks in flat and hilly terrain (Table II.5) are not available from the BCEOM Report.

a. Earthworks

108. Tables II.5 (for flat and hilly terrain) and II.6 (rolling terrain) list the operations and activities considered under this heading and define the corresponding substitution slopes and break-even wage rates for the intermediate quality. These have been combined together in the manner described in para. to form the production functions illustrated in Figure II.5.

109. SWKP. In the case of earthworks, intermediate substitution is possible, as has been shown in section D, Figures II.2, II.3, and II.4. Taking the case of hilly terrain illustrated in Figure II.3, operation e.1 in Table II.5 corresponds to the intermediate substitution AL, whereas operation e.2 corresponds to substitution LJ. Similarly, in rock excavation for earthworks, the overall substitution is subdivided into three segments represented by lines BD, DJ and JK in Figure A.4 of Appendix A. (Tables II.4 and A.5 indicate the construction methods which these letters represent). Each of these segments has been incorporated into the production functions in decreasing order of the break-even wage rate. In totalling the column at the foot of Table II.5 to determine the values of E and 1 at the extremities of the functions, only the values representing the overall substitution slopes (e.g. AJ in Figure II.3) are included.

110. Total substitution for all activities is possible at the intermediate level of quality and the overall slopes of the functions are:

Terrain	Haul length	U.S.$ per day
Flat	100 m	1.66
Rolling	400	1.01
Hilly	200	1.30

Hence the overall benefits of total substitution reduce as the length of haul increases.

111. It will be noted that the order of substitution varies slightly depending on the nature of the terrain but the general shapes of the three functions are similar. With a wage rate of $2.00 per day, the proportions of the total equipment contents for which it would be financially advantageous to substitute are given below:

Terrain	Equipment content in U.S.$		%
	Total	Substitute with W = 2	
Flat	3,486	2,749	80
Rolling	7,306	4,409	60
Hilly	10,509	6,873	65

The limiting values of W at which these substitutions are advantageous are 3.35, 3.27 and 3.56 with increasing difficulty of terrain.

112. The main substitution within these figures are hand-loaded tractor/trailer units (including hand excavation) for scrapers, and labour for dozers in the clearing and grubbing activity. The same substitutions would be possible at the high level of quality though the proportion of equipment substituted would be marginally less owing to the increased equipment content of the spreading and compacting activities.

113. BCEOM. (Rolling Terrain). Total substitution in earthworks is possible for the intermediate quality but would be profitable only at low wage rates, the overall breakeven wage rate being $0.47. At a wage rate of $1.00 per day, only the loading, transporting, laying, trimming and compacting of topsoil activity which constitutes slightly under 13 per cent of total equipment costs in the equipment intensive approach, could be substituted for profitably.

Table II.5: Production Functions for One Kilometre of the Hypothetical Road Projects:

Earthworks, Intermediate Quality, Flat and Hilly Terrains

(SWKP Estimates Only)

(Units: E1. E2, W = US$; l_1, l_2 = man days)

Operation or Activity				Flat Terrain - 100m Haul					Hilly Terrain - 200 m Haul					
No.	Description	Unit	Quantity	E_1	l_1	E_2	l_2	W	Quantity	E_1	l_1	E_2	l_2	W
a	Clearing and grubbing	m^2	25,000	1000	-	-	281	3.56	25,000	1000	-	-	281	3.56
b	Stripping topsoil	m^2	15,000	100	-	-	300	0.33	15,000	100	-	-	300	0.33
c	Excavating ditches in soft material	m^3	200	16	-	-	14	1.17	480	39	-	-	33	1.17
d	Excavating ditches in rock	m^3	-	-	-	-	-	-	120	321	-	-	171	1.87
e.1	Earthworks in soft material-	m^3	5,000	2165	-	(575)	(490)	3.35	14,250	7324	-	(2023)	(1396)	3.80
e.2	excavating, loading, hauling, unloading and spreading	m^3	5,000	(575)	(490)	-	1280	0.73	14,250	(2023)	(1396)	-	5507	0.49
f.1	Rock in earthworks-	m^3	-	-	-	-	-	-	750	1395	1	(1062)	(53)	5.57
f.2	excavating, loading, hauling	m^3	-	-	-	-	-	-	750	(1062)	(53)	(102)	(1112)	0.91
f.3	and unloading	m^3	-	-	-	-	-	-	750	(102)	(1112)	-	1339	0.45
g	Compacting and finishing soils	m^3	5,000	46	-	-	187	0.24	10,000	91	-	-	375	0.24
h	Loading, transporting, laying, trimming and compacting topsoil	m^2	4,000	159	8	-	41	4.81	6,000	239	12	-	61	4.81
	Totals		-	3486	8	-	2103	1.66	-	10509	13	-	8067	1.30

Notes: W is in $ per day.
Rows e.1, e.2, f.1, f.2 and f.3 are the intermediate substitution slopes for the interdependent activities. The figures in brackets are consequently excluded from the totals.

Source: SWKP Report, p. 62.

e.1	corresponds to	AL	in Figures II.4 and II.5.
e.2	"	LJ	" " .
f.1	"	BD	Figure A.4 (Appendix A).
f.2	"	DJ	" " .
f.3	"	JK	" " .

See Tables II.4 and A.4 for description of construction methods.

TABLE II.6: Production Functions for One Kilometre of the Hypothetical Road Projects:

Earthworks, Intermediate Quality, Rolling Terrain(400 m Haul)

(Units: E1, E2, W = US$; l_1, l_2 = man days)

Operation or Activity				SWKP Estimate					BCEOM Estimate				
No.	Description	Unit	Quantity	E_1	l_1	E_2	l_2	W	E_1	l_1	E_2	l_2	W
a	Clearing and grubbing	m^2	25,000	1000	-	-	281	3.56	1140	21	-	1751	0.66
b	Stripping topsoil	m^2	15,000	100	-	-	300	0.33	915	-	-	1266	0.72
c	Excavating ditches in soft material	m^3	360	30	-	-	25	1.17	137	2	-	270	0.51
d	Excavating ditches in rock	m^3	40	107	-	-	56	1.87	61	19	52	149	0.07
e.1	Earthworks in soft material-	m^3	9,800	5422	-	(2293)	(959)	3.27	6896	-	2146	10640	0.44
e.2	excavating, loading, hauling, unloading and spreading	m^3	9,800	(2293)	(959)	-	5845	0.47	403	-	-	2481	0.16
f.1	Rock in earthworks-	m^3	200	380	-	(302)	(14)	5.57	312	37	234	702	0.11
f.2	excavating, loading, hauling	m^3	200	(302)	(14)	(46)	(296)	0.91					
f.3	and unloading	m^3	200	(46)	(296)	-	397	0.45					
g	Compacting and finishing soils	m^3	7,500	68	-	-	281	0.24	449	-	-	2072	0.22
h	Loading, transporting, laying, trimming and compacting topsoil	m^2	5,000	199	10	-	51	4.81	1512	40	-	469	3.53
	Totals		-	7300	10	-	7236	1.01	11825	119	2432	19800	0.47

Notes: W is in $ per day.

For SWKP: Rows e.1, e.2, f.1, f.2 and f.3 are the intermediate substitution slopes for the interdependent activities. The figures in brackets are consequently excluded from the totals.

For BCEOM: Row e.1 excludes spreading and represents hauling by bullock cart. Row e.2 is spreading.

Sources: SWKP Report, p. 62.
BCEOM Report, p. 56 (with adjustments with respect to quantities to put on comparable basis. Spreading has been calculated on basis BCEOM appendix which differs with p. 56).

For SWKP:
e.1 corresponds to AL in Figure II.4.
e.2 " LJ "
f.1 " BD in Figure A.4.
f.2 " DJ "
f.3 " JK "
See Tables II.4 and A.4 for description of construction methods.

PRODUCTION FUNCTIONS FOR EARTHWORKS FOR ONE KILOMETER OF THE HYPOTHETICAL ROAD PROJECTS — INTERMEDIATE QUALITY

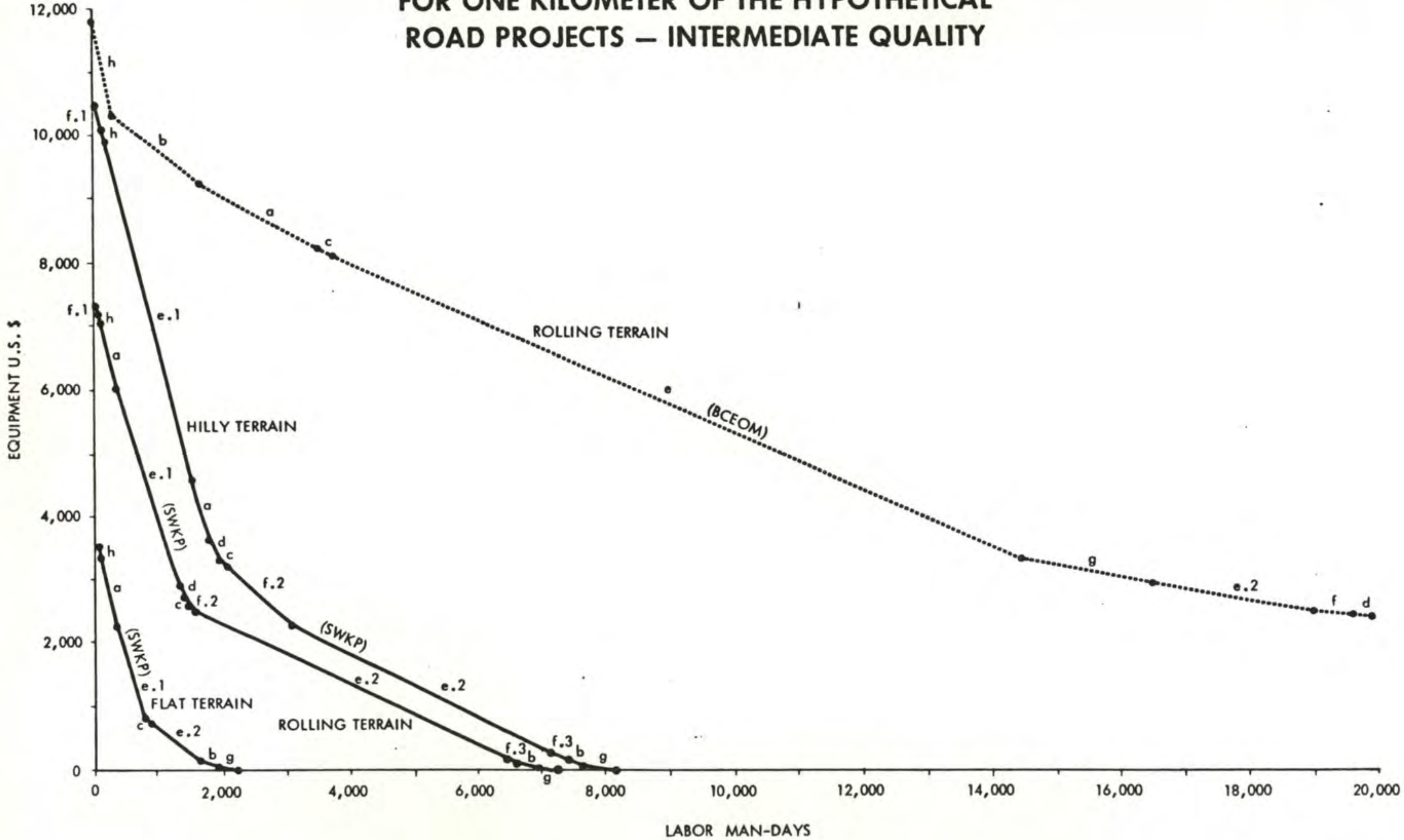

Figure II.5

b. Sub-bases and Bases

114. The operations and activities considered for the gravel sub-base are listed in Table II.7 while those for the gravel, the macadam and crushed rock bases are contained in Tables II.8, II.9, and II.10, respectively. The production functions are illustrated in Figure II.6.

115. SWKP. For the gravel sub-base and base total substitution is possible apart from the loading, hauling, unloading and spreading of water operation, and the overall break-even wage rates are $0.95 and 0.56 per day respectively. The differences are mainly due to the varying haul distances assumed.

116. For macadam base, substitution is impracticable for loading, hauling, unloading and spreading water. The long haulage distance also restricts substitution possibilities. The average slope of the production function is $0.65 per day. Similar considerations apply to the crushed rock base and, in addition, crushing of the rock is assumed to be a category 'E' activity. The average substitution slope is $0.64 per day.

117. With a wage rate of $2.00 per day, the proportions of the total equipment content for which it would be financially advantageous to substitute are given below:

	Equipment content in U.S.$		%
	Total	Substitute with W = 2	
Gravel sub-base	2106	1454	69
Gravel base	1595	868	54
Macadam base	3379	577	17
Crushed rock base	3807	577	15

The limiting values of W at which these substitutions are advantageous are 4.94, 3.98, 4.36 and 4.36 respectively.

118. The substitutions within the above figures are:

(1) Gravel sub-base and base: the substitution for a fully equipment-intensive operation for excavating, loading, hauling (by truck), unloading and spreading gravel by a labour-intensive operation using tractor/trailer units for hauling.

(2) Macadam and crushed rock bases: spreading base course materials by hand instead of by equipment, loading excavated rock by hand in the quarry (into trailers) instead of by shovel.

119. Substitution possibilities would be less at the higher level of quality since in this case spreading (and compacting) the base-course materials are category 'E' activities.

120. BCEOM. For the gravel subbase and base total substitution is possible except for the watering operation, and the overall breakeven wage rates are 0.74 and 0.27, respectively. It may be noted that for the excavating loading and hauling (1 kilometre) of gravel for the subbase BCEOM hypothesized a dozer assisted scraper operation for the equipment intensive solution, with a resulting high cost. As can be seen from a comparison with the gravel base operation, the scraper is highly inefficient and this method would not in fact lie on the production function. The BCEOM breakeven wage rates for the compacting and finishing of gravel subbases and bases, $5.78 and $2.09, respectively, considerably exceed the corresponding estimates of SWKP, $1.06 for both operations.

121. For the macadam base, substitution is practicable in the quarrying of stone, production of materials, loading, and spreading of materials activities for which the breakeven wages range from $6.77 (for the handloading of a trailer as opposed to mechanical loading of trucks)1/ to 0.05 (for unloading of stones at the crusher site). The overall substitution slope for the macadam base is 0.30. Essentially the same conclusions apply for the crushed rock base, with the substitution slopes ranging from 6.781/ to 0.06 for the same activities, and the overall substitution slope is 0.16.

122. With a wage rate of $1.00 per day, no substitution would be profitable, since the only activity with a higher breakeven wage is the loading in quarry activity, which is interdependent with the hauling and unloading operations and for which the overall breakeven wage is well below 2.00 (viz. 0.23 and 0.15 for macadam and crushed rock respectively). According to the BCEOM data, wage rates would have to drop to $0.60 and 0.52 for crushed rock and macadam respectively before any substitution would become profitable.

1/ It should be understood that the BCEOM activities a.1, a.2, and a.3 are interdependent so that they must be considered only as a group. The overall substitution slopes (breakeven wage) for this group are 0.23 for macadam and 0.14 for crushed rock quarrying.

Table II.7: Production Functions For One Kilometre of the Hypothetical Road Projects

Gravel Sub-Base, Intermediate Quality

(Units: E1, E2, W = US$; l_1, l_2 = man days)

Operation or Activity				SWKP Estimate					BCEOM Estimate				
No.	Description	Unit	Quantity	E_1	l_1	E_2	l_2	W	E_1	l_1	E_2	l_2	W
a.1	Excavating, loading	m^3	1,700	1969	-	(1673)	(42)	6.96	(2668)	-	(1456)	(1341)	0.90
a.2	hauling, unloading and spreading	m^3	1,700	(1673)	(42)	(515)	(277)	4.94	(123)	(9)	-	(516)	0.24
a.3	gravel	m^3	1,700	(515)	(277)	-	2093	0.28	2791	9	1456	1857	0.72
b	Loading, hauling, unloading and spreading water	m^3	100	47	-	47	-	*	53	1	53	1	*
c	Compacting and finishing	m^2	11,200	90	-	-	84	1.06	87	4	43	25	2.09
	Totals			2106	-	47	2177	0.95	2931	14	1552	1883	0.74

Notes: * Substitution impracticable.
W is in US $ per day.

For SWKP: Rows a.1, a.2 and a.3 are the intermediate substitution slopes for the interdependent activities; the figures in brackets are consequently excluded from the totals.

For BCEOM: Row a.1 excludes spreading and represents hauling by trailer pulled by tractor.
Row a.2 is spreading.

Sources: SWKP Report, p. 65.
BCEOM Report, p. 55.

For SWKP

a.1 corresponds to AB in Figure A.6.
a.2 " BH " A.6.
a.3 " HK " A.6.
Table A.7 describes the construction methods represented.

TABLE II.8: Production Functions for One Kilometre of the Hypothetical Road Project:

Gravel Base, Intermediate Quality

(Units: E1, E2, W = US\$; l_1, l_2 = man days)

Operation or Activity				SWKP Estimate					BCEOM Estimate				
No.	Description	Unit	Quantity	E_1	l_1	E_2	l_2	W	E_1	l_1	E_2	l_2	W
a.1	Excavating, loading	m^3	1,200	1498	-	(1289)	(30)	6.96	(829)	-	(273)	(921)	0.60
a.2	hauling, unloading and spreading	m^3	1,200	(1289)	(30)	(630)	(195)	3.98	(422)	-	(204)	(2295)	0.10
a.3	gravel	m^3	1,200	(630)	(195)	-	2738	0.25	(8[illegible])	(9)	-	(365)	0.23
									1333	9	477	3581	0.24
b	Loading, hauling, unloading and spreading water	m^3	70	33	-	33	-	*	37	1	37	1	*
c	Compacting and finishing	m^2	8,000	64	-	-	60	1.06	140	7	40	24	5.78
	Totals			1595	-	33	2798	0.56	1510	17	554	3605	0.27

Notes: * Substitution is impracticable.
W is breakeven wage in \$ per man day.

Notes:

For SWKP: Rows a.1, a.2 and a.3 represent the intermediate substitution possibilities for the interdependent activities; the figures in brackets are consequently excluded from the totals.

For BCEOM: Row a.1 represents excavating and loading.
Row a.2 represents hauling by bullock cart.
Row a.3 represents spreading.

Sources: SWKP Report, p. 65.
BCEOM Report, pp. 59, 65.

For SWKP:
a.1 corresponds to AB in Figure A.7;
a.2 " BH " A.7;
a.3 " HK " A.7.
Table A.7 describes the construction methods represented.

TABLE II.9: Production Functions For One Kilometre of The Hypothetical Road Projects:

Macadam Base, Intermediate Quality

(Units: E1, E2, W = US$; l_1, l_2 = man days)

Operation or Activity				SWKP Estimate					BCEOM Estimate				
No.	Description	Unit	Quantity	E_1	l_1	E_2	l_2	W	E_1	l_1	E_2	l_2	W
a.1	Excavating, loading, hauling,	m^3	1,200	1035	2	(667)	(86)	4.36	(1138)	(73)	(9)	(3888)	0.10
a.2	and unloading rock	m^3	1,200	(667)	(86)	(502)	(435)	0.47	(549)	-	-	(81)	6.77
a.3	in quarry for base	m^3	1,200	(502)	(435)	-	1935	0.33	(242)	(7)	-	(4568)	0.05
									1929	80	9	8537	0.23
a.4	Ditto for chippings	m^3	140	150	-	(108)	(10)	4.36	(Stones for chippings included in a.1 - 3)				
a.5		m^3	140	(108)	(10)	-	226	0.50					
b.1	Production of base material (40/70)	m^3	1,200	975	-	-	1875	0.52	1465	17	-	2808	0.52
b.2	Production of chippings (15/25)	m^3	140	441	-	-	280	1.56	(Chippings included in b.1)				
c.1	Loading, hauling, un-								(298)	-	(298)	-	*
c.2	loading and spreading	m^3	1,200	1298	-	1080	30	6.96	(600)	-	(600)	-	*
c.3	base course material								(246)	(18)	-	(810)	0.31
									1144	18	898	810	0.31
d	Loading, hauling un-loading and spreading water	m^3	35	16	-	16	-	*	18	-	18	-	*
e	Compacting and finishing	m^2	8,000	64	-	-	60	1.07	50	7	50	7	*
	Totals			3979	2	1096	4406	0.65	4606	122	975	12162	0.30

Notes: * Substitution impracticable. W is breakeven wage in $ per man day. BCEOM assumed a 20% shrinkage factor between stones and crushed material.

For SWKP: Rows a.1, a.2, and a.3 represent the intermediate substitution possibilities for the interdependent activity; the figures in brackets are consequently excluded from the totals.

For BCEOM: Rows a.1, a.2 and a.3 refer, respectively, to the excavation of stones; loading of stones and hauling by trailer pulled by tractor;and unloading at the crusher site. Rows c.1, c.2 and c.3 refer to loading, hauling and spreading. of base materials.

Source: SWKP Report, p. 66.
BCEOM Report, pp. 61, 67.

For SWKP:
a.1 corresponds to BD in Figure A.5.
a.2 " DE "
a.3 " EK "
Table A.7 describes the construction methods represented.

TABLE II.10: Production Functions for One Kilometre of the Hypothetical Road Projects

Crushed Rock Base, Intermediate Quality

(Units: $E1$, $E2$, W = US$; l_1, l_2 = man days)

Operation or Activity				SWKP Estimate					BCEOM Estimate				
No.	Description	Unit	Quantity	E_1	l_1	E_2	l_2	W	E_1	l_1	E_2	l_2	W
a.1	Excavating, loading, hauling,	m^3	1,200	1035	2	(667)	(86)	4.36	(947)	(61)	(624)	(3240)	0.10
a.2	and unloading rock	m^3	1,200	(667)	(86)	(502)	(435)	0.47	(457)	-	-	(67)	6.78**
a.3	in quarry	m^3	1,200	(502)	(435)	-	1935	0.33	(201)	(6)	-	(3806)	0.06
									1605	67	624	7113	0.15
b	Production of base course material	m^3	1,200	810	-	810	-	*	875	12	875	12	*
c.1	Loading, hauling, un-	m^3	1,200	1865	-	1656	30	6.96	(298)	-	(298)	-	*
c.2	loading and spreading								(1153)	-	(1153)	-	*
c.3	base course material								(246)	(18)	-	(425)	0.60
									1697	18	1451	425	0.60
d	Loading, hauling unloading and spreading water	m^3	70	33	-	33	-	*	37	1	37	1	*
e	Compacting and finishing	m^2	8,000	64	-	-	60	1.07	44	4	44	4	*
	Totals			3807	2	2499	2025	0.64	4258	102	3031	7555	0.16

Notes: ** W does not agree because of rounding errors.
* Substitution impracticable.

For SWKP: Rows a.1, a.2, and a.3 represent the intermediate substitution possibilities for the interdependent activities; the figures in brackets are consequently excluded from the totals.

For BCEOM: Rows a.1, a.2 and a.3 refer, respectively, to the excavating of stones; loading of stones; and hauling by trailer pulled by tractor and unloading at the crusher site.
Rows c.1, c.2, and c.3 refer, respectively, to loading, hauling and spreading of base materials.

Sources: SWKP Report, p. 66.
BCEOM Report, p. 63.

For SWKP
a.1 corresponds to BD in Figure A.5.
a.2 " DE "
a.3 " EK "
Table A.4 describes the construction activities represented.

PRODUCTION FUNCTIONS FOR SUB – BASE AND BASES FOR ONE KILOMETER OF THE HYPOTHETICAL ROAD PROJECTS – INTERMEDIATE QUALITY.

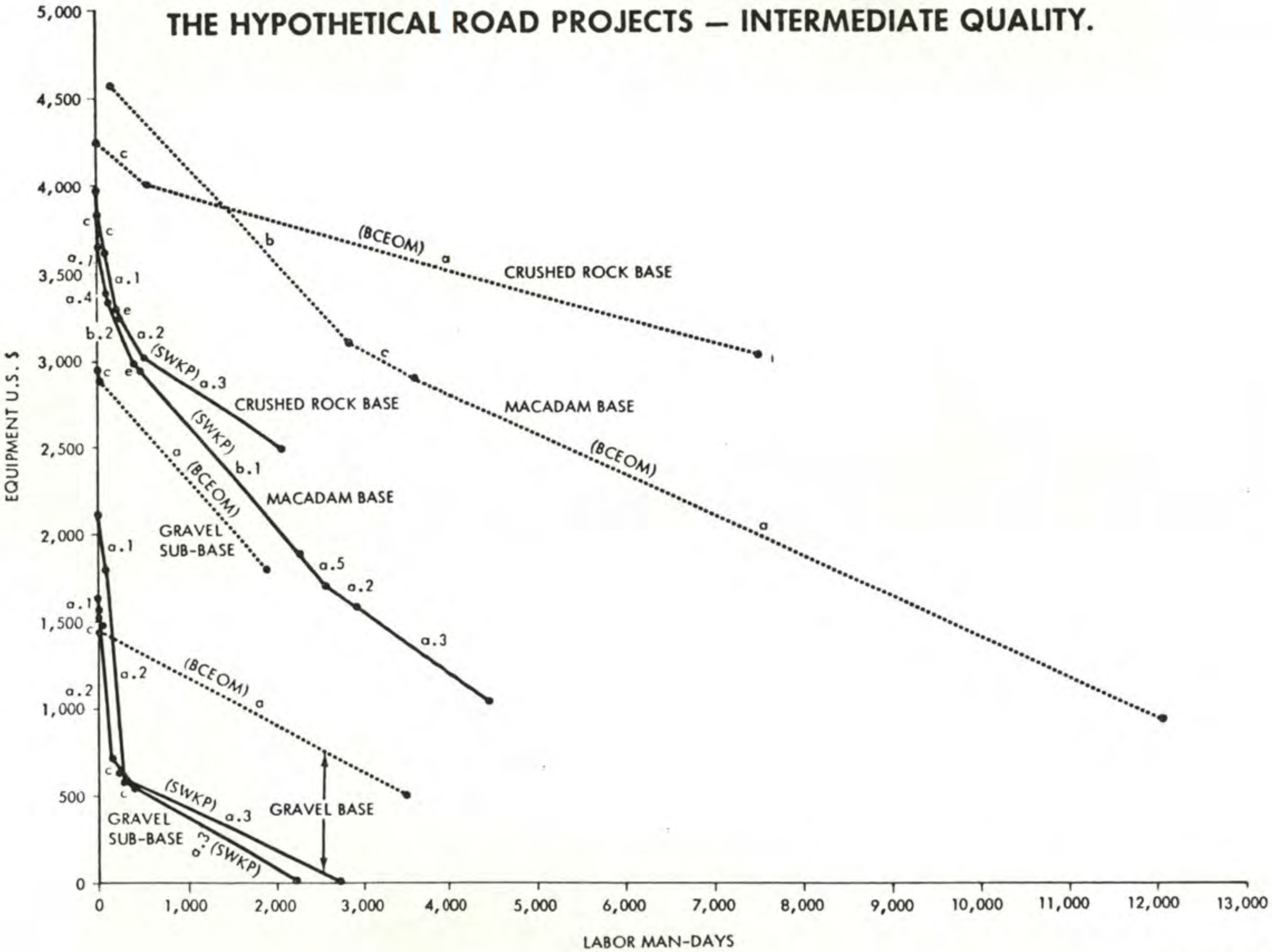

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Figure II.6

c. Surface Dressings

123. The activities considered for bituminous surface dressing of the various types of base are listed in Tables II.11 and II.12. The surface dressing for a macadam base differs from the others in that the bitumen is applied in a single coat and the chipping size is larger. Figure II.7 shows the corresponding production functions.

124. SWKP. Apart from the loading, hauling, unloading and spreading of chippings and bitumen (where partial substitution is possible), all activities can be carried out by labour. The overall breakeven wage rates for the macadam surface dressing is $1.54 per day and slightly lower at $1.23 per day for the other types.

125. At a wage rate of $2.00 per day, substitution for none of the activities is financially advantageous but at a wage of $1.00 per day, substitution would be profitable for all activities except a.2 (hand excavating and hauling of stones in quarry by bullock cart).

126. For high quality work, category 'E' activities would be required for spreading bitumen and compacting and hence the scope for substitution would be reduced.

127. BCEOM. For the BCEOM estimates, substitution possibilities are limited to the loading, hauling, and spreading of chippings and to the brooming and cleaning of macadam surfaces. The substitution slopes range from 0.22 for loading, hauling, unloading and spreading chippings to 1.78 for brooming and cleaning macadam surfaces. The overall substitution slope for surface treatment for macadam base is 0.97, and for gravel or crushed rock base, 0.41.

TABLE II.11 Production Functions For One Kilometre of the Hypothetical Road Projects

Surface Dressing: For Macadam Base, Intermediate Quality.

(Units E1, E2, W = US$; l_1, l_2 = man days)

Operation and Activity				SWKP Estimate					BCEOM Estimate				
No	Description	Unit	Quantity	E_1	l_1	E_2	l_2	W	E_1	l_1	E_2	l_2	W
a.1 a.2	Loading, hauling, unloading and spreading chippings	m^3	140	205	-	126	70	1.13	(106) (18)	- (2)	(106) -	- (139)	* 0.13
b	Loading, hauling, heating, unloading and spreading bitumen	tonne	15.4	249	1	70	102	1.76	94	2	94	2	*
c	Compacting and finishing	m^2	7,000	42	-	-	26	1.58	12	-	12	-	*
d	Brooming and cleaning surfaces	m^2	7,000	15	-	-	8	1.78	91	28	-	79	1.78
	Totals			511	1	196	206	1.54	312	32	212	220	0.58

Notes: W is in US $ per day.
* Substitution impracticable. For gravel and crushed rock bases the bitumen is applied in two coats.

For BCEOM: Row a.1 refers to loading, hauling, and unloading and row a.2 to spreading.
Row (b) and totals: apparently do not include cost of loading, hauling, heating and unloading bitumen; BCEOM cost in row b is solely for spreading.
Row (d) figures for brooming and cleaning adjusted to reflect quantity (7000 m^2) used by SWKP.

Source: SWKP Report, p. 69.
BCEOM Report, p. 61.

TABLE II.12: Production Functions for One Kilometre of the Hypothetical Road Projects

Surface Dressings for Gravel and Crushed Rock Bases, Intermediate Quality

(Units El, Eq, W = US$; l_1, l_2 = man days)

Operation and Activity				SWKP Estimate					BCEOM Estimate				
No	Description	Unit	Quantity	E_1	l_1	E_2	l_2	W	E_1	l_1	E_2	l_2	W
a.1	Excavating, loading, hauling and unloading	m^3	84	90	-	(65)	(6)	4.36	166	184	52	270	1.32
a.2	rock in quarry	m^3	84	(65)	(6)	-	135	0.50	(38)	-	-	(6)	6.78**
a.3									(17)	(1)	-	(318)	0.05
									221	185	52	594	0.41
b	Production of chippings	m^3	84	264	-	-	210	1.26	318	32	318	32	*
c	Loading, hauling, unloading and spreading chippings	m^3	84	165	-	116	42	1.18	117	1	117	1	*
d	Loading, hauling, heating, unloading and spreading bitumen	tonne	16.8	270	1	77	114	1.76	102	2	102	2	*
e	Compacting and finishing	m^2	7,000	42	-	-	26	1.58	7	-	7	-	*
f	Brooming and cleaning surfaces	m^2	14,000	31	-	-	17	1.78	-	-	-	-	-
	Totals			862	1	193	544	1.23	765	220	572	739	0.37

Notes: ** W does not agree because of rounding errors.
* Substitution impracticable.
W is breakeven wage rate in $ per man day.

For SWKP: Rows a.1, a.2, and a.3 are the intermediate substitution slopes for the interdependent activities; the figures in brackets are consequently excluded from the totals.

For BCEOM: Row a.1, a.2, and a.3 refer, respectively, to the excavation of stones; loading of stones; and hauling by trailer pulled by tractor and unloading at the crusher site (from gravel base example).
Row b and totals apparently do not include cost of loading, hauling, heating and unloading bitumen; BCEOM cost in row b is solely for spreading.

Sources: SWKP Report, p. 69.
BCEOM Report, p. 58.

For SWKP
a.1 corresponds to BD in Figure A.5.
a.2 " DK "

Table A.7 describes the construction methods represented.

PRODUCTION FUNCTIONS FOR SURFACE DRESSING FOR ONE KILOMETER OF THE HYPOTHETICAL ROAD PROJECTS — INTERMEDIATE QUALITY

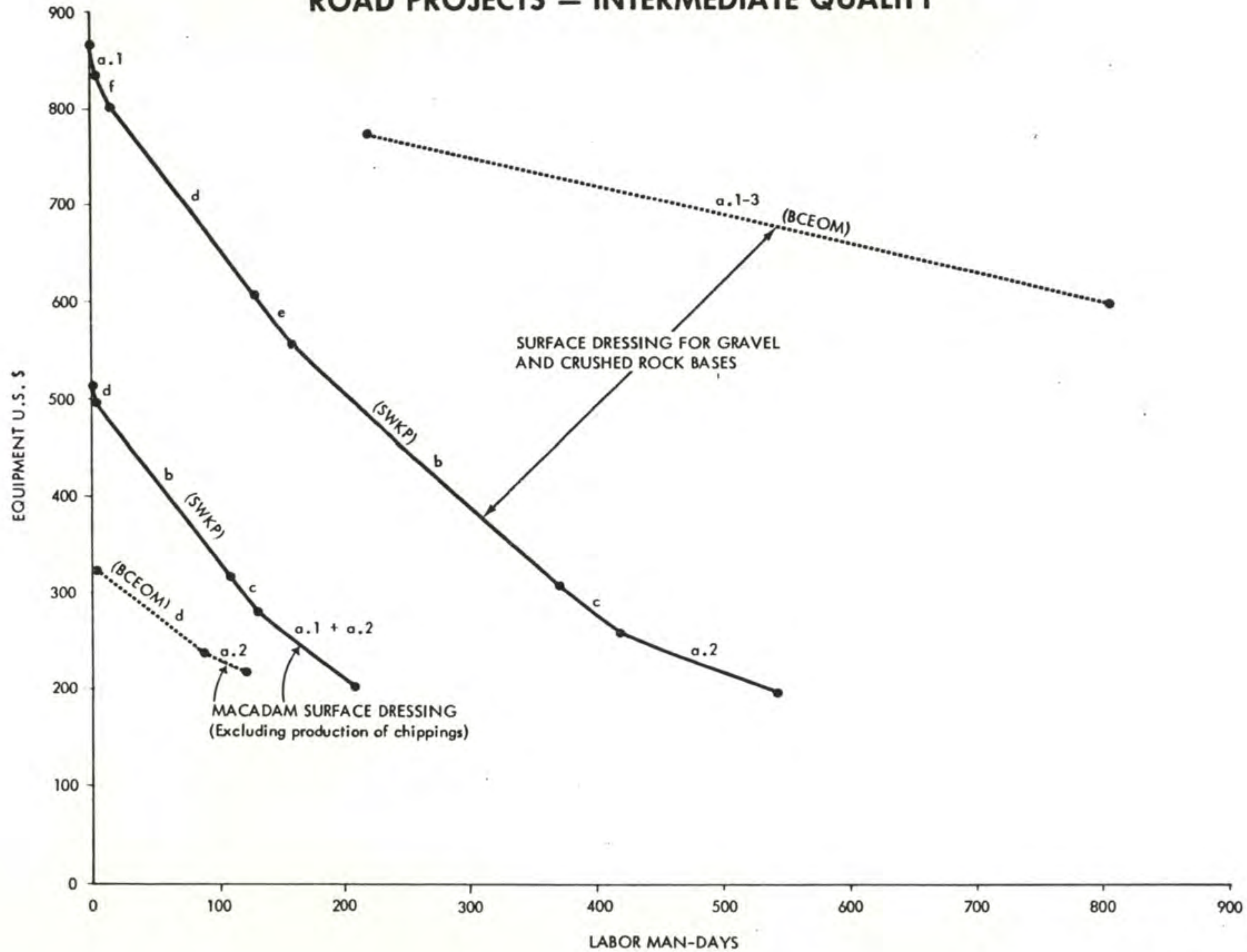

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Figure II.7

2. Comparison of the Costs per Road Kilometer for Different Mixes of Equipment and Labour and Different Construction Qualities

128. In order to examine the impact of different mixes of equipment and labour methods on construction costs per road kilometer, and the effect of the construction quality specified on the feasibility of substituting labour intensive methods, a final series of analyses were performed for the hypothetical road projects. In these analyses for both high quality and intermediate quality specifications the optimal combination of equipment and labour methods for an assumed wage of US$1.00 per day was first determined and the costs of the various operations (earthworks, subbase, base, and surfacing) were added together to yield a figure approximating the total basic cost for the hypothetical road kilometre.[1] A further calculation was then made, substituting step-by-step more labour intensive techniques for each activity for which substitution is technically feasible, so that the "inefficiency costs" of employing successively more labour could be calculated.

129. We give herebelow the results of the first calculations which refer to the case of a Type A road in rolling terrain. The stepwise analysis of the costs of employing more labour is presented in Chapter V. Supplementary analyses prepared by SWKP of the costs using either fully equipment intensive or fully labor intensive techniques for all three road types in flat and hilly as well as rolling terrain are given in Appendix A (part 4).

130. Table II.13 presents the estimate of costs of the Type A road (gravel subbase, gravel base, and two coat surface dressing) in rolling terrain for intermediate and high quality for the equipment intensive solution, the optimal combination of methods (when the wage rate for unskilled labour is $1.00 per day) and the maximum labour solution for both the SWKP and BCEOM data. The optimal combination of methods has been found from the equipment intensive solution (as given in Tables II.6 - II.12) by substituting labour for equipment in all those operations for which the breakeven wage rates exceeds (or equals) $1.00, the price of labour assumed in this exercise. The more detailed tables listing the separate activities from which Table II.13 has been drawn are given in Appendix A (part 5).

131. A comparison of the cost figures derived from the SWKP and BCEOM data reveal major differences as expected, with the BCEOM figures being much higher in every case. However, the SWKP and BCEOM estimates are relatively closer for the equipment intensive solution than for the optimal

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1/ Excluding structures, mobilization, engineering supervision, administrative and miscellaneous costs.

Table II.13: Comparison of SWKP and BCEOM Costs for Equipment Intensive, Optimal and Labor Intensive Methods for One Kilometre of Type A Road (Rolling Terrain) for Wage = $1/Day

(U.S. Dollars)

	SWKP									BCEOM								
	Equipment Intensive Solution			Optimal Mix			Labor Intensive Solution			Equipment Intensive Solution			Optimal Mix			Labor Intensive Solution		
	E1		L1	Eo		Lo	E2		L2	E1		L1	Eo		Lo	E2		L2
A. Intermediate Quality																		
Earthworks	7,306	3,316	10	2,736	4,123	1,387	-	7,236	7,236	11,825	11,944	119	10,313	10,861	548	2,380	22,180	19,800
Gravel Subbase	2,106	2,106	-	562	923	361	47	2,224	2,177	2,931	2,945	14	2,887	2,922	35	1,552	3,435	1,883
Gravel Base	1,595	1,595	-	663	918	255	33	2,831	2,798	1,510	1,527	17	1,409	1,443	34	554	4,159	3,605
Two Coat Surface Dressing	862	863	1	258	673	415	193	737	544	765	985	220	613	925	312	596	1,225	629
Subtotal Equipment/Labour	11,869		11	4,219		2,418	273		12,755	17,031		370	15,222		929	5,082		25,917
Total Costs per Kilometre,1/ Intermediate Quality		11,880			6,637			13,028			17,401			16,151			30,999 2/	
B. High Quality																		
Earthworks	7,374	7,384	10	2,832	4,219	1,387	137	7,092	6,955	12,083	12,202	119	10,571	11,119	548	3,087	20,815	17,728
Gravel Subbase	2,181	2,181	-	1,023	1,258	235	508	2,601	2,093	3,025	3,075	50	3,025	3,075	50	1,649	3,628	1,979
Gravel Base	1,649	1,649	-	989	1,155	166	457	3,194	2,737	1,565	1,585	20	1,565	1,585	20	689	4,396	3,707
Two Coat Surface Dressing	900	901	1	535	811	276	470	875	405	807	1,028	221	655	968	313	638	1,268	630
Subtotal Equipment/Labour Total Cost per Kilometre,1/ High Quality	12,104	12,115	11	5,379	7,443	2,064	1,572	13,762	12,190	17,480	17,890	410	15,816	16,747	931	6,063	30,107	24,044

1/ Excluding structures, engineering supervision, mobilization, administrative and miscellaneous costs.
2/ Since there is greater technical scope for (inefficient) substitution of labour for equipment in the intermediate quality than the high quality level, the cost of the intermediate quality exceeds that of the high quality for the maximum labour solution.

combination and labour intensive solutions as can be seen from the following table:

Table II.14: Ratio of BCEOM and SWKP Estimates of Total Costs per Road Kilometer, Type A Road - Rolling Terrain

	Equipment Intensive Method	Optimal Mix	Labour Intensive Method
Intermediate Quality	1.43	2.43	2.37
High Quality	1.48	2.25	2.19

This is simply another evidence of the greater feasibility for labour substitution inherent in the SWKP estimates, as was seen previously in Figures II.5, II.6, and II.7. For the optimal combination of methods SWKP shows considerable savings over the equipment intensive method, while BCEOM shows very little change in method and costs between the two cases. For the labour intensive solution, the estimates based on BCEOM data are much higher than the SWKP estimates since the data adopted by BCEOM show much greater labour inputs necessary to offset withdrawal of equipment; this implies of course that deliberate manualization of construction technology beyond the optimal combination will create more jobs according to the BCEOM estimates, but at greater inefficiency cost per job.[1/]

The Effect of Quality Standards on the Substitutability of Labour and Equipment (High Quality versus Intermediate Quality)

132. The relaxing of construction quality standards from high to intermediate levels is shown to have little overall effect on the total costs of the projects and still smaller effect on the optimal combination of methods for either the SWKP or BCEOM estimates, as can be seen from a comparison of the percentage of equipment in costs for the various cases is given in Table II.15. According to the SWKP estimate for the optimal method, equipment constitutes approximately 72.3 percent of total costs for the high quality case and 63.5 percent for the low quality case. The corresponding figures for BCEOM are 94.4 and 94.2 percent

1/ See Chapter V, part A below.

respectively. Thus, in the SWKP case the additional labour employment made profitable (at wage = $1 per day) when quality standards are relaxed is only about 11 percent of total costs (or an increase in labour days of 17 percent) while according to the BCEOM data there is essentially no change in the optimal mix. In either case the additional employment generated is small, suggesting that relaxation of construction quality standards may be a poor way to create additional employment. Depending on the benefits deriving from the higher quality standards,[1] it may be more efficient to maintain high quality and subsidize the employment of more labour.

133. Again, it must be emphasized that geometric design standards have not been varied here except to accommodate terrain to some extent, i.e. the geometrics are the same for both the high and intermediate quality construction standards. In actual practice, it may be profitable to relax geometric standards to some extent to take better advantage of labour intensive methods of construction. For example, equipment involved in earthworks in the optimal solution still constitutes 38 percent and 63 percent of total costs in the SWKP and BCEOM estimates, respectively, and relaxation of geometric standards to permit reductions in the quantities and cost of earthworks might be profitable, but these savings will have to be compared with the resulting increase in user costs (vehicle operating costs). Such analyses have not been possible in the present study due to the limitation of available data and time but are being investigated in subsequent studies in conjunction with the IBRD Highway Design Study.[2]

* * *

Conclusions of the Engineering Analyses appear at the end of Chapter III.

1/ See the following paragraph and footnote.
2/ See Highway Design Study Phase I: The Model, Economics Department Working Paper No. 96 (January, 1971.)

Chapter III

Qualifications of the Engineering Analyses

A. LIMITATIONS OF THE ANALYSES

1. It is emphasised that the foregoing analyses are for the purposes of illustrating the problems and effects of substituting labour for equipment and they do not represent the actual costs of carrying out the work. Firstly, they have been based on arbitrarily assumed rates for the costs of equipment and labour whereas, in practice, actual costs (financial or economic) might be considerably different. Secondly, it has been necessary to utilise several different sources of labour and equipment productivity data and some distortion is consequently inevitable.

2. While an attempt has been made to simulate some of the effects of the environment on the nature and volume of activities by relating earthwork quantities, haul distances, etc. to the nature of the terrain, in practice the effects would be much more complex and they could differ substantially from the simple assumptions made. For example, a new road in flat terrain passing through rice paddy would involve more extensive earthworks and much longer haul distances than those assumed to be representative of flat terrain.

3. No account has been taken of the effect of the environment on productivity rates, either on or between differing types of equipment, or on the relative productivity rates of equipment and labour.

4. The geometric design standards have been assumed to vary in accordance with the terrain but not to accommodate labour-intensive techniques though some allowances in the latter respect would almost invariably be made in practice.

5. No account has been taken other than in a general way of the engineering problems that would be associated with labour substitution, such as:-

(1) scale - the size of the project and the rate at which construction has to be carried out;

(2) the timing and sequencing of activities making up the project;

(3) idle time of equipment and labour;

(4) the compatibility of labour- and equipment-intensive techniques on the same site;

(5) mobilisation and other fixed costs as they differ between the two techniques, including supervision, overheads, administration, logistic support, etc.;

(6) differences in the nature and volume of activities due primarily to the difference in techniques, such as temporary works, etc., and

(7) the practical difficulties of aggregating basic production functions beyond the simple grouped operation level in that substitution for one activity could influence other activities in a variety of ways.

6. These limitations and their effects are discussed in this chapter, while the organizational aspects of labour substitution are described in Chapter IV.

B. THE EFFECTS OF THE ENVIRONMENT ON THE SUBSTITUTION PROBLEM

7. The physical environment can be defined in terms of climate, vegetation, topography, geology and soils, and these are all inter-related in a geographical sense. The social environment is determined by such things as conditions and standards of living and many other factors. To some extent they are related to the physical environment.

8. Consideration of the wide range of possible combination of these factors has led to the general conclusion that none can effect the technical feasibility of labour substitution in any of the basic road construction activities**, but will be a major influence on the profitability of such substitution.**

9. The environment influences the scope for substitution in three main ways, by:

(1) its effect on the productivity of labour;

(2) its effect on the productivity of equipment, and

(3) determining the nature and volume of activities which make up a project.

10. The environment affects the productivity of equipment and labour in differing ways and its impact varies with the nature of of the activity. Conditions conducive to high plant productivity may be far from ideal for labour, and vice versa. Again, conditions favouring a particular activity may not favour others. **A detailed** understanding of the **specific** environment is therefore essential to determine the true scope for labour substitution.

THE PRODUCTIVITY OF LABOUR

11. In general, the factors affecting the productivity of labour may be divided into two broad groups; those affecting the capacity of labour (i.e. possible rate of output) and those which affect the performance of labour (i.e. actual output). The scope for increasing productivity by modifying the capacity factors is largely restricted to long-term measures. Unfortunately, performance invariably falls below capacity but there is scope for narrowing the gap since many of these factors are within the control of the employing agency and/or the government of the country, and short-term measures can often show immediate benefit.

12. Factors commonly affecting capacity, listed generally in descending order of importance, are:-

Standards of nutrition;
Standards of health;
Traditional skills, methods and tools;
Effective working times;
Climate - particularly temperature and humidity;
Adaptability.

13. The report of an ILO study in India ("Men Who Move Mountains") identifies the main reason for the consistently higher output rates of members of the Malabari tribes engaged on earthworks as being the higher nutritional standards enjoyed by them. The un- or under-employed unskilled workers in the labour-surplus developing countries often exist on a near-starvation diet and the effects of years of under-nourishment cannot be overcome in a short period. Nutritional problems are closely allied to those of health. Malaria, filaria, intestinal parasites and other debilitating tropical diseases are endemic in many of these countries. They are due in part to the lack of pure water, poor or non-existent medical facilities, bad hygiene and absence of sanitation. Although certain of these factors can be partially overcome in the organisation of large groups of labour in camps, the effects of these diseases extend well beyond the removal of the cause and are often permanent.

14. Traditional skills, allied to methods and hand tools, can be particularly important to productivity in certain activities. In many countries there are tribes or social groups who by long standing custom apply themselves to particular types of work and the work will not be undertaken by other people; high rates of productivity are common and use for these particular skills can often be found in road and bridgeworks. It is sometimes customary for whole families to be engaged with a traditional division of tasks between adult males, adult females and children. Traditional methods often appear inefficient to foreigners and attempts to change rather than to adapt them are met with resistance and often lower productivity. Traditional tools, particularly in earthmoving, have been developed over the centuries to perform specific functions often of an agricultural nature and they may well not be suited to carrying out the basic activities in road construction. Changes to more efficient hand tools are essentially a long-term measure - they are invariably difficult to adapt to and may involve the building up of a completely different set of muscles. To these difficulties must be added the natural resistance to change inherent in under-developed and rural areas.

15. The capacity of labour, in terms of productive hours worked per day and productive days per year, can have a major effect on output. Daily working hours are often governed by custom or decree; productivity throughout the year is affected by the climate

(particularly rainfall and its consequent effects), absenteeism for various causes, and traditional and religious holidays. In Moslem countries output is significantly reduced during the annual fasting period.

16. The effect of climate on capacity has been given a low ranking in that indigenous people are accustomed to working in their normal climatic conditions. However, it is recognised that there are particular combinations of temperature and humidity which are conducive to efficient working although acclimatisation goes some way towards reducing these effects. The effect of climate (and altitude) on capacity would be much more pronounced if labour was required to work in unfamiliar climatic conditions.

17. The adaptability of labour and its ability to learn new techniques has been ranked as of least importance in the context of substituting (unskilled) labour for equipment. The vast majority of labour that could be employed to replace equipment would require little skill to master the use of the hand tools involved and they would invariably have some ingrained knowledge, if not skill, gained in other fields of many of the basic construction activities.

18. The factors commonly affecting performance are listed below, again generally in descending order of importance:-

Management and organisational skill;
Incentives to work;
Consequences of unemployment;
Social attitudes;
Organisation of labour;
Living conditions.

19. Management and organisational skill is ranked as the most important of these factors and its effects are significant at all levels; from the ganger or overseer ensuring that labour is productively employed and has the right tools and materials to do the work, to the higher levels of management integrating the work of large bodies of labour. The relationship between management, at all levels, and those who actually do the work, is of great importance. A particular type of management skill is required for labour-intensive work which differs significantly from that required for equipment-intensive work, the former requiring pronounced leadership qualities.

20. The main incentive for labour to work is the wages structure, not only in absolute terms of what can be bought with the cash received, but the rate in relation to that which other workers receive. To control the performance of large bodies of labour it is essential to relate output to wages, either by a task or a piecework system. Taskwork is simpler to operate but the benefit to the workers is solely in terms of time saved and this may not

be of great value to them. Piecework is more complicated to administer but has the advantage that both labour and management share in the benefits from increased production, in terms of higher wages or reduced unit rates; the nature of road construction generally means that it must be applied on a group basis. Whichever the system adopted, it is essential that tasks or norms of production be properly assessed taking into account the full circumstances of each case. While task work is frequently common on force account projects, piecework is seldom used largely because of administrative difficulties and the possibilities of abuse.

21. The consequences of unemployment have a bearing on discipline and hence the performance of labour. In circumstances where unskilled work is not freely available, i.e. where there is an unemployment problem, the ultimate disciplinary deterrant of dismissal can, if effected, lead in some countries to starvation for the worker and his family. In other countries, notably those with surplus land, social customs ensure that the unemployed are looked after by other more fortunate members of their tribal group. These traditions are more pronounced in rural areas and the effect is of less significance in the urban areas where the unemployment problems are invariably greater. This factor is likely to be of greater importance on small projects using locally recruited personnel who are less dependent on employment income than on large projects drawing labour from a wider area (or using mobile labour) whose dismissal could lead to deprivation.

22. Social and political attitudes towards manual work vary considerably from country to country. There is sometimes a social barrier between skilled and unskilled workers, and manual work is accepted only as a last resort. Increasing educational standards tend to make manual labour unacceptable and, on occasions, the use of equipment-intensive methods is dictated by national pride. Under these circumstances it is not unusual to find that labour engaged on manual operations is poorly paid and regarded as inferior; there is consequently very little pride in work and productivity suffers accordingly. At the other extreme, where the virtues of hand labour are extolled at all levels, there is recognition of achievement within the community and productivity is increased accordingly. While the latter cannot be achieved overnight, it is clear that the substitution of labour for equipment must be encouraged at the highest levels for it to be successful, and must never be regarded as a retrograde step.

23. Productivity can often be restricted by the attitudes of trade unions and other labour organisations that are concerned with improving the standards of living of their members. Where labour is well organised in this fashion, it is essential that their views be taken into account by management not only in the

day-to-day running of a project but in the overall administration and organisation. With proper consultation, a good union can be of considerable assistance. On large projects, the incidence of strikes can be minimised and both the reliability and productivity of labour can be improved.

24. The importance of good living conditions for labour varies considerably. On small projects dependent on locally recruited labour, there is little that can or need be done. On large projects imported labour might be entirely dependent on the employer for food and shelter. Good conditions lead to good productivity but the extent to which it is economic to provide them is largely a matter of scale. On a very large project, labour camps could include accommodation, proper water supplies, sanitation, health, feeding and recreational facilities, together with the specialist staff required for their operation. While it might be economic to provide facilities on such a scale for a large project such as a dam, they could seldom be considered for road projects which of necessity cover a wider area. However, simple measures such as bulk purchase of feedstuffs and the provision of elementary health and sanitation facilities can be of considerable assistance in improving relations with and the productivity of labour.

25. A wide range of factors affect the capacity and performance of labour, and wide variations in productivity are therefore to be expected. Rates of output can vary considerably under normal conditions and may be unacceptably low in very difficult environments. The trade-off between labour and equipment would remain constant if the environment affected both labour and equipment productivity to the same extent, but this is seldom so in practice and the scope for labour substitution depends to some degree on this fact.

THE PRODUCTIVITY OF EQUIPMENT

26. The factors affecting labour described in the previous section have similar effects on the performance of equipment in that they influence the capacity and performance of the skilled personnel operating and maintaining the equipment. Their impact varies in accordance with the nature of the activity. Environmental factors also have a direct effect on the equipment.

27. The skill and adaptability of labour and, in particular, its inherent mechanical aptitudes are probably the most important of the factors affecting the capacity of the operators and mechanics. Familiarity with lorries and similar hauling equipment and their maintenance is common in most countries but more sophisticated equipment such as heavy earthmoving plant is not so well known. Labour skilled in the operation and maintenance of

such plant is often not available and there is no alternative but to train the most suitable labour obtainable. Apart from the time required for initial training, skill can be developed only by practical experience over a lengthy period and the full benefits of training are often not realised until some years later.

28. The performance of equipment is directly related to that of the operators and mechanics. For a given output, the number of personnel involved is far less than for a labour-intensive project. The management and organisation of the labour involved is still of prime importance since it is essential to keep machines operating to their full capacity to attain maximum benefit. The low labour content per unit of work, both in time and cost, offers the opportunity to provide substantial incentive to improve performance while achieving overall reductions in cost.

29. Apart from these factors directly related to the labour required for equipment operations and maintenance, there are other factors affecting the capacity and performance of the equipment itself. Equipment is often required to perform operations for which it was not specifically designed. It is impracticable to provide a full range of specialised equipment (assuming it exists) for each basic activity; to a large extent the cost of mobilising equipment and its availability in relation to the volume of each activity governs the choice. Certain types of equipment are more adaptable than others, and the overall requirements of a project may lead to the selection of such equipment in preference to plant of a more specialised nature.

30. The age and condition of equipment affect productivity, mainly due to reduction in utilisation caused by increased incidence of breakdowns and difficulties of maintenance. Equipment on road construction in many of the developing countries is often used for periods well in excess of its normal economic life and this places greater strain on the available maintenance facilities. The effective productivity of such equipment can be very low.

31. Of prime importance to productivity are the maintenance facilities, both those provided on site as part of the project and others in the area which can be relied upon for support. The availability of spare parts in terms of the time elapsing between ordering and receipt can have a major influence on equipment utilisation. Where time for an operation is critical, it may be necessary to provide spare units to allow for these factors.

32. On very small projects it is seldom economic to provide other than the simplest routine maintenance facilities. On the other hand, major projects could justify comprehensive workshops

and large stocks of spare parts, and there would be no need to rely on external agencies for immediate support. However, such an ideal environment can seldom be justified in road construction. To obtain maximum utilisation of equipment, large stocks of spare parts must be held on site, particularly where these are not immediately available from other adjacent sources. Consequently, the utilisation that can be expected from equipment increases with the size of the project.

33. Of the climatic factors, rainfall is normally the most significant. It is particularly important in earthmoving operations where it can restrict work by its effects on the engineering properties (and subsequent uses) of the soils being moved and, in certain circumstances, can dictate the type of equipment to be used. Of equal importance is the time which must elapse after rainfall before equipment can be used without causing excessive damage. This is frequently much longer than the rainfall period. Extreme climatic conditions invariably increase the wear and tear of equipment and place greater demands on maintenance.

34. The accessibility of the site can restrict the size and type of equipment and necessitate the use of smaller, less efficient, units. The topography and condition of site haul routes affect productivity in the hauling activities and it may well be economic to undertake substantial temporary works to achieve greater output. These factors can also influence the choice of haulage equipment.

35. There is usually a need to maintain traffic while construction is in progress and it is difficult to assess the effect of this on productivity. Effects are related to the traffic volume and clearly are of more significance in the higher type of road, particularly in difficult terrain. In the United Kingdom, it is often said that the cost of dualling an existing road is greater than that of building a new dual facility, but such extremes will seldom apply in the developing countries.

36. The bad effects of factors influencing the productivity of equipment can be partially offset by good management and proper organisation. With the high capital investment involved high unit costs prevail with idle or inefficiently used plant. In many of the developing countries carrying out road construction by force account methods, it is not normal to debit the project with realistic hire charges for equipment. This invariably leads to low productivity since the true cost of the work is not immediately apparent.

THE NATURE AND VOLUME OF ACTIVITIES

37. For a given road, defined in terms of cross-sectional geometrics, traffic loading and quality, the physical environment influences the nature and volume of the basic activities in many ways. The trade-off between labour and equipment and the scope for labour substitiution varies with activity and hence must be dependent, to some degree, on the environment.

38. Of the climatic factors, rainfall generally has the most influence on the nature and volume of activities; it determines the type and frequency of drainage structures, side drains etc. and the construction activities associated with these items will clearly be more significant in areas subjected to high or intense rainfall. High rainfall favours the use of those materials, such as rock and non-plastic soils, which can be handled and placed at higher natural moisture contents. Conversely, low rainfall coupled with absence of readily available natural water supplies, could favour such types of construction as stabilisation by bitumen in preference to cement. The pattern of rainfall throughout the year, together with other climatic factors, affects the natural moisture content of local materials and governs the volumes of the activities needed to adjust the moisture to the optimum state. The extent to which earthwork slopes, drainage channels, etc. need to be protected is also related to the rainfall. Prevailing temperatures and humidities can have similar, though less marked, effects. The direction of the prevailing wind and its velocity in areas of sand dunes can be the prime factor in fixing the profile of a road, with its resultant effect on earthwork quantities. Road location and design can also be influenced by snow, fog and exposure to high winds.

39. The density and type of vegetation affect activities concerned with clearing, grubbing and removal of topsoil. It also has an indirect effect on the retention of moisture in the ground and this, in turn, affects excavation and compaction activities. The vegetation covering has a direct bearing on the establishment of vegetation on shoulders and earthwork slopes. For example, where vegetation is abundant, natural processes can often be relied upon to provide protection without the prior necessity for topsoiling.

40. Topography is particularly important in relation to earthmoving although its effects can be offset by reducing design standards in difficult terrain. Earthwork quantities increase as the terrain becomes more difficult but frequently there are compensating effects in that the engineering qualities of the soils tend to improve leading to greater usability of excavated soils in embankment and steeper permissible side slopes in cuttings. It is also often found that local materials suitable for pavement

construction are more readily available in areas of pronounced relief. Drainage works are usually more frequent in hilly areas than in flatter country and steeper gradients lead to a greater need for protective linings in drainage channels. Access problems are often increased but haulage distances may be reduced.

41. The topography of an area is related to the geology. Geology has an obvious effect on all earthwork operations influencing the difficulty or otherwise of excavation, nature of the available materials and haul distance. The nature of the soils similarly affects the type and size of the basic activities. Some soils may have to be excavated, discarded and replaced with others of a better quality; processing of soils to reduce their natural moisture content may be necessary, and moisture contents may have to be increased to achieve satisfactory compaction.

42. All these factors combine variously in nature to produce a wide spectrum of physical environments which often vary continually with time. The factors and their effects are taken into account in the selection of the alignment for a road and in the design and specification processes which define the nature and volumes of the basic activities required for construction.

43. Some allowance has been made in the hypothetical road projects for the effectsof the environment on the nature and volume of activities. However, it is emphasised that these would be far more complex in practice and they could vary between wide extremes.

44. Equipment intensive methods favor wider safety margins and overbuilding, whereas labour intensive methods favor very close tolerance limits and staged construction.

C. ASSOCIATED ENGINEERING PROBLEMS

THE PROBLEM OF SCALE

45. The hypothetical road projects may be used to illustrate the problems of scale. Quantities per kilometre for excavating in bulk in soft material (including loading, hauling and unloading) are:-

	Terrain		
	Flat	Rolling	Hilly
Excavating	5,000	9,800	14,250 m^3
Average haul	100	400	200 m

To achieve an average weekly output of one kilometre of road, and assuming that earthworks could not be possible during 4 months of the year, average weekly outputs during the construction season would need to be:-

Terrain		
Flat	Rolling	Hilly
7,500	14,700	21,375 m^3

46. For a labour-intensive project, the high outputs and increased haulage distances would be achieved by using more labour. If the physical conditions of the site imposed a limitation on the numbers who could be usefully employed in a given area, the required rate of output could normally be achieved by spreading the work over a greater area. However, there would be no economies of scale; in fact, there might be some marginal reduction in output due to a lower degree of control. The unit cost of carrying out the work would remain much the same, apart from the effect of increasing the haulage distance.

47. On the other hand, higher output on an equipment-intensive project can be achieved either by using more equipment (subject to any site limitations) or by using larger units. The effect of equipment size on unit rates is illustrated in Table III-1 which is based on productivity rates quoted by Spence Geddes and UK Plant Hire Rates.

48. Assuming a 60-hour working week for scrapers during the construction season, the hourly output rates and the corresponding theoretical numbers of scraper units required are shown in Table III-2 based on an average weekly output of one kilometre of road.

Table III-1: Outputs and Unit Rates for Tractor-Drawn Scrapers Excavating Soft Soil

Scraper Size m^3	Hire Rate $/hour	100m Haul		200m Haul		400m Haul	
		Output m^3/hour	Cost $/$m^3$	Output m^3/hour	Cost $/$m^3$	Output m^3/hour	Cost $/$m^3$
3.05 (4 yd^3)	7.77	19	0.41	15	0.52	10	0.78
4.57 (6 yd^3)	9.68	31	0.31	23	0.42	15	0.64
6.10 (8 yd^3)	11.60	41	0.28	31	0.37	22	0.53
9.16 (12yd^3)	15.26	59	0.26	45	0.34	31	0.49

Source: SWKP Estimates

Table III-2: Tractor-Scraper Units Required for Construction of Hypothetical Road Projects

Terrain	Flat	Rolling	Hilly
Average Haulage Distance	100 m	400 m	200 m
Hourly Output Required	125 m^3	245 m^3	356 m^3
Scraper Size	Theoretical Number of Units Required		
3.05 m^3 (4 yd^3)	6.6	24.5	23.8
4.57 m^3 (6 yd^3)	4.0	16.3	15.5
6.10 m^3 (8 yd^3)	3.0	11.1	11.5
9.16 m^3 (12 yd^3)	2.1	7.9	8.0

Source: SWKP Estimates

49. In practice, it would not be wise to use a large number of small scrapers since supervision and administration is more difficult and unit costs are high. Similarly, a small number of large scrapers could also be unwise, since a breakdown of one unit could seriously interrupt the programme of work. In the above example, flat terrain would tend to favour the use of the smaller units, while rolling and hilly terrain would favour units even larger than those considered.

50. Comparing the use of the 6 yd^3 scrapers (US $0 31/$m^3$) with a labour-intensive wheelbarrow operation (US $0.51/$m^3$ at $2.00/day) in flat terrain, the break-even wage rate would be US $1.21/day. In hilly terrain, using 12 yd^3 scrapers, the corresponding break-even wage rate would be US $0.64/day.

51. Similar analyses could be carried out covering other operations and activities. On a recent project in India, it was shown that hand loading of vehicles was cheaper than using a small powered shovel but that labour could not compete with larger loading equipment. It may be concluded that the scope for labour substitution is greater on the smaller projects where, for one reason or another, the size of equipment is restricted.

TIMING AND SEQUENCING PROBLEMS

52. Labour-intensive projects invariably take longer to complete than those using equipment (provided that an adequate supply of spare parts and competent mechanics are available). The longer construction period is due to the lower rate of labour productivity when compared with that of equipment. Theoretically, the use of a larger labour force would overcome this problem but constraints in practice would include:-

(1) the non-availability of labour, particularly during the planting and harvesting seasons;

(2) the practical difficulties involved in mobilising and administering large bodies of labour;

(3) the lack of skilled supervisory staff and shortage of training facilities, and

(4) the physical limitations of the site restricting the amount of labour that can usefully be employed.

53. Lengthening of the construction period could have undesirable effects in that it could delay other projects dependent on the road

and the benefits arising from investment in the highway construction could be deferred. At the same time some of the costs would be deferred. All these factors would have to be taken into account in assessing the extent to which labour substitution could take place. Optimal timing of costs and benefits could be attempted by planned stage-construction; completing the road to motorable standards in the first season (bridges and drainage works and partial earthworks); and completing earthworks and laying the pavement subsequently. This practice is not uncommon in many of the developing countries.

54. While this may go some way towards overcoming the overall problem, other timing problems might still occur within a construction season. These could include the need to complete certain works before the onset of the rainy season to preclude subsequent damage, which may necessitate the use of equipment with its higher rates of productivity. However, these problems are not solely restricted to labour-intensive methods and might be of even greater significance where additional equipment cannot be mobilised rapidly to offset shortfalls in planned productivity.

55. Coupled with the timing problem is that of sequencing, the arrangement of activities in their correct order. Apart from straightforward requirements, such as the need to complete earthworks before laying the pavement, there are invariably others more complex. For instance, it may be necessary to complete some earthworks or structures before access to a borrow area can be achieved. Such constraints may be of equal or even greater significance with equipment-intensive methods.

56. Sequencing requirements can affect the overall timing and programming for a project and may dictate that certain activities must be carried out by equipment-intensive methods. It can consequently affect the nature and amount of equipment required and its utilisation rate.

57. A work programme suited to a labour-intensive method might not be applicable to equipment-intensive methods and there is a wide range of possible programmes for work involving partial substitution. In assessing the scope for labour substitution, work programmes must take account of many factors, including:-

(1) constraints on the availability of equipment and labour which might differ in time;

(2) the effect of the environment on productivity as it varies with time (e.g. some earthmoving equipment is largely unproductive during and for some time after heavy rainfall whereas

other types are not so affected by climatic changes);

(3) the optimum starting date for a project might be dependent on the equipment/labour mix, and

(4) the relative flexibility of equipment and labour.

58. Where the time to complete a project is of importance, the scope for substitution may be largely confined to those activities which are not on the critical path of the flow network of activities.

59. Sequencing problems can lead to enforced substitution; even though it may not be economic to do a particular activity by labour, to do so may lead to higher overall productivity. Conversely, the need to keep equipment fully utilised may lead to its use on activities for which it is less suited than labour.

IDLE TIME

60. Idle time of equipment or labour on a road construction project can normally be attributed to:-

(1) climatic effects, particularly rainfall;

(2) mechanical breakdowns of equipment;

(3) difficulties in sequencing operations, and

(4) lack of proper organisation.

These factors vary with the nature of the work and with the type of equipment.

61. Rainfall has a noticeable effect on many earthmoving operations since excessive moisture content can restrict the use of the material in embankments unless it is dried out. Scraper operations are particularly affected since a larger area of excavation is opened up at one time. On the other hand, excavation by shovels (or hand labour) can be so arranged to minimise the harmful effects of rainfall.

62. It is often necessary to restrict the movement of earthmoving plant during and immediately after heavy rain to avoid damage to haul roads and partially completed works. Static plant and equipment handling materials unaffected by rain (e.g. rock products) are affected to a much lesser extent.

63. The effects of rainfall can be most significant in the United Kingdom where the utilisation rate for scrapers can be as low as 40%, even though work is available. In countries where seasonal effects are pronounced, it is common to suspend all earthmoving operations at certain times of the year and equipment is idle during these periods.

64. Rainfall also affects the utilisation of labour but generally to a lesser extent. Labour is more flexible than equipment and can be used in work not affected by rain. Casual labour can be laid-off and some of the cost of idle time can thereby be avoided, particularly that due to seasonal effects.

65. Some idle time of equipment is due to mechanical breakdown. The incidence of break-downs is a function of the age and condition of the plant, the skill of the operators and maintenance staff, and the conditions under which it is working. The availability of spare parts and repair facilities and the skill of the maintenance staff determine the time required to effect repairs. It is good practice to adopt preventative systems of maintenance at the expense of losing part of the productive time of the equipment.

66. Sequencing difficulties can lead to under-utilisation of equipment. At one extreme, particular operations may need the use of a crane for short terms at isolated intervals and there may be no other work on which it can be utilised during the intervening periods. Equipment such as bitumen distributors may have capacity in excess of the overall construction rate and it may be utilised on average for only 2 or 3 days a week. With longer than average hauls, loading equipment (or labour) may be idle waiting the return of vehicles; conversely, with shorter hauls, vehicles may be idle awaiting their turn for loading. Some of the idle time due to sequencing difficulties is unavoidable since the nature of the work varies from day to day.

67. A breakdown of one piece of equipment can lead to the stoppage of a whole operation (and have adverse effects on others) and it is not always possible to use the associated equipment on other work. The balance between capacities of loading and hauling equipment is particularly critical.

68. All these factors can be aggravated by lack of proper organisation - inadequate supplies of spare parts and materials, lack of forethought in planning the day-to-day activities in advance and of flexibility in planning to overcome expected and unexpected difficulties. The specialised nature of road-building equipment means that much of it cannot be directed to other work when climatic and other factors preclude activities being carried out in their normal planned sequence. These problems can be partially

overcome by the careful selection of equipment, both in relation to size and type, so as to retain the maximum possible degree of flexibility. On the other hand, labour is inherently more flexible and, while some idle time is often unavoidable, high rates of utilisation can be achieved with proper management.

69. The unit rates for equipment costs used in the analyses of the hypothetical road projects contain some allowance for idle time due to climatic effects and for breakdowns/maintenance since the rates are for daywork.1/

70. To illustrate the effect of idle time on the costs of owning and operating equipment, a typical case of a scraper has been taken, and the utilisation rate has been assumed to vary from 1,000 to 2,500 hours per year. The calculations, which are based on average operating conditions, are shown in Table III-3 Taking 2,000 hours utilisation per year as a standard, the effect on hourly costs is:-

Utilisation Rate	Effect on Hourly Cost
50%	+ 15.4%
67%	+ 8.3%
100%	-
125%	- 1.0%

A utilisation rate of 2,000 hours/year is near optimum for this type of equipment under the conditions (and costs) assumed and unit costs increase rapidly with under-utilisation.

71. The hourly output of such a scraper excavating in soft material, loading, hauling 100 m, unloading and spreading would be about 76 cubic metres. Comparing this with a labour-intensive operation (hauling by wheelbarrow) where 0.256 man days are required for one cubic metre, the effect on the break-even wage rate is given below:-

Utilisation Rate of Scraper Hours/year	Cost by Equipment $/m^3$	Break-even wage Rate for Unskilled Labour $/day
1,000	0.281	1.10
1,333	0.264	1.03
2,000	0.243	0.95
2,500	0.241	0.94

72. It should be noted that no allowances have been made for mobilisation costs, profit, supervision, etc. in these figures.

1/ The plant hire contractor charges only for the time that the equipment is fully available for use, and bears the cost of maintenance and repairs himself. These, of course, he expects to recover from the rates charged.

Table III-3: Typical Owning and Operating Costs of a Scraper

ASSUMPTIONS				
Life in hours	10,000	10,000	10,000	10,000
Utilisation, hours/year	1,000	1,333	2,000	2,500
Life in years	10	6	5	4
DEPRECIATION				
Delivered price	$60,000	$60,000	$60,000	$60,000
Less value of	10,000	10,000	10,000	10,000
Amount to be depreciated	$50,000	$50,000	$50,000	$50,000
Hourly depreciation rate	$ 6,000	$ 6,000	$ 6,000	$ 6,000
INTEREST, TAXES, INSURANCE & STORAGE				
Average yearly investment				
% of purchase price	52%	58.3%	60%	62.5%
Amount per year	$33,000	$34,980	$36,000	$38,100
Yearly charges (10% of average yearly investment)	$ 3,300	$ 3,498	$ 3,600	$ 3,810
Hourly charges	$ 3.30	$ 2.62	$ 1.80	$ 1.52
OPERATING COSTS				
Tyre life, hours	4,500	4,500	4,500	4,500
Total tyre replacement cost	$10,000	$10,000	$10,000	$10,000
Hourly tyre replacement cost	$2.22	$2.22	$2.22	$2.22
Tyre repair cost, per hour	$0.33	$0.33	$0.33	$0.33
Fuel and lubricants, per hour	$1.40	$1.40	$1.40	$1.40
Repairs, per hour (20% of depreciation cost)	$5.40	$5.40	$5.40	$5.40
Operator's wages (1)	$2.70(2)	$2.06(2)	$1.35	$1.44(3)
Total costs per hour	$21.35	$20.03	$18.50	$18.31

Notes (1) Operator's costs at $1.35 per hour

(2) Idle time of operator charged

(3) Allowance made for overtime.

Source: SWKP Estimates

COMPATIBILITY OF EQUIPMENT AND LABOUR

73. Apart from the very simple roads, some equipment will invariably be needed in road construction and, in practice, partial substitution of labour for equipment will often be the best solution. Consideration is therefore given to the difficulties that may arise in mixing the two methods on the same site and the ways in which they may be overcome.

74. One of the main difficulties in integrating equipment- and labour-intensive methods is that of sequencing, due to the wide disparity in their relative rates of productivity. Shortfalls in labour output, of little significance in themselves, can lead to under-utilisation of expensive equipment with consequent increases in cost.

75. This difficulty can be overcome by good advance planning and programming, starting the labour-intensive activities at a sufficiently early date to allow some slack to cater for (unforeseen) contingencies. Examples are keeping clearing and grubbing operations (by hand) well ahead of earthwork operations using equipment; opening borrow pits and gaining base-course and other local materials in advance of their requirements.

76. Some unskilled labour working with equipment can increase the productivity of the latter by undertaking that part of the activity for which equipment is not particularly suited (e.g. trimming excavations). The extent to which this is advantageous depends on the relative cost; in the United States the proportion of unskilled labour employed on a road project is very low, whereas quite large numbers of unskilled labour can be usefully employed on equipment-intensive projects in other countries where labour costs are lower. However, there can be danger in using too much unskilled labour on a confined site.

77. Hand labour coupled with equipment can often improve the quality of workmanship, particularly in the finishing operations and in confined areas where equipment cannot operate efficiently.

78. The size of equipment is also of importance and it may often be appropriate to sacrifice some of the economies of scale inherent in the large units to match the lower rates of output of hand labour. It is uneconomic to load large vehicles by hand in view of the lengthy waiting time during loading. Tractor/trailer units are more compatible with hand loading; with several trailers to each tractor, the more expensive tractor can be fully utilised.

79. Similarly, a tractor is a multi-purpose vehicle which can be used for a variety of tasks such as towing water bowsers, bitumen boilers, rollers, etc. It can serve as the motive power for a variety of unpowered equipment and its flexibility helps overcome the sequencing problems referred to earlier. Reductions in the variety of equipment types also eases the maintenance and spare parts problem.

80. In general, the problems of compatibility are not serious and can be overcome by the judicious choice of equipment types and sizes, and by adequate planning.

MOBILISATION AND OTHER FIXED COSTS

81. In the list of basic construction activities these costs were identified in terms of:-

Activity	13.1	Site overheads, logistic support, etc.
	13.2	Head office overheads and profit
	13.3	Administration
	13.4	Mobilisation, including transport to site offices.

None of these costs were taken into account in the analyses of the hypothetical road projects.

82. Under Activity 13.1 would be included such items as:-

(1) site offices, stores and general workshops;

(2) facilities for maintaining equipment and adequate supplies of spare parts;

(3) provision of and facilities for maintaining tools;

(4) materials testing laboratory;

(5) site transport;

(6) insurance of the work and compliance with other conditions of the contract, and

(7) accommodation for supervisory staff, labour camps and health and welfare facilities.

These costs arise partly from the provision of the facilities initially and, thereafter, from their operation and maintenance.

83. Site overheads (activity 13.1 in Table II-1), vary greatly from job to job. There is no clear-cut definition of what constitutes a site overhead and practices differ. Certain of these costs are sometimes treated as labour or equipment charges by marking-up the unit rates accordingly; on other occasions, separate provision is made by the insertion of corresponding bill items in the contract. In amount, they are primarily related to the size of the labour force/amount of equipment used, and hence to the required rate of progress rather than to the size of the project. The construction period determines the recurrent costs of maintenance and operation but they are normally of less importance than the initial costs.

84. Of particular significance is the cost of spare parts for equipment. On an equipment-intensive project in Nigeria completed some 10 years ago, where there was little local support for equipment, the value of spares held on site by the contractor was about $250,000, some 15 % of the contract price. In such circumstances the value of spares on the site could be as much as 15% to 20% of the original cost of the project.

85. Generally speaking, the site overheads for an equipment-intensive project would be greater than those for a labour-intensive project. However, this advantage could be more than outweighed if large labour camps and associated facilities were required.

86. For contract work, allowance has to be made in the rates for head office overheads and profit (activity 13.2 in Table II-1). This would include such items as:-

(1) general supervision and visits to site;

(2) financing of the project;

(3) general running costs of the head office, and

(4) profit.

On force account work these costs, except profit, would still be incurred but it is seldom customary to debit them against the project. There would not be a great deal of difference between labour- and equipment-intensive projects in this respect.

87. Administration and supervision[1] comprises the salaries, allowances and other costs of administrative and supervisory staff, including engineers, inspectors of works, overseers, clerks, storekeepers and timekeepers, together with administrative costs of running the project. In general, these are likely to be greater on a project employing large bodies of unskilled labour.

88. The mobilisation (and demobilisation) costs of equipment[2] depend on the location of the site and ease of access to it. They are of significance only where small quantities of work are involved. Taking the case illustrated in Table III-3, a mobilisation cost of US $1,000 would increase the hourly owning and operating costs of a scraper (assuming one year's work on site) by between US $0.75 and 0.40, depending on the utilisation rate. The effect on unit rates would not be great except where small quantities of work and low utilisation rates are involved.

89. It is impossible to generalise on the mobilisation costs of unskilled labour since these would need to take into account the distance to the site from the place of recruitment, the mode of transport, the conditions of employment, the availability of labour and other similar factors. However, experience has shown that mobilisation costs in many of the labour-surplus developing countries can be extremely low.

90. An analysis of a recently completed highway contract in the United Kingdom showed that on-costs[3] were about 25% of the tender price, i.e. a mark-up rate of 33⅓%. The breakdown of the on-costs is given below:-

	%
Provision of site buildings	2.5
Maintenance of site buildings	1.0
Site transport	1.5
Supervisory staff salaries	6.0
Staff facilities	1.0
Total site overheads	12.0
Head office overheads	4.0
Project financing	2.0
Mobilisation	2.0
Profit	5.0
Total	25.0

Apart from this on-cost applied to all bill rates, provision was made in the labour rates used for costing bill items for holiday pay, labour taxes, hand tools, sickness benefits, and other associated payroll costs.

1/ Activity 13.3 in Table II-1
2/ Activity 13.4 in Table II-1
3/ Broadly equivalent to the total "Management and Other" section 13 in Table II-1

91. It is difficult to draw any firm conclusions on the effects that these factors would have on the scope for labour substitution but it seems that the total on-costs might be higher on a labour-intensive project. However, it is clear that these costs are important and that they must be clearly identified and taken into account in determining the trade-off between labour and equipment.

PROBLEMS IN COMPARING ALTERNATIVE TECHNIQUES

92. Attention has already been drawn to one of the important limitations in the analyses of the hypothetical road project in that the geometric design standards have been kept the same though in practice some changes would undoubtedly be made to accommodate labour-intensive methods. To assess the true scope for labour substitution in a particular environment, it is not sufficient to compare labour-intensive and equipment-intensive techniques for a road adapted to that environment. The designs themselves would need to be orientated towards the particular technique while at the same time providing the same levels of quality and service. For example, a crushed stone base (equipment-orientated) should be compared with an equivalent thickness of macadam base (labour-orientated) rather than comparing labour-and equipment-intensive methods of crushed stone base construction. A further example is the roadside ditch, where the traditional trapezoidal shaped section (which cannot be excavated efficiently by machine) has been largely replaced by the grader-dug vee-ditch; it is difficult to construct (and maintain) the latter by hand labour.

93. In some cases differing alignments should be compared (making due allowance for variations in vehicle operating and road maintenance costs) since modern route location practice has been influenced by the greater productivity of equipment.1/

94. Civil engineering works are commonly defined by a list of items in a bill of quantities. However, the bill items do not define the volume or full extent of the work to be carried out and are devised solely as a basis for payment. Many of the basic activities are unlisted and their cost is "deemed to be included in the tendered rates and prices". Some of the unlisted activities are common to both labour- and equipment-intensive techniques, whereas others may differ in both nature and volume depending on the technique or type of equipment used. An example of the former case is the bulking of soil and rock on excavation where for purposes of payment, no allowance (or one on an arbitrary basis) is provided

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1/ See Highway Design Study, Phase I Model: IBRD Economics Department Number 96.

in the bill but a precise estimate would be necessary to determine the volumes of the excavating, loading, hauling, unloading, spreading and compacting activities.

95. The volume of a basic activity is often dependent on the way in which it is carried out. For example, the excavation of a foundation by equipment invariably entails greater quantities of excavating (also backfilling and possibly foundation concrete) since hand labour can work to closer tolerance in these circumstances. Furthermore different equipment gives different volumes.

96. The nature of activities may differ, particularly in respect of unlisted temporary works which are commonly not a pay item. The need for haulage routes is minimised on a labour-intensive project; tractor-drawn scrapers can operate over less well-maintained routes than pneumatic-tired equipment. Conversely, labour-intensive methods may lead to additional works such as timbering on excavations. The use of labour may result in less efficient use of materials to produce an equivalent end-product.

97. The technical scope for substitution of labour in earth-moving and other similar operations is largely dependent on the length of haul. In the analyses of the hypothetical road project the substitution possibilities were assessed on the basis of an average haul. In practice, this would not be adequate and recourse would have to be made to a detailed mass-haul design to properly determine the scope.

THE AGGREGATION PROBLEM

98. The production functions prepared in the analyses of the hypothetical road projects are of limited value in that they do not take into account the effects of the environment on productivity, both in place and in time, the relative efficiencies of differing types of equipment performing the same activity, scaling, timing and other similar problems.

99. Environmental effects could be eliminated from the functions by defining a 'standard' environment and other environments could be related to the standard by a simple rating system. However, the relationship between environment and productivity varies with activity and the environment varies with time, and separate ratings for each activity would be required on a time scale.

100. Differing types of equipment carrying out the same activity would give differing trade-offs and substitution slopes in the basic production functions and, in effect, there would be a separate basic production function for each type of equipment suited to each activity.

An added complication is that certain types of equipment (particularly that used in earthworks) essentially combine several basic activities as one operation and corresponding additional functions would be required. It becomes apparent that the number of basic production functions would greatly exceed the number of basic activities.

101. The problem of scale could be overcome in the basic production functions by using rates of output rather than quantities of work. However, this would introduce complexities in grouping basic functions to be representative of operations or groups of operations.

102. There are also problems in combining the basic functions to the operation or group level. Assuming that the basic functions are representative of the most efficient ways of carrying out the basic activities by equipment- and labour-intensive methods, their combination would not necessarily represent the most efficient way of carrying out the operation. While account can, to some extent, be taken of this problem in the aggregation of a few activities, the problem becomes complex at the stage where the operations are grouped together.

103. Taking the simple case of a grader which can be used to greater or less effect in the following activities:-

(1) Light clearing, or assisting other equipment in more dense vegetation;

(2) Excavating drainage ditches;

(3) Maintaining haul routes;

(4) Spreading materials;

(5) Finishing.

Under particular circumstances, it might appear economically advantageous to substitute for one or more of these activities. But doing so would affect the utilisation rate of the equipment; mobilisation charges would have to be spread over a lesser volume of work and, consequently, the effective trade-off between labour and equipment in the other activities would be changed, most probably to the advantage of labour.

104. As a further example, the analyses of individual operations might indicate advantages in using scrapers for medium-haul earthworks and tractor/trailer units for long hauls of earthworks and base course materials. However, to obtain minimum costs for the two operations on the same site, and taking into account

the problems of scale, etc., it might be best to use other methods for medium-haul earthworks. The possible combinations of this nature are innumerable.

105. It is clear that the aggregation process is most complex and optimisation on an activity basis will seldom be compatible with that on a project basis. In addition, it would need to take account of various other constraints that might be applied in practice in assessing the scope for substitution, such as minimising financial or resource cost, minimising foreign exchange cost, varying the construction period and timing, taking account of the relative availability, type and mobilisation costs of equipment and labour, varying the quality of the finished road, and so on. These factors could vary from country to country and even within a country.

106. The complexity of these problems leads us to believe that the aggregation process can best be carried out by a computerised mathematical model simulating the highway construction process and incorporating optimising procedures.

107. The input to such a model would be a definition of the project, possibly in terms of a normal bill of quantities, together with a flow network relating bill items in their construction sequence and breaking down each bill item into individual sequential activities. Other input data would define the environmental conditions (in relation to time), the required objectives (such as maximising labour substitution, etc.) and external constraints (e.g. budgetary or time considerations) together with costing data in the required form.

108. The model would draw on 'standard' productivity data and adjust it in the light of the environmental conditions, as varied by time. The flow network would be analysed to optimise the project as a whole in accordance with the imposed constraints and objectives. Such a model could handle a sub-division of the basic activities at a detailed level, allowing for differing types of equipment, soil types and a wide range of environments. The standard productivity data would be in the form of basic production functions and the aggregation process would optimise the equipment/labour mix from these levels without attempting to optimise individual operations. The data bank could be updated continuously as more productivity data becomes available (to allow for new types of equipment, methods of construction, etc.) and corrected to suit conditions in particular countries. Its scope could eventually be widened to deal with other civil engineering works such as airfields, dams and irrigation works.

109. In view of the wide range of productivity data and variability in its quality, it would be advisable to incorporate into the model a procedure for dealing with probability. Many of the variables can be considered as stochastic.

110. The output from such a model could take many forms, such as a detailed programme of work with equipment, labour and materials requirements, together with estimates of cost, all in accordance with the imposed constraints. There are various refinements which could be added to the programming process, such as evening-out equipment and labour requirements and the combined effects of various constraints could be studied.

111. Enquiries have been made as to whether such a model already exists or is being developed. While similar models including optimisation and stochastic techniques have been developed in other fields of engineering including building construction, no direct research into this problem appears to have been undertaken. The Road Research Laboratory, as the UK member of the International Road Research Documentation scheme, has been unable to trace any record of this type of research.

Conclusions of the Engineering Analyses

(i) Examination of the list of basic activities and of the categories assigned to each leads to the general conclusion that it is technically feasible to carry out a large proportion of the basic construction activities in road construction by labour and that the technical scope for substitution increases only to a limited extent as quality standards are relaxed. In the example analyses given above, it was found that labour could be substituted for all but about 10 to 20 percent of total road construction costs for the higher quality construction standards, while relaxation of standards[1/] to an intermediate quality permits labor substitution for only an additional 5 to 8 percent of costs (i.e. for all but about 2 to 15 percent of total costs).

(ii) The economic feasibility of labor substitution will depend, inter alia, on the productivity rates of equipment and labor and the wage assigned to unskilled labor. The example analyses for Road Type A in rolling terrain utilizing identical assumptions concerning wages and prices, but employing the differing data and assumptions concerning productivity rates given by SWKP and BCEOM, yield markedly different conclusions concerning the economic feasibility of substitution. At a wage of $1.00 per day the optimal combination of methods would involve about 28 and 37 percent labor costs for the high and intermediate quality cases, respectively, in the SWKP estimates and only about 6 percent in either case for the BCEOM analyses.

(iii) The institutional framework is a major factor in explaining these differences: the BCEOM estimates reflect productivity rates weighted toward experience derived in public "makework" projects, such as the National Promotion in Morocco, where there is little incentive to achieve efficient utilization of labor, whereas the SWKP estimates are weighted more by experience derived from dam projects in South India which were oriented to achieve maximum labor productivity.

(iv) As an overall conclusion, the greatest scope for substitution occurs in the interdependent activities of excavating in bulk, loading, hauling, unloading and spreading. Of these, only the last activity is affected by the level of quality. Reliable productivity data for these activities are consequently of greater importance than for the other less significant activities.

1/ Design geometrics have not been varied, i.e. are the same for both the intermediate and high quality construction standard. Relaxation of design geometrics may in fact be warranted to take better advantage of labor intensive methods, but savings in construction costs will have to be offset by the resulting increase in road user (vehicle operating) costs. Analyses of this kind will be investigated in subsequent studies in conjunction with the IBRD Highway Design Study. See Highway Design Study Phase I: The Model, Economics Department Working Paper No. 96 (January, 1971).

(v) The feasibility of using intermediate technologies involving a mixture of modern equipment and manual methods appears promising and should be further investigated. For example, according to the SWKP estimates handloading of detachable low slung trailers pulled by tractors may be optimal for moving earthworks and materials over certain haulage distances when wage rates for unskilled labor are in the range of US$3.50 per day or less. However, handloading of trucks would never appear sensible (except in isolated instances), since the cost of detaining the truck longer while loading it greatly exceeds the savings in loading costs according to any estimate.

(vi) Other conclusions relating to the methods used in the analyses are:

(1) To permit the full analysis of labour substitution possibilities, disaggregation should be carried out to such a degree that an activity could be carried out either solely by labour or solely by equipment.

(2) The list of basic construction activities needs to be further sub-divided to allow for differing types of equipment, haulage methods, a greater range of soil types, loading heights, etc.

(vii) The cost of supervision is an important factor for the comparison between the equipment and the labour alternatives. Research is needed to quantify this cost, and also the cost of mobilization.

(viii) If the substitution of labour for equipment is to be successful, it must be encouraged at the highest possible levels and not be confined solely to the highway construction industry. It must also be socially acceptable to the people of the country.

Chapter IV

Organization and Management of Large Labour Forces

INTRODUCTION

1. The main conclusion of the engineering studies is that there is considerable technical scope for the substitution of labour for equipment in road construction. This chapter is concerned with the practical problems of labour substitution and whether these might impose a further constraint on substitution possibilities.

A. RECRUITMENT OF LABOUR

2. The analysis of the hypothetical road projects assuming labour-intensive methods at intermediate levels of quality indicates that the unskilled labour content per kilometre could range from some 7,657 man days for a type A road in flat terrain to about 14,945 man days for a type B road in hilly terrain. Making some allowance for idle time, work-free days and excluded activities (culverts, bridges etc.), a labour force of between 2,550 and 4,980 would be required to achieve a construction rate of 1 km. of road per week. Seasonal effects could increase these figures by some 50 per cent suring the months most favourable to construction.

3. In addition to these basic elements of the work force, there would be a need for engineers and administrators skilled in the management of labour-intensive work, junior engineers and assistants, overseers, surveyors, artisans, clerks, storekeepers and other miscellaneous subordinate staff, the majority of whom would need to be skilled in their particular field of work.

4. To have the maximum impact on local underemployment problems, and to reduce need for camp facilities, labour should be recruited locally as far as possible. Certainly, the unskilled workers, the lower supervisory levels, and the more common varieties of artisans are usually recruited as closely as possible, whether by a contractor or a public authority. The success of recruitment may depend on wages offered, the difficulty of the work, its timing, the extent of the poverty of those being recruited, the need for them to travel, either daily to sites, or over a long distance to the site, in which case accommodation requirements enter as a further variable. If sufficient or certain types of men are not available locally, or are not attracted by the work, or do not hear of it, it may be necessary to send recruiting officers to areas with known labour surpluses and use the services of labour exchanges.

5. In the construction of a large dam in Mysore, India, by labour-intensive means, on which up to 20,000 people worked, persons had to be recruited from up to 1,000 kilometres away. Most of these returned to their home villages for seasonal work.[1/] Recruiting can be eased by taking advantage of units or groups already in existence, such as villages, families or the groups of the petty contractors.

6. In some less developed countries labour expects to move from job to job using such transport as is available. In some cases it may be necessary to pay a travelling allowance to attract labour. Only where the sites are in areas which are completely undeveloped or without transport should it be necessary to offer transport.

7. With the increasing standards of education common to most developing countries, there should be no great difficulty in obtaining adequate numbers of subordinate personnel though they may need some additional training before they become fully effective. However, there could be a problem in recruiting senior staff of the right calibre.

B. ORGANISATION OF THE LABOUR FORCE

8. It is difficult to define an ideal organisation for a labour-intensive road construction project since much depends on the nature and volume of the activities. The basic unit is the gang, of some 10 to 20 unskilled labourers, under the control of a ganger or headman. The latter is normally a working member of the group and is often elected by the group either because of natural leadership qualities or on traditional grounds. Essentially his function is to enforce discipline and to ensure that productivity targets are obtained. For most activities, no special training or knowledge is required, he need not be literate and his rate of pay is normally only marginally greater than that of an unskilled labourer.

9. Gangs are grouped and each group is supervised by an overseer. Generally a group is given a particular type of task to perform, such as clearing and grubbing, forming cuttings and embankments, quarrying and breaking stone, laying base courses, etc. The size of the group is a function of the nature of the work and the area over which it is spread. For a large cutting or embankment, a single overseer could control up to about 200 men, while for other

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1/ "Men Who Move Mountains", ILO Management Development and Productivity Mission to India, New Delhi, 1963.

more specialised operations, the number might not exceed 30 or 40. The function of the overseer is to control and organise the work for his group. He is responsible for:

- ensuring proper standards of workmanship and productivity;
- keeping records of hours worked and work done; and
- maintaining an adequate supply of materials and tools.

He is usually assisted by a timekeeper and, where appropriate, checkers to record production. The overseers and their assistants would have to be literate and possess a reasonable degree of intelligence.

10. Working parallel with the 'unskilled' groups are 'specialist' groups who would undertake more skilled operations such as surface dressing, and culvert construction. These groups would contain trained artisans and their numbers would be dependant on the nature of the work.

11. The overseers of the 'unskilled' groups are generally chosen from the gangers showing the greatest intelligence and leadership. They may be considered to be of much the same status as a fully-trained artisan. For the 'skilled' groups, overseers would need to have specialised knowledge and they would normally be selected from amongst the artisan grades.

12. In some of the lesser developed countries where labour intensive methods are currently employed, the labour gangs and their overseers are supplied by petty contractors and a similar pattern of organisation is followed. In these cases, the overall management of the project is carried out by the employing agency which accepts responsibility for the co-ordination of the work of the various petty contractors.

13. Above the overseer is the inspector of works. Numbers of these are related to the type of work, but one inspector to 4 to 6 overseers is a common ratio where close control of quality is unnecessary. In the more critical operations there may be one inspector to each overseer. Generally on a large project there is at least one inspector for each of the main operations such as earthworks, drainage and pavements. Large individual works, such as bridges or major earthworks may justify their own site inspector. While the inspectors are responsible for the control of all workmen assigned to them, they are essentially concerned with the technical side of the work. They are generally selected from the overseer grade and, lacking formal engineering training, tend to specialise in one or other of the basic road construction operations.

14. The numbers of engineers required to properly supervise a labour-intensive project depends not only on the size and nature of the work but also on the quality, experience and effectiveness of their subordinates. Quite large projects have been satisfactorily completed under the supervision of a single engineer with a well-trained and experienced labour force. However, there would generally be a need for at least 3 or 4 engineers to supervise road construction at an acceptable rate of say 1 km per week.

15. Apart from their general duties of administering and controlling the work, specific tasks which would normally be undertaken by the engineering staff would include:

(1) setting out the work;

(2) planning and sequencing of operations;

(3) measurement of work, particularly where a petty contract system is operated;

(4) materials control, both quantitively and qualitatively; and

(5) control of workmanship.

16. In carrying out these functions, the engineers would be assisted by various subordinate staff and provision within the project organisation, would have to be made for the following:

(1) general administration, including payment of staff and the keeping of records;

(2) maintenance of equipment, since some would undoubtedly be required except on the simplest of projects;

(3) ordering, receipt and issuing of tools and materials;

(4) maintenance of hand tools;

(5) soils and materials testing facilities, and

(6) camp maintenance and operation, including sanitation, health, water and food supplies, welfare facilities etc.

17. It is clear that the successful management of a large labour force entails a fairly complex organisation. However, the use of a petty contract system can simplify these requirements at the lower levels to some degree, particularly where this procedure has been established by custom and petty contractors are efficient and competitive. Where this cannot be done however, and where natural discipline tends to be deficient, a militaristic or para-militaristic organisation on the lines described may be desirable.

18. The foregoing comments are confined to the organisation required on site. The headquarters organisation, either the Public Works/Highways Department or that of a main contractor, is equally important in providing the necessary support in terms of facilitating supplies and providing assistance when difficulties are encountered. The degree to which authority should be delegated to the site supervisory staff must vary with circumstances but on force account works government regulations often place a severe burden on the site staff and reduce their efficiency. Problems arise since force account work is frequently not investigated nor planned to the same degree of detail as work carried out by contract.

C. TRAINING

19. Where large bodies of unskilled labour are employed, it is normal to restrict the activities carried out by each group. While this reduces the flexibility of labour to some degree, it eases the effort required for, and the cost of, training. The time that can, or has to be, devoted to training is related to the complexity of the operation and volume of work to be carried out. Clearly more effort can be devoted to training, particularly in the semi-skilled operations (such as surface dressing), if there is opportunity for continuity of employment in that operation, since this will reduce the need for and the cost of higher level supervision when the operation is carried out. However, while specialisation in this way promotes productivity and reduces training requirements, it has the disadvantage that work can become dull. Allowing some variety removes this problem and allows the worker to use all his muscles relatively evenly.

20. Many of the basic activities do not require the use of particular skills which are unfamiliar to unskilled labour and such training as may be required can often be provided 'on-the-job' by the overseer through the headman. More formal training may be necessary for the semi-skilled operations and, for example, where unfamiliar types of hand tools are to be used.

21. Apart from the cases instanced above, there is usually little need for the training of headmen who are normally selected for their leadership qualities.

22. Where overseers are not conversant with the methods and procedure in the more specialised activities such as compaction and finishing, mixing concrete, spreading bitumen and the like, formal training sessions are essential to attain adequate standards. The P.W.D. school in Northern Nigeria ran most

successful one-month courses for training road construction and maintenance overseers which included lectures on technical aspects, including reasons for required degrees of quality, demonstrations of the various activities performed by trained gangs, practical carrying out of these activities by the course members with rotation of the leadership function, and demonstration of and instruction in administrative record keeping.

23. Where inspectors of works are promoted from the ranks, little further training is necessary, as the few required are selected largely on the demonstrated basis of their knowledge and ability. Some less developed countries have excellent schools for training inspectors of works.

24. Other staff required would include engineers, engineering assistants, surveyors, clerks and storekeepers. Generally, the construction technique chosen makes little difference to the numbers required and their duties are only slightly affected by the technique. They are normally provided by the local education systems and little additional training is needed. Where adequate numbers of trained engineers are not available, they would have to be obtained from overseas until the local educational institutions could meet the needs.

D. MANAGEMENT

25. The prime object in supervising labour-intensive work must be to keep the performance of labour as close as possible to its capacity. Mention has already been made of the most important factors affecting the productivity of labour. It is essential that management does its utmost to create an environment conducive to high productivity and recognises the activities where this is most important. Particular skill is required on projects where equipment- and labour-intensive methods are mixed since shortfalls in labour productivity, of little significance in themselves, can lead to under-utilisation of expensive equipment with consequent high increases in cost.

26. In the developed countries there is a notable lack of experience of, and training facilities for, organising and managing large bodies of unskilled labour. Certain of the less developed countries, such as China, India and Pakistan, have ample current experience of these problems whereas others are not so fortunate. It will be largely up to the developing countries to develop their own techniques, drawing on past experience elsewhere. The importance of good management cannot be over-emphasised and it may well be necessary to develop special facilities for the training of indigenous engineers.

27. Few engineers in modern societies have any experience of labour-intensive methods. The training of these engineers is orientated towards equipment-intensive methods. Few are

likely to be particularly knowledgeable about the problems of large-scale man-management. Hence, it would seem desirable for engineers involved in labour-intensive techniques to be given some introduction to the problems likely to be encountered.

28. In terms of training and education, the need for additional and improved management training may be the most important implication of a switch to more labour-intensive methods of road construction. The management problems associated with a change of technique might be considerably eased by the use of critical path planning techniques. In addition, the opportunity to study labour-intensive techniques already employed elsewhere would be of considerable value in familiarising management with the problems. Even so, it may be necessary to tolerate less efficient production and perhaps lower quality output for a period following a change of technique and expect part of the educational process to be achieved by the experience of learning by doing.

E. LABOUR CAMPS

29. Where local residents are employed, and the sites remain close to their homes, there is no need for any camps to be provided. Although men have been known to walk up to 20 kilometres each way each day to the sites, this exertion reduces their working efficiency.[1/] It is probably therefore desirable as far as possible to transport the men to and from their own villages in trucks attached to the project as far as roads allow.[2/]

30. In Nigeria as recently as the 1950s it was not found necessary, even in sparsely settled areas, to provide accommodation for those who travelled to the sites from distant places. The contractor or public authority then had to provide no more than a water supply and latrines. These workers should be discouraged as far as possible from bringing families. As living conditions rise, however, or it becomes necessary to attract workers out of cities, it may become necessary to provide camps with reasonable facilities.

31. It is sometimes suggested that camps be soundly constructed for later permanent occupation as villages. This is a policy frequently followed with dam construction where new irrigation areas are to be opened up. A dam, however, is a single site and a reasonably long-term activity, whereas a road, especially in easy agricultural country, can be expected to progress away

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1/ ILO Technical Meeting on Productivity and Employment in Public Works in African Countries, Lagos, 1963.

2/ J. Mueller, "Labour Intensive Methods in Low-Cost Road Construction -- a Case Study," International Labour Review, Geneva, April 1970, p. 359.

from the camp fairly quickly. In some newly opened up areas there may be scope for this, and some well sited camps may be suitable for occupation by maintenance gangs.

32. Of necessity, highway construction workers must be mobile and, in the absence of reasonable alternative facilities, there is little inducement for labour to seek other than casual employment. While this might be acceptable for the unskilled labour element, provision would have to be made for the accommodation of permanent skilled staff in many cases, down to the level of overseers and artisans. There is invariably a need for some camp facilities, if only to accommodate offices, stores, and maintenance facilities.

33. The nature of the camps will vary depending on the intended length of occupation and the size and nature of the project. In some cases, they will consist of primitive shelters, built largely by the labour forces themselves using entirely local materials. On the other hand, a major bridge being constructed over several years or a base camp could justify higher standards for some, if not all, of the buildings. For the more important needs there could be advantage in using specially pre-fabricated buildings which can be taken down and re-erected elsewhere as the work proceeds, or even mobile caravans.

34. Clean and adequate water supplies, at the camp and on the worksites, are very important. Care should be taken to ensure that camps are provided with washing facilities, including those for clothes. Camps and worksites should be provided with latrines, which should be looked after by a responsible person, and properly closed down on the cessation of work.

35. Medical facilities, at least of an elementary nature, would be required in all but the simplest of camps. The concentration of men on a site gives the public health authorities an excellent opportunity to check general health, and measure the effects of work as an aid to generally preserving health in labour-intensive activities. The willingness to care for their health can be expected to have beneficial psychological effect on the men.[1/]

36. The provision of recreational facilities is important, especially as workers are likely to lose interest in traditional forms of entertainment. Such facilities as cinema, sportsfield, canteen, areas set aside for religion, and the organisation of entertainment and adult education can all assist in the maintenance of morale.[2/]

1/ J. Mueller, op. cit.

2/ U.N. Economic Commission for Asia and the Far East, "Earthmoving by Manual Labour and Machines", Bangkok, 1961.

37. Workers recruited locally will continue to provide their own food. Recruits from distant places usually prepare their own food, perhaps jointly hiring a cook, depending on local traditions. Some petty contractors, however, do feed their men, and provide the necessary facilities and cooks, and consider this 'keep' as part of the wage. On the construction of the large dam in Mysore 1/ this was shown to have some advantage. The only worthwhile explanation for 80 to 100% greater productivity from the Malabari workers was that they had a better diet (4500 calories with 130 grams of protein, compared with 2900 calories and 20 grams for the others). Such communal feeding may be very important in building up the general physical condition of previously unemployed persons, especially as 3000 calories per day is needed for heavy physical work.2/

38. Even where contractors or public authorities do not supply food etc. they or the welfare authorities may find it useful to make arrangements for supplies to be transported from local markets, and even to ensure an adequacy of supplies to preserve productivity and to avoid the tendency for local retailers to increase their prices.3/

39. Large camps might require some form of policing, either internally or by arrangement with the local authorities, to enforce the necessary degree of camp discipline and to avoid possible conflict with the local residents of the area.

F. PAYMENT OF LABOUR

40. The wage rates paid need to be no higher than is necessary to obtain the willing services of the workers. As previously discussed, to attract men to work, especially those with no immediate need for additional income, these wage levels need to be higher than local subsistence wages.1/ 2/ 4/ 5/ Over time, this can be expected to draw the normal rate for slack season labouring upwards.5/ This may in turn require adjustment to the wages of the permanent workers in the area. Wages should be increased as productivity rises, to preserve justice between the gangs and such increases must be no faster than productivity increases.

41. Payment of wages on a piecework as opposed to a taskwork basis provides a better incentive to work,2/ 3/ but daily rates avoid the complications of measurement.1/ A compromise used successfully in Nigeria is payment on a gang/task basis. This reduces administration costs (which can be high with labour-intensive techniques) and preserves the incentive to the natural gang unit which may have been hired. The rates need to be fairly set, agreed upon in advance with the headmen, and willingly changed should conditions prove more difficult than expected. Any quality tests needed should be simple and unambiguous.

1/ "Men Who Move Mountains", op. cit.

2/ ILO, Lagos, "Public Works", op. cit.

3/ J. Mueller, op. cit.

4/ S. S. Berry, "Economic Development with Surplus Labour: Further Complications Suggested by Contemporary African Experience", <u>Oxford Economic Papers</u>, July 1970, p. 275.

5/ J. W. Thomas, "Rural Public Works and East Pakistan's Development", Harvard University Center for International Affairs, Economic Development Report No. 112, September 1968.

42. There is no reason why wages should not be paid partly in food. Some developed countries with food surpluses sometimes hesitate to give this food away for fear that less developed countries will become dependent on gifts when it would be 'better' if they found a longer term solution to food shortages. Such countries might therefore be happier if they knew the food was to be used to finance developmental works. The inclusion of food in the wage, especially prepared food served communally has the advantage that workers' diets can be controlled. Further, giving food in return for work removes the charity aspect associated with its distribution in the form of gifts.1/ Many rural dwellers, however, will already have adequate food supplies (although perhaps not 'ideal' diets) and may not be attracted by payment in such form. For them the payment in food may be in the form of diet supplements, whereas for any urban dwellers, the payment can be in the form of very basic food. Where there are problems of transporting, storing, or preserving the food, the additional costs may make it preferable to pay in cash.2/

G. DESIGNING AND PLANNING FOR LABOUR-INTENSIVE MEANS

43. The design of a road may need to be modified to allow for labour-intensive techniques. It may be modified to avoid difficult terrain even if distance is increased, use steeper gradients, adopt local materials such as timber or stone for bridges, or allow for greater thicknesses etc. to compensate for the inability of labour to perform certain tasks to the same high quality. Alternative designs can be evaluated in terms of additional costs and the benefits of additional employment.

44. The scheduling of the construction of a road may also need to be modified. In particular, account must be taken of the times when labour is scarce (for example in the planting and harvesting seasons), or when the weather may make work intolerable or unproductive (eg. very wet or hot periods). Such scheduling may require borrow-pits, for example, to be opened up well in advance of actual construction. The economic evaluation must consider the extent that this method of construction delays completion of the road compared with equipment-intensive means. In this respect, alternative timing strategies should be considered. For instance, in one season it may be possible to clear the route and form the road and in a second season to pave it. In fact, if the road is to or through a newly developing area, traffic can be expected to be very light at first, and improvements can be made as traffic grows. This form of staged construction has been quite common in the developing countries and is well-suited to labour-intensive methods.

1/ A. Ardant, "A Plan for Full Employment in Developing Countries", International Labour Review, Geneva, July 1963, p. 15.
2/ J. W. Thomas, op. cit.

45. Particular care must be taken in scheduling works not to offend local practices connected with religion, food, family, commerce etc. These matters should be known in advance, and taken into account in planning the work and hiring the labourers - eg. if necessary, all of one tribe should be paid off before any of another tribe are engaged, persons subordinate by tradition should not be placed in supervisory positions etc.

46. To some extent the problems involved in recruiting, providing the infra-structure for and training large bodies of unskilled labour can be reduced by matching the build-up rate at the commencement of a project to that of the staff engaged on administering and managing it. This seldom occurs since there is a natural tendency, invariably encouraged at all levels, once a project has been approved to get work started on the ground as quickly as possible. The physical problems can also be reduced to some extent by dividing a project into several smaller contracts or sections, though this often tends to the need for additional administrative effort and possibly to some reduction in control.

H. LONG-TERM PLANNING

47. The cost of mobilising, training and demobilising large groups of labour is not inconsiderable and can be minimised only by ensuring continuity of employment. While some fluctuation in the numbers employed is unavoidable, and indeed desirable, due to seasonal effects, there could be advantage in offering permanent employment to at least the more highly skilled staff.

48. Permanent employment is not generally offered to labourers. Under surplus labour conditions, care should be taken to avoid any thought that there is entitlement to continuity of work. To the extent, however, that petty contractors are able to find work for most of the time, some rural dwellers are almost certain to find moving from site to site, with all its inconveniences, an attractive life, especially if they can thereby earn higher income and the production on the family farm is not affected. Further, petty contractors will be keen to offer permanent employment to the more efficient men. In fact, the canal and railway constructions in Britain in the nineteenth century attracted many men who adopted navvying work for long periods, which absorbed much of the surplus rural labour.

49. Higher-level staff should be offered permanent employment if possible. Good overseers can be transferred from job to job, or if they are unwilling to leave their home districts, placed on the maintenance staff as far as possible. Inspectors of works and technical assistants are, like engineers, usually

permanently employed. Artisans should be offered permanent employment only if they are in short supply, which is often the case.

50. If any programme designed to employ more people in road construction is to succeed, it must be persisted with. Contractors, even petty contractors, will not adjust their methods and organisations if they feel that the inducements offered to them to change their technique are to be short-lived. Further, as more people would be affected by fluctuations in contracts awarded (apart from fluctuations in road work designed to accommodate other activities), it is desirable for works to be planned so that continuity can be offered for the permanent workers. The subsequent contracts need not necessarily be in road work if the contractors are capable of organising other labour-intensive works. The implication, however, is that Public Works should be planned over a longer term than may at present be the case.

51. For the substitution of labour for equipment to be successful, it is essential that the concept be fully supported and actively encouraged at the highest possible levels. It cannot be successful as a short-term expedient and must form part of a general policy, not only in relation to highway construction. It must also be socially acceptable to the people of the country.

I. SOCIAL AND ECONOMIC CONSEQUENCES OF USING MORE LABOUR

52. Generally speaking, the employment of previously surplus labour may require expansion of certain parts of the economy, will result in increased consumption expenditure, and possibly consumption imports, probably slower growth (unless additional highly productive investment can now take place when it could not earlier), reduced imports of equipment, and encouragement to certain types of production. The size of the road construction industry, however, is such that some effects - eg. increased production - may be very minor indeed, at the national level at any rate. Other costs may result from slower completion of the project, or reduced durability of the assets created. (To the extent that the social opportunity cost of capital is high, this may be of little consequence). Further, if market wage rates have, for legal or other reasons, to be paid to the newly employed workers, the higher cost of roads will result in less road work being performed, or reductions in other areas of government activity. To the extent that road standards have been too high, a lower standard of road may merely reflect the high social opportunity cost of capital.

53. At the macro level, the wages paid to the newly employed road workers will in general represent a transfer from those at present employed, and capitalists, both at home and abroad, or if the employment is financed by inflationary means, will take from

the present high income earners. The reduction in the use of equipment could reduce borrowings (although it need not, for investment can still occur in the work of the labourers) and hence returns to capitalists. Areas with large numbers of unemployed will benefit at the expense of areas where people are more fully employed for similar reasons.

54. The organisational adjustment necessary for the employment of more labour has costs of its own until completely in effect; a contractor may therefore perceive for some time costs even higher than the usual market prices.

55. The educational budget should not be noticeably affected by the training requirements of labour-intensive methods of building roads. Most training needed will be on the job, that of overseers will be carried out by the employers, and that of artisans and engineers will in general be unaffected, apart from initially introducing engineers to the problems. In fact, the problem of training sufficient mechanics, fitters etc. to service equipment may be slightly eased by the change to labour-intensive methods.

56. Large groups of itinerant workers, separated from their homes, may be subject to bouts of lawlessness, requiring additional policing. Discipline can be more easily enforced if the workers are housed in properly organised camps. This would also assist in the control of hygiene. To the extent that while at home, these workers are lawful and their hygiene acceptable, there will be additional costs to the government, resulting from their new employment.

57. Although some research has been done into labour-intensive means of road construction, and a certain amount known from the past, there is still a very great need for research into all aspects of the problem. This activity will almost certainly add to government expenditure, but in the social rather than public works section of the budget.

58. There are other less general and less direct economic effects which would enter any perfect calculation of social opportunity costs, but which are very difficult to value in practice. For example, many of the forms of organisation and skills used in labour-intensive road construction should have direct transfer to other areas, such as clearing, cleaning ditches etc. Similarly, urban dwellers will have knowledge of methods which may be useful in construction generally. Certain men will have obtained leadership experience, and all will have gained something in work discipline. Many men, and whole families, will gain from better nutrition and health. Further, the additional rural income may permit improvements to farms and increases in rural productivity and perhaps even in farm employment. To the extent that all effects reduce the population

drift to the cities, they will save the social costs thought to be created by urban overcrowding and unemployment.

59. Labour-intensive methods increase the scope for local entrepreneurs, who can reasonably easily recruit men, even if they could not raise sufficient capital to buy equipment. This has the added benefit that the repatriation of profits overseas is reduced, easing the call on foreign exchange. The general encouragement thus given to local enterprise and management development could have considerable benefits in other sectors of the economy. In Iran, for example, government policy results in almost all road contracts being awarded to Iranians.1/

Expatriate consulting engineers are required to take local partners and trainees as part of the same policy.

60. On the other hand, it has been argued that labour-intensive methods require such a large number of high quality supervisors that other types of activity are hindered. There would seem to be little basis for this contention, for the number of engineers, technical assistants and artisans is little affected by the technique. In fact, the use of large numbers of men, with promotion from among them to ganger, overseer, or inspector of works, would seem to possess the advantage that the location of leadership talent is facilitated.

61. Two less desirable economic consequences could follow unless particular care is taken. First, if the previously unemployed, certain districts, or the community at large, come to feel that productivity does not matter, harm could be done to the growth of the economy. Second, if protected unions are never made to feel the effects of competition, they may become vested interests or sources of corruption. The greater number of contractors likely to exist with labour-intensive methods could lessen this problem, but the tendering system needs to be open and uncorruptible.

62. Most of the social effects of using more labour would be favourably regarded by the residents of less developed countries, on account of the redistributive effects among persons and regions, the reduced dependence on expatriates, and the general improvement in human dignity and happiness as more people are employed. Traditional family life may be disrupted to a degree, but less so than if people drift to cities; in any case, traditional life will have to alter if any growth is to be achieved, and the very act of moving away from home will sometimes act as a spur to innovation and change. If governments employ directives to induce extra employment, certain undesirable social effects could result; such directives are discussed fully in the next chapter.

63. The general social desirability of the results should be reflected at the political level. A failure to provide work

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1/ Economist Intelligence Unit files

is likely to be detrimental to the survival of any government. Promises of more work, and achievement of that goal, would be advantageous. In those countries which are not fully democratic, however, there could be some fear of the results of grouping large numbers of men together, on account of the opposition they can organize. This may in the long run be less of a problem, however, than a revolt of highly dissatisfied unemployed. On the other hand, successful creation of employment may add considerably to the respect which people feel for their governments and institutions,[1/] and the development of decision making can assist political development.[2/] If budgetary problems prevent absorption of large numbers in public works, the politicians may prefer stable underemployment to unstable full employment, as long as a reduction in general underemployment can be observed.

CONCLUSIONS

64. The main conclusions reached in this chapter are summarised below:-

(1) recruiting, organising and managing large labour forces in roadwork are possible, although the adjustments and learning necessary have costs of their own;

(2) knowledge and experience of these techniques is largely confined to such countries as China, India and Pakistan;

(3) the main training effort is required at the overseer level, with unskilled and semi-skilled workers being trained 'on-the-job', but there should be no cost to the educational budget;

(4) the need for additional and improved management training may be the most important implication of a change to more labour-intensive methods;

(5) payment for unskilled and semi-skilled work is best made on a gang/task basis, partly in food if desired;

(6) planning, designing and scheduling of road works should take account of the labour-intensive methods to be adopted;

1/ R. V. Gilbert, "The Works Programme in East Pakistan", International Labour Review, Geneva, March 1964, p. 213.

2/ J. W. Thomas, op. cit.

(7) permanent employment should not be offered to unskilled workers, but planning should be such as will allow a continuity of work; all policies adopted should be persisted with;

(8) it is essential that the concept of labour substitution be actively supported as a general policy at the highest possible levels; it must also be socially acceptable to the people of the country, and

(9) in most developing countries, the social and economic costs of organizing large groups of labour are not felt to outweigh the advantages obtained.

11.2 Finally, it is concluded that the practical problems involved in labour substitution can be overcome and, in general, will not impose major constraints on the possibilities of substitution.

Chapter V

Potential Job Creation in Road Construction

1. In this chapter, an attempt is made to assess the scope for substituting equipment by labour in road construction and to quantify to the extent possible its potential impact on the unemployment problem in less developed countries. Scope or potential of labour substitution here thus means the number of additional labour days required to substitute a given input of equipment. Section A is essentially a theoretical exercise: it is based on the hypothetical road projects presented in Chapter II and presents a method of evaluating a range of labour substitution possibilities and calculating their economic costs. Section B by contrast draws on an important case -- the National Promotion program in Morocco -- to illustrate some of the practical problems and limitations of employment creation in public works. Finally Section C attempts to compare in a general fashion the scope for, and cost of, labor substitution in road construction with that in other industries, while Section D describes the nature and extent of the labour surplus problem in less developed economies.

A. Calculation of the Scope and Economic Costs of Maximum Labour Substitution in the Hypothetical Road Projects.

2. The analysis presented below is based on the SWKP and BCEOM data for one of the nine hypothetical road projects. The data were analyzed in terms of additional labour/days created by adopting successively more labour-intensive techniques in the various construction phases. The increases in cost that would be associated with different inputs of labour and equipment were evaluated. Comparing these costs with those of the optimal technique (at a given price of labour and equipment), it is possible to establish what might be called an "inefficiency cost" for providing additional employment opportunities.

3. The case selected is one kilometre of Road Type A (gravel subbase and base) of intermediate quality, in rolling terrain. The optimal solution, i.e. that combination of equipment and labour inputs producing the road kilometre at least cost on the assumption of a wage of $1/day for unskilled labour was determined from the relevant tables in Chapter II and Appendix A, for each of the four construction groups - Earthworks (E), Gravel Subbase (GSB), Gravel Base (GB) and Surface Dressing (SD) in combination. A further calculation was then made, substituting step-by-step more labour intensive techniques in each activity for which substitution was technically feasible up to the point where the production function has a slope equal to a wage rate of $0.20 per day (which was defined as the practicable limit of substitution). The cost of each step in the successive substitution of more labour intensive methods at a wage for unskilled labor of $1/day then exceeds that of the optimal solution by a calculable amount, which will be the higher, the lower is the breakeven wage rate for the substituted activity and vice versa. Table V-1 below illustrates the results of these calculations from the SWKP data.

Table V-1: Comparative Cost of Optimal and Maximum-Labor Solutions for 1 Km. of Road Type A, Rolling Terrain for Wage = $1/Day Intermediate Quality

Estimates Based on SWKP Data

(U.S. Dollars)

Activity		Optimal Solution Eo	Optimal Solution Lo	Maximum-Labor Solution E2	Maximum-Labor Solution L2	Breakeven Wage W
Earthworks						
E1	Clearing and grubbing	-	281	-	281	+
E2	Stripping topsoil	100	-	-	300	0.33
E3 + 4	Excavating in bulk-soft materials, loading, hauling, unloading, spreading	2,293	960	-	5,845	0.47
E5	Compacting and finishing	68	-	-	281	0.24
E6	Excavating in bulk rock	302	14	-	397	0.79
E7	Excavating ditches in soft materials	-	25	-	25	+
E8	Excavating ditches in rock	-	56	-	56	+
E9	Laying trimming, compacting topsoil	-	51	-	51	+
		2,763	1,387	-	7,236	
	Total Earthworks	4,150		7,236		
Gravel Subbase						
GSB1-2	Excavating, loading, hauling, unloading, spreading gravel	515	277	-	2,093	0.28
GSB3	Loading, hauling, unloading spreading water	47	-	47	-	*
GSB4	Compacting and finishing	-	84	-	84	+
		562	361	47	2,177	
	Total Gravel Subbase	923		2,224		
Gravel Base						
GB1-4	Excavating, loading, hauling, unloading, spreading gravel	630	195	-	2,738	0.25
GB 5	Loading, hauling, unloading, spreading water	33	-	33	-	*
GB 6	Compacting and finishing	-	60	-	60	+
		663	255	33	2,798	
	Total Gravel Base	918		2,831		
Surface Dressing						
SD 1-3	Excavating, loading, hauling, unloading rock in quarry	65	6	-	135	0.50
SD 4	Production of chippings	-	210	-	210	+
SD 5	Loading, hauling, heating, unloading, spreading bitumen	77	114	77	114	*
SD6-8	Loading, hauling, unloading, spreading chippings	116	42	116	42	*
SD 9	Compacting and finishing	-	26	-	26	+
SD 10	Brooming and cleaning surface	-	17	-	17	+
		258	415	193	544	
	Total Surface Dressing	673		737		
Subtotal: Labour/Equipment		4,246	2,418	273	12,755	
TOTAL COST PER KILOMETER		6,664		13,028		

(Excluding engineering supervision, mobilization, housing, administrative, and miscellaneous costs).

\+ Labor intensive technique is optimal.
* No possibility of further substitution.
Eo, E2 Equipment Cost
Lo, L2 Labor Cost (also labor days at $1/day).

$$W = \frac{Eo - E2}{L2 - Lo}$$

Table V-2: Sequential Substitution of More Labor-Intensive for More Equipment-Intensive Methods of Construction - Road Type A, Rolling Terrain, for Wage = $1/Day Intermediate Quality

Estimates Based on SWKP Data

Activity	Optimal Solution Labor/ Days	Optimal Solution Cost in $	Substitution for Activity ($ / Km.) E6	SD 1-3	E 3 + 4	E2	GSB1+2	GB 1-3	Maximum-Labor Solution Cost in $ E5	Maximum-Labor Solution Labor/ Days
Earthworks	1,387	4,150	4,231	→	6,823	7,023	→	→	7,236	7,236
Gravel Subbase	361	923	→	→	→	→	2,224	→	2,224	2,177
Gravel Base	255	918	→	→	→	→	→	2,831	2,831	2,798
Surface Dressing	415	617	→	737	→	→	→	→	737	544
Total Cost	-	6,664	6,745	6,809	9,401	9,601	10,902	12,815	13,028	-
Total Labor Days	2,418	-	2,801	2,930	7,815	8,115	9,931	12,474	12,755	12,755
Additional Cost			81	64	2,592	200	1,301	1,913	213	
Additional Labor/Days			383	129	4,885	300	1,816	2,543	281	
Marginal Cost/Labor Day			0.21	0.50	0.53	0.67	0.72	0.75	0.76	
Average Cost/Labor Day										0.62

4. SWKP: Table V-1 shows that there are seven activities in all, for which substitution is practicable, i.e. for which the breakeven wage is$0.20 or higher. Four of these activities occur in the Earthworks group and one each under Gravel Subbase, Gravel Base and Surface Dressing. If labor intensive techniques were adopted for all seven activities, the cost of the project would increase from $6,664 to $13,029 or by 95 percent, and the number of labor days would increase from 2,418 to 12,755 or by 427.5 percent.

5. Table V-1 further shows considerable differences in the breakeven wage rates for the seven "substitutable" activities, ranging from $0.79 for excavating bulk rock to $0.24 for compacting and finishing. Table V-2 below shows the result of substituting labor sequentially starting with that activity which has the highest breakeven wage rate for 1 Km. of Road Type A, Rolling Terrain, Intermediate Quality based on the SWKP data.

6. The first activity to be substituted is that with the highest breakeven wage rate, E6. This will create 383 additional labor/days at a cost of $81, which is equivalent to a marginal cost of $0.21 per labour/day. By substituting activities GB-1-3 another small increase in labour/days (129) is gained at additional costs of $64; the marginal cost per labour day however goes up sharply to $0.50 per labour/day. It is only with the third substitution (E 3+4) that a substantial increase in labour/days (+4885) is effected and for a relatively small further increase in marginal cost per labour/day: up from $0.50 to $0.53. Total costs per Km. rise to $9,401 an increase of 41 percent over the optimal solution. The difference between the third substitution and the optimal solution ($9,401 - $6,664=) $2,737 is the inefficiency cost for providing (7,815 - 2,418=) 5,397 labour/days of additional employment. This means a marginal cost per additional labour day at this level of $0.51: substitution is indicated if the shadow wage rate is $0.50 per labour/day or less. By carrying the exercise through four more sequential steps, the maximum labour solution is reached. This provides 10,337 additional labour/days for a cost increase of $6,364 or $0.62 per additional labour/day.

7. BCEOM: In Tables V-3 and V-4 below, the exercise is repeated, based on BCEOM figures. The remarks under 6 for Table V-2 apply equally to the interpretation of Tables V-3 and V-4. Since some of the activities are aggregated differently in the French estimates, there are three more substitution steps. The successive substitution of more labour intensive for more equipment intensive solutions results in a cost increase from the optimal to the maximum labour solution of $9,807 or 61 percent, for an increase in labour days from 929 to a total of 20,160 or by a factor of 21.

Table V-3 Comparative Cost of Optimal and Maximum-Labor Solutions for 1 Km. of Road Type A, Rolling Terrain for Wage = $1/Day Intermediate Quality

Estimates Based on BCEOM Data

(U.S. Dollars)

Activity	Optimal Solution Eo		Optimal Solution Lo	Maximum-Labor Solution E2		Maximum-Labor Solution L2	Break Even Wage ω
Earthworks							
E1 Clearing and grubbing	1,140		21	-		1,751	0.66
E2 Stripping topsoil	915		-	-		1,200	0.72
E3 Excavating, loading, hauling, unloading	6,896		-	2,146		10,640	0.45
E4 Spreading	403		-	403		-	*
E5 Compacting and finishing	449		-	-		2,072	0.22
E6 Excavation in bulk rock	312		37	312		37	*
E7 Excavating soft in small quantities	137		2			270	0.51
E8 Excavating rock in small quantities	61		19			149	0.47
E9 Laying, trimming, compacting topsoil	-		469			469	+
	10,313		548	2,861		16,654	
Total Earthworks		10,861			19,465		
Gravel Subbase							
GSB 1 Excavating, loading, hauling, unloading, gravel	2,668		-	1,456		1,341	0.90
GSB2 Spreading	123		9	-		516	0.24
GSB 3 Loading, hauling, unloading, spreading water	53		1	53		1	*
GSB 4 Compacting and finishing	43		25	43		25	*
	2,887		35	1,552		1,883	
Total Gravel Subbase		2,922			3,435		
Gravel Base							
GB 1-2 Excavating and loading	828		-	273		921	0.60
GB 3 Hauling and unloading	422		-	422		-	*
GB 4 Spreading	82		9	-		365	0.23
GB 5 Loading, hauling, unloading, spreading water	37		1	37		1	*
GB 6 Compacting and finishing	40		24	40		24	*
	1,409		34	772		1,311	
Total Gravel Base		1,443			2,083		
Surface Dressing							
SD 1 Production stones	52		270	52		270	*
SD 2 Loading stones	-		6	-		6	+
SD 3 Hauling and unloading stones	17		1	17		1	*
SD 4 Production 10/15 chippings	318		32	318		32	*
SD 5 Bitumen spreading	102		2	102		2	*
SD 6 Loading chippings)							
SD 7 Haul (10 km.) chippings)	117		1	117		1	*
SD 8 Spread chippings)							
SD 9 Compacting and finishing)	7		-	7		-	*
	613		312	613		312	
Total Surface Dressing		925			925		
Subtotal Equipment/Labour	15,222		929	5,798		20,160	
TOTAL COST PER KILOMETRE		16,151			25,958		

(Excluding engineering, supervision, mobilization, housing, administrative, and miscellaneous costs.)

+ Labor intensive technique is optimal.
* No possibility of further substitution.

Eo, E2 Equipment Cost

Lo, L2 Labor Cost (also labor days at $1/day).

$$\omega = \frac{Eo - E2}{L2 - Lo}$$

Table V-4: Sequential Substitution of More Labour Intensive for More Equipment Intensive Methods of Construction - Road Type A, Rolling Terrain, for Wage = $1/Day Intermediate Quality

Estimates based on BCEOM Data

	Optimal Solution		Substitution for Activity ($/Km.)									Maximum Labor Solution	
Activity	Labor Days	Cost in $	GSB-1	E-2	E-1	GB1	E-7	E-8	E-3	GSB-2	GB4	$ E6	Labor/ Days
Earthworks	548	10,861	→	11,212	11,802	→	11,933	12,002	17,892	→	→	19,515	16,654
Gravel Subbase	35	2,922	3,051	→	→	→	→	→	→	3,435	→	3,435	1,883
Gravel Base	34	1,443	→	→	→	1,809	→	→	→	→	2,083	2,083	1,311
Surface Dressing	312	925	→	→	→	→	→	→	→	→	→	965	312
Total Cost	-	16,151	16,280	16,631	17,221	17,587	17,718	17,787	23,677	24,061	24,335	25,958	→
Total Labor/Days	929		2,270	3,536	5,266	6,187	6,455	6,585	17,225	17,732	18,088	20,160	20,160
Additional Cost/$			129	351	590	366	131	69	5,890	384	274	1,623	
Additional Labor/Days			1,341	1,266	1,730	921	268	130	10,640	507	356	2,072	
Marginal Cost/Labor Days			0.10	0.28	0.34	0.40	0.49	0.53	0.55	0.76	0.77	0.78	
Average Cost/Labor Day													0.49

8. Even given the reservations about the figures arrived at for the hypothetical road projects, a brief comment is indicated on the differences between the two sets of figures presented in Tables V1-2 and V3-4. The optimal solution based on the BCEOM data has an unskilled labor content of only 40% that of SWKP while the maximum labor solution arrived at from the BCEOM data provides 63% more man-days than SWKP estimates. These results reflect the impact of the different productivity rates - especially for unskilled labor - which the two engineering consultants derived from their data sources. Some of these are no doubt a reflection of the differences in actual experience between British and French contractors and Public Works Departments, but the differences highlight once again the crucial importance of specific productivity data for any given case: the impact on unemployment will be very different if say, construction of 1 Km. of a certain type of road provides 20,199 or 12,755 days of unskilled employment.

9. In order to examine whether high quality standards would significantly limit the scope for substituting equipment by labor, one final exercise was done, based on SWKP figures, for the case of the High Quality Road, Type A. The results are presented in Table V-5 below. They would seem to indicate that, contrary to current engineering thinking, even with high quality construction standards the possibilities for substitution are in fact only slightly reduced. Earthworks, which provide the bulk of the labor days in the intermediate quality examples, are only affected by high quality strictures in the compacting and finishing activity and still offer wide scope for substitution. For the gravel subbase and the gravel base, substitution is restricted in the spreading as well as the compacting + finishing activities but there is still considerable substitution potential. The table thus shows that the maximum practicable labour substitution even for the high quality road still may provide 12,190 labor/days compared with 12,755 in the intermediate quality alternative. The average cost per additional labour day created is no higher than for the intermediate quality example, i.e., $0.62/labor day.

10. Table V-6 presents the results from equivalent calculations based on BCEOM data. These again show, that high quality standards do not rule out extensive use of labour: there is only one activity - compacting and finishing of earthworks - for which substitution in the high quality case is on a slope of the production function equal to a wage rate of less than $0.20/day. Retaining the equipment intensive technique for this activity results in a total cost of the maximum labour solution per kilometre of high quality road slightly less than that for the intermediate quality road. (See footnote 2, Table II-13 for comment).

Table V-5: Sequential Substitution of More Labour Intensive for More Equipment Intensive Methods of Construction - Road Type A (Rolling Terrain) for Wage = $1/day High Quality

Estimates based on SWKP Data

Activity	Optimal Solution: Labor Days	Optimal Solution: Cost in $	Substitution for Activity ($1 Km.): E6	SD 1-3	E 3 + 4	E2	GSB 1+2	Maximum Labour Solution: Cost in $ GB 1-3	Maximum Labour Solution: Labor Days
Earthworks	1,387	4,219	4,300		6,892	7,092	→	7,092	6,955
Gravel Subbase	235	1,258	→	→	→	→	2,601	2,601	2,093
Gravel Base	166	1,155	→	→	→	→	→	3,194	2,737
Surface Dressing	276	811	→	875	→	→	→	875	405
Total Cost	-	7,443	7,524	7,588	10,180	10,380	11,723	13,726	-
Total Labour/Days	2,064		2,447	2,576	7,461	7,761	9,619	12,190	12,190
Additional Cost/$			81	64	2,592	200	1,343	2,039	
Additional Labor Days		-	383	129	4,885	300	1,858	2,571	-
Marginal Cost/Labour Day			0.21	0.50	0.53	0.67	0.72	0.79	
Average Cost/Labour Day									0.62

Table V-6: Sequential Substitution of More Labour Intensive for More Equipment Intensive Methods of Construction - Road Type A, Rolling Terrain, Wage for Unskilled Labor=$1/day High Quality

Estimates based on BCEOM Data

	Optimal Solution		Substitution for Activity ($/Km.)								Max. Labor Solution	
Activity	Labour Days	Cost in $	GSB-1	E-2	E-1	GB-1	E-7	E-8	E-3	GSB-2	$ GB4	Labour/ Days
Earthworks	548	11,119	→	11,470	12,060	→	12,191	12,260	18,150	→	18,150	14,582
Gravel Subbase	50	3,075	3,204	→	→	→	→	→	→	3,628	3,628	1,979
Gravel Base	20	1,585	→	→	→	1,951	→	→	→	→	2,262	1,355
Surface Dressing	313	968	→	→	→	→	→	→	→	→	968	313
Total Cost	-	16,747	16,876	17,227	17,817	18,183	18,314	18,383	24,273	24,697	25,008	—
Total Labor/Days	931		2,272	3,538	5,268	6,189	6,457	6,587	17,227	17,815	18,229	18,229
Additional Cost/$			129	351	590	366	131	69	5,890	424	311	
Additional Labour/Days			1,341	1,266	1,730	921	268	130	10,640	588	414	
Marginal Cost/Labour Day			0.10	0.28	0.34	0.40	0.49	0.53	0.55	0.72	0.75	
Average Cost/Labour Day												0.52

B. The National Promotion Scheme of Morocco: A Case Study in Employment Creation.

11. The analysis carried out above is one tool with which to assess the theoretical employment creation potential of road construction projects. But given the reservations spelled out in the previous Chapters with regard to the hypothetical road example projects, it is evident that in reality a great number of constraints will be influencing and limiting actual employment creation through public works significantly. In an effort to document some of these constraints, SEDES undertook an analysis of the "National Promotion" program in Morocco, one of the more important attempts made in recent years to absorb unemployment in road construction.

The Moroccan Economy

12. To place the National Promotion program in the context of the Moroccan economy, a brief overview of the economic situation is presented first.

Population and Employment: The present population of Morocco is about 15 million, 11 million of which live in rural areas. Over the 1960-70 period, population has increased at a rate of 3.15%; it is hoped that this rate will go down to 2.7% for the 1970-1980 decade. The active population (= 4.2 million men over age 15) is increasing at a rate of 3.3% annually, as the demographic wave of the fifties reaches active age. In order to maintain present levels of employment, the five-year plan for 1968-1972 cites a figure of 140,000 additional jobs to be created annually. Optimistically, the Plan foresees the creation of just under 100,000 jobs per annum: 55,000 in agriculture, 8,500 in government, but no more than 5,400 for industry, crafts and public works taken together, the remainder to be provided in other fields.

13. Although there are no official statistics on unemployment, a rate of between 18%-20% for the urban areas seems realistic. Rural underemployment is also significant: in 1966, Tiano[1/] cites the following figures for the male and female active population combined:

Urban employment deficit:	500,000	jobs
Rural employment deficit:	465	million man/days

For 1970 it is estimated that, in all, 9,000 new permanent jobs were created. Some of the pressure on the job-market was eased by continued emigration: in the same year, there were 32,800 emigrants, 80% of whom went to France.

The Overall Economic Picture: The level of industrialization in Morocco is quite low and, given the current level of investments, is unlikely to improve much in the near future. In contrast to its neighbours in the Maghreb, the country does not possess any major oil-fields and earns its foreign exchange from three main resources: phosphate, tourism, and citrus fruit.

1/ A. Tiano: "Le Maghreb entre les Mythes", P.U.F., 1967.

In 1967 GDP per capita amounted to $190, with an annual growth rate of about 0.6%. . Income disparties in monetary terms are considerable, although consumption of home production slightly moderates the disproportions between sectors. Industrial wages can be up to 30 times those earned by a labourer in agriculture (about DH500/year)[1/] There are equally large disparities between different social strata. A crucial feature of Moroccan public finance is an imbalance between operating and investment budget. In contrast to most countries, it is the operating rather than the investment budget, which is curtailed during periods of austerity. The result is a deterioration in the value of investments due to lack of upkeep. In the field of Public Works, this leads to a run-down of equipment because of lack of maintenance, with consequently low rates of equipment utilization and high equipment costs.

14. Government policies to promote employment in public works include both fiscal measures and direct action. The first take the form of differential duties on imported equipment: since trucks are now assembled locally, the government imposes duties of 40% on imported trucks and 30% on all other imported equipment. Locally manufactured cars and trucks by contrast only carry a tax of 12%. As these duties must be paid not only by private industry but also by Public Works Departments who buy equipment, it might be assumed that given the budgetary constraints of the latter, these taxes would tend to slow down mechanization in road construction. In practice, however, this does not happen because the investment budgets are almost exclusively financed out of foreign loans. In 1970, for example, Morocco was granted a loan by the IBRD for purchase of road construction equipment (bulldozers, graders and loaders) on which no taxes were levied.

By far the more important effort in the field of employment creation has been the direct action program of National Promotion. Its scope and organization are therefore set out next in more detail.

The National Promotion Program

15. National Promotion is under direct responsibility of the Head of State. Its declared objectives are:

- to provide opportunities of productive and profitable work for the rural underemployed;

- to foster people's involvement in Government sponsored

1/ $1 = Dirham (DH) 5.

development efforts by providing opportunities for participation in the planning and execution of program activities;

- to slow down migration from the land by means of improving conditions of rural life and work in the disadvantaged regions and raising the standard of living of their inhabitants.

National Promotion has been in existence since 1961 and currently provides some 20 million man-days of unskilled labour annually. In accordance with its objectives, National Promotion focuses on technically simple projects with high inputs of unskilled labor and substantial improvement potential for agricultural production (small irrigation projects, arboriculture) as well as in infrastructure (roads, feeder roads, communal buildings) and regional development (clearing land of brush or stones, soil-protection, reforestation).

16. Administratively, there are four project categories, each of which is financed differently.
Part One - A projects are financed from the budgets of the Ministries (e.g., Ministry of Agriculture, or Public Works), or Provincial Governments. Workers employed in this project category are remunerated as follows:

- unskilled labor is paid DH 4/day, DH 2.4 of which are paid in cash by the Technical Service and the remainder in kind (= 4 kg. of wheat) by the National Promotion;

- workers who provide the services of an animal in addition to their own, are paid DH 6/day, DH 2.40 of which is in cash from the Technical Service, the rest in kind from National Promotion (one supplementary ration to feed the animal);

- overseers (of 50 men of less) and time-keepers are paid DH 6/day, DH 4.4 of which are paid in cash by the Technical Service and the remainder in kind by the National Promotion;

- craftsmen and supervisors receive DH 8/day in cash from the Technical Service.

These wage rates are considerably lower than those paid by private firms; they often result in a shortage of supervisory skills in the program.
Part Two B projects are financed exclusively by National Promotion. Remuneration levels are the same as under Part One A. Finally, there are smaller projects of strictly local interest: Part Two-C projects provide payment for unskilled labor in kind only; for Part Two-D projects, equipment and skilled labor are furnished, but there is no remuneration for unskilled labor. Infrastructure projects hardly ever fall under the C and D categories.

All National Promotion projects are ruled by the following constraints:

- non-wage expenditures (e.g., small equipment, transportation) cannot exceed 20 percent of the total project cost;

- all equipment requirements have to be channelled through the central provincial authorities of National Promotion, even if projects are under the direction of one of the technical services such as the Ministry of Public Works. This tends to create delays and inefficiencies.

17. Organizationally the actual work projects are planned at the provincial level. They are discussed and worked out each year between the technical services and the local authorities concerned, and sent to the Central Office of National Promotion for checking and approval. A similar check is carried out by the representatives of USAID which contributes part of the remuneration through its provisions of wheat.

National Promotion work-sites rarely employ more than 300 people - hence problems of housing and administration, as well as the effect on the local economy are not important. Generally, nothing more than tents, and if necessary water, are provided. All workers and foremen are recruited by the local "caid" (North African Magistrate), who also handles all payments to workers regardless of which authority finances the project (e.g. Province, Public Works, Agriculture, etc.). Workers can only be hired on their own village territory and generally are not allowed to work on a site under the authority of another caid. This makes it very hard to develop competence among foremen and workers and results in very low outputs of work: for earthworks this is seldom higher than $1m^3$/day. Also, there is no organization of work on an incentive basis, although it is admitted that this would result in much greater productivity. The Moroccan experience thus would seem to confirm the importance of institutional factors and incentives (see Chapter IV) for actual outputs achievable by labor intensive methods.

18. Limitations and Problems: It has been found, that there are considerable differences in mobilization potential for National Promotion work, both by region and seasonally. The greatest "mobilizable" population is in the Rif: Tetouan provides 32,000 out of a total of an average 200,000 employed by National Promotion. Overall in the country, September and October are the most favorable, May and June the least favorable months for attracting labor. But while the program has been far from negligible in alleviating some of the hardships of rural underemployment, there are two problems it has done little to solve: urban unemployment, and especially the unemployment of the young.

An attempt to tackle the latter problem was in fact made in 1966. The pilot project was the construction of a 50,000 m^3 dam on the "Bou Regreg"; it offered 67,000 workdays in all. But the response was so poor that the follow-up projects foreseen in the Plan were never carried out. The young have shown themselves frankly hostile to projects of this kind - not only because they are little inclined to do manual labor (especially for no pay) but also because they consider these projects dead-end jobs and a palliative rather than a cure to their unemployment problem.

Even in the rural context where National Promotion has been most successful, some serious problems have developed which have led to a stagnation in National Promotion activities in recent years:

(i) One problem has been the delay of payments to the workers, resulting from hold-ups in the passing of the requisite financial legislation, and from complicated transfers of funds from the various authorities concerned to National Promotion and finally to the local caids, delays which are further exacerbated by the lack of qualified accounting personnel at the local level. It is in fact quite common that men will quit the site after having worked for one or two months without being paid. Often they do not claim their wages, or they sell their "work-card" to a local tradesman at a very low price. Thus, while the delegation of responsibility for National Promotion efforts down to the local level may be desirable politically, it nevertheless, by creating a multiplicity of decision centers, results in irrational decisions injurious to the people the program is designed to help.

(ii) The limitation of the wages of skilled workers to DH 8/day when private contractors pay two to three times that amount practically deprives National Promotion of competent skilled labor.

(iii) The constraint that 80 percent of National Promotion funds have to be spent on salaries - laudable in its intention of safeguarding the "human investment" character of the program, has some unanticipated 'secondary' consequences. Of the remaining 20 percent, at least half is spent on transportation; this leaves only a very limited amount to spend on "back-up" equipment. Even where the introduction of mixed methods of construction could significantly improve productivity, their adoption is unlikely, or even impossible, both for financial and for ideological reasons. Some experiments in this direction have, however, been started recently in the Tetouan district. Public works departments there use a bulldozer followed by 30 men - and while it is as yet too early to draw any final conclusion, results seem to be of interest both in terms of cost and employment.

(iv) A coherent policy for National Promotion is very difficult to achieve, because the different Ministries contributing to its funds out of their budgets see it as a vehicle for achieving different and sometimes conflicting goals. For the technical ministries, such as Public Works and Water Resources and Forests, it is a factor of production among others and they want to use it as efficiently as possible: by using mixed methods of construction, or even by raising wages to obtain higher productivity. For the Interior Department by contrast the most important aspect of National Promotion is its contribution to lowering social discontent and preventing social disorder: they want to affect a maximum number of people and productivity considerations are secondary.

But given all the difficulties and limitations of the program, National Promotion is still providing almost 20 million labor/days annually and thus has a solid achievement to its credit. Its importance in road construction is examined in the next section.

19. Achievements of National Promotion in Road Construction: At the inception of the program, infrastructure projects - most of them construction of tertiary roads, - provided the bulk of National Promotion work. But the authorities later decided that the major focus of National Promotion should be on land improvement, and road construction activities now present only some 30% of National Promotion work. Table V-7 below details the development of road construction works carried out by National Promotion from 1961 to 1969 and their relative importance in the overall program.

The table shows that maintenance activities have declined, while the number of days spent on construction of new roads have increased. Regional tables (not reproduced here) show that infrastructure activities are most important in the Rif provinces and in the enclaves in the South. By contrast, the road construction activities in the central regions (Fes, Casablanca, Rabat) are negligible, partly because a dense network of roads exists, but no doubt also due to the fact that the urban unemployed are very hard to attract into National Promotion.

With regard to the total number of days worked in National Promotion, the table shows a stagnation of activity in the last four years. Having shown the extent of road construction presently handled by National Promotion, we must next relate it to the total public works activities in the country.

This will allow us to evaluate the substitution potential between equipment and labor in the Moroccan road construction industry.

20. The Road Budget: Tables V-8 and V-9 below show, for the last three years, the total budget of the Ministry of Public Works and the Communications and the part of it allocated specifically to road expenditures.[1/] Expenditures on roads amounted to 13 to 15% of the budget of the Ministry of Public Works, or 2.2 to 2.7% of the total government budget, and 0.5 to 0.6% of GDP. Road construction is thus not a major part of total economic activity.

1/ BCEOM: "The Moroccan Transportation Plan", Preliminary Report, Paris, February 1971.

Table V-7: Road Construction Activities Within the Framework of National Promotion (1961-69)

(Number of Days Worked and Output)

	1961	1962	1963	1964	1965	1966	1967	1968	1969
Total Number of Days Worked	7,242,500	13,514,000	4,849,000	14,954,000	13,813,000	21,393,000	19,614,000	19,747,000	19,360,500
Of these: Road Construction: Total NDW	7,242,500	7,175,000	1,711,000	4,623,000	4,622,500	7,767,000	7,350,000	5,537,000	6,944,000
Opening of ungraded roads NDW	3,042,000	3,573,000	861,000	2,145,000	3,563,000	5,211,500	4,596,000	3,057,000	4,901,000
Number of linear km.	928	834	410	1,000	1,810	2,957	2,726	1,582	2,650
Road grading NDW	2,730,000	3,602,000	850,000	2,464,000	786,000	2,322,000	2,714,000	2,463,000	1,339,000
Number of linear km.	16,277	2,504	820	3,184	2,306	2,538	4,875	2,906	2,634
Supply of materials NDW	978,000			14,000	175,000	77,500			94,000
m^3				44,575	13,291	24,040			56,900
Civil engineering structures NDW	492,500				46,000	39,000		5,600	342,000
Units					46	252		1	1,026
Construction of bridges NDW					14,000	54,000		11,000	238,000
Units								7	21

Table V-8: Total Budget of the Ministry of Public Works and Communication

(DH 000)

	1968	1969	1970
PART ONE: Operating Budget			
Maintenance, heavy repairs	41,275	41,276	41,968
Other operating budget	78,551	78,079	79,368
Subtotal	119,826	119,555	121,336
PART TWO: Investments	361,050	430,200	446,155
Total	480,876	549,755	567,491

Table V-9: The Road Budget

(DH 000)	1968	1969	1970
PART ONE Fund Allocations to Roads			
Maintenance, rebuilding and new pavements (Primary and secondary roads)	30,000	30,000	36,800
Subsidies to Provinces for maintenance of tertiary roads	6,500	6,500	-
Maintenance of Tourist Itineraries	300	300	300
Subtotal	36,800	36,800	37,100
PART TWO Fund Allocations to Roads (Five Year Plan)			
Completion of 3-year plan	5,000		
New works - Government	2,500	3,800	6,060
IBRD projects			0,500
Heavy repairs - Government	4,000	14,600	4,186
IBRD projects			7,474
Transport study			2,000
Acquisition of equipment			8,000
Tourist itineraries	3,725	2,500	2,400
Tertiary roads - general network	5,850	6,560	10,500
Beetroot projects	4,000	20,500	9,000
Specific project (Loukhos, Derro)	2,500		0,200
Mine roads (Three-year Plan completion)	0,238		
Subtotal	27,813	47,960	50,320
TOTAL BUDGET ALLOCATIONS to Roads	64,613	84,760	87,420

To these funds are added pro-rata allocations from a general budget fund for Personnel, Equipment and miscellaneous expenditures, which increased the figures for the overall road budget in the years considered to:

1968 = DH 77 million

1969 = DH 99 million

1970 = DH 101 million

No separate figures on employment in road construction are available, but estimates1/ put employment in the total sector of "Construction and Public Works" at 77,000 in 1968 and 82,000 in 1970, which amounts to 1.60% and 1.65% of total employment in these years. This is roughly the same number of jobs as were provided by National Promotion: assuming 250 mandays of work per year, it offered the equivalent of 80,000 full time jobs, with just under one third of these in road construction (see Table V-7).

These figures would seem to suggest that any contribution to employment creation through manualization of road construction activities can at best only be a very limited one. This impression is further confirmed when we look at the present organization of the road construction industry.

The Road Construction Industry

21. Unlike that in many other countries, the Moroccan road construction industry still uses labor intensive methods relatively extensively. Besides National Promotion, whose activities are restricted to very simple works on tertiary roads, Public Works Departments use Force Account labour for maintenance work. Wages for Force Account labor are about one-third of those paid by private firms: about DH 500/month for a foreman with 15-20 years experience; DH 6/day for a truck or grader operator. Then there are also quite a number of private contractors, who use labour almost exclusively. Some of them have annual turnovers of more than DH 1 million. Most of the unskilled labor is recruited locally, while supervisors, technicians and specialists are permanent personnel. Wages vary from DH5/day for unskilled labor to DH20/day depending on the work site, with the company providing equipment for camps and water, if necessary. Highly mechanized private contractors, of which there are some ten with an estimated annual turnover of

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1/ IBRD: "Current Economic Position and Prospects of Morocco", EMA-42, September 1971.

DH 20 million for new construction, are thus still only a minor component of the road construction industry. They do however carry out all works on primary roads. Even in the construction of secondary and tertiary roads the choice of technique for the various construction activities seems to be influenced most by financial considerations:

Earthworks, offering by far the greatest scope for labor substitution according to the engineering analyses (see Chapter II) are no longer carried out by manual labor on secondary road projects, probably because figures (from Public Works in Tetouan province) show the following variations in cost by type of contractor:

Private firm using labor:	DH $5.20/m^3$
National Promotion: (with its lower salary levels)	DH $4.76/m^3$
Mechanized private firm:	DH $3.40/m^3$

Structures and drainage ditches etc. for secondary roads are however quite commonly built by labor and Public Works Department engineers report that the quality of work varies from excellent with some firms to mediocre with others.

Additional Employment Potential in Road Construction

22. In a final exercise, it has been attempted to assess how many jobs could be created assuming that deliberate policies towards this end - which would of course need to be translated into budgetary allocations - were put into effect. Clearly, the National Promotion effort has not as yet realized its maximum potential: it is estimated that at least 60-70 million work days/year would be required to cure rural underemployment. In the field of road construction activity specifically, there would seem to be enough developments projects to be carried out to provide employment for the next ten years. With intensive technical training efforts at all levels and a streamlining of decision-procedures, it would seem realistic to assume that infrastructure activities could reach double the present level in about seven years time. This would mean the creation of 28,000 new jobs (corresponding to about 7 million man-days) in all, or 4,000 new jobs annually. This development would be greatly facilitated if - as has been foreseen in the Plan - private contractors who have experience in working with unskilled labor were employed for organizing and supervising National Promotion Workers. Continuing and extending the practice of using local tradesmen for various complementary functions in connection with road construction (e.g., supply of material, simple structures, etc.) would be an additional employment-creating factor.

23. If, however, we finally, relate the employment creation potential of the road construction sector - 4,000 new jobs annually - to the number of jobs needed to maintain even the present level of employment - 140,000 new jobs annually - it must be concluded that manualization of road construction activities, while a useful element in a necessary and worthwhile effort to alleviate the acute problems of under- and unemployment, is no panacea for their solution. Its most serious limitation results from the fact that its potential is least where the problems are greatest: in the areas of urban unemployment and unemployment of the young.

C. Comparative Evaluation of the Scope for Labor Substitution in Road Construction and other Industries.

24. The Morocco case seemed to point up two conclusions:

(i) The employment potential for unskilled labor in road construction, while by no means negligible, is of limited impact: at best, it offers less than 3% of the additional jobs needed to maintain present levels of employment.

(ii) The employment potential for unskilled labour in road construction is, however, considerable compared to that in other industries;

It was next attempted to assess whether the Morocco case is exceptional, or whether it can be considered as fairly typical for other less developed countries as well.

25. When available statistical sources were examined to determine what proportion of GDP and government expenditures in less developed countries typically are spent on roads, it was found that, generally, figures are available only for 'transport and communications' or 'public works' as a whole. Also, figures include current (viz. administration and maintenance) as well as capital expenditures. The limited data available show that, typically, expenditures on 'transport and communications' account for 10-20 percent of the total government budget or some 2 percent of GDP. For India (1968) and Pakistan (1969), figures of 1% and 0.55% of GDP respectively are quoted for road expenditures.[1/] The same source gives breakdowns of expenditures between new construction and maintenance for a few selected countries. These figures would indicate a pattern of road expenditures that shows considerable variation over time, with spending on maintenance only slightly more stable than that on new construction. Expenditures on roads then do not constitute a very large part of the total economic activity in less developed countries. Continued scope for improving networks can be expected where rural output is increasing. It is unlikely, however, given the

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1/ International Road Federation: "World Road Statistics, 1965-1969," Geneva, 1970.

many pressures on the scarce available resources of governments in these countries - that a much greater proportion of their budgets will (or should) be allocated for road works.

26. While figures for expenditures specifically on roads are difficult to find, there is even less information on the kilometrage (by type) of roads built with the funds allocated, and almost no data on the employment generated by road construction, or even by public works generally. In Morocco, it has been estimated that one kilometer of road provided 20,000 - 30,000 man-days of labor 1/. In Tunisia, 8,700 kms. of road constructed by predominantly equipment intensive methods required 8,615,000 man-days of labor, i.e. just under 1,000 labor days per km. constructed 2/. With variations as large as these, calculations, on the basis of 'average cost' per km of road, of investment costs per permanent job created in road construction as compared with that in other industries (for which available data are almost equally weak), was therefore not considered meaningful at this stage.

27. A second approach to relate the employment potential in road construction with that in other industries was to compare the number of persons employed per year per unit of output. Table V-10 below shows some figures on this for selected countries and industries. It can be seen from Table V-10 that figures for the same industry vary significantly between countries. The figures for India are consistently high, reflecting more labor intensive methods of industrial production. Some of the differences can be attributed to different definition of industrial activities which make the data not strictly comparable, but roughly it can be concluded, that the different industrial activities provide between 50 and 250 permanent jobs per million dollars of output. If, in a grossly simplifying approximation we assumed that the cost for the hypothetical kilometre of road in say, Table V-3 would be of the order of $50,000 if all additional expenses such as overheads, mobilization costs, etc. were added, there would then be:

$$\frac{968 \text{ (labor days)}}{210 \text{ (labor days/yr)}} = 4\text{-}5$$

annual jobs, or 100-125 annual jobs per million dollars of output for the optimal solution at a wage of $1/day. The equivalent for the maximum labor solution on the other hand would be:

$$\frac{20.160 \text{ (labor days)}}{210 \text{ (labor days/yr)}} = 96$$

annual jobs, and assuming an increase in cost of 60% for the labor intensive method, between 1,200 and 1,400 annual jobs would be associated with one million dollars of output. Thus, the equipment intensive methods of construction are clearly within the range shown for other industrial activities, whereas the labor intensive solution gives a substantially higher figure.

1/ International Labour Office: "Technical Meeting on Productivity and Employment in Public Works in African Countries", Lagos, 1963.

2/ G. Ardant: "A Plan for Full Employment in Developing Countries", International Labour Review, July 1963.

Table V-10: Number of Persons Employed Per Annum For One Million Dollars of Output

	India (1)	Morocco (2)	States of Africa and Madagascar (3)
Milk products	...	120	50
Wheat flour	73	40	...
Breweries and soft drinks	...	150	...
Vegetable oils	32	30	170
Woolen yarn	283	130	...
Cotton yarn	577	150	115 (4)
Paper	312	80	36
Tires and tubes	90	...	70
Fertilizers	138	100	32 24 (4)
Soap	68	...	30
Glass	...	100	100
Cement	198	130	129 (4)
Metal products	271	160	130

Sources:

(1) Profiles of manufacturing establishments - United Nations - 1967.

(2) Technical coefficients - DCEP - Rabat - August, 1962.

(3) Possibilities of industrialization in the States of Africa and Madagascar: in association CEE - SEDES - 1966.

(4) Various reports by SEDES on industry in the Ivory Coast, Laos and Cameroon.

28. Quite apart from the very approximate character of the figures used in this calculation, there is another important proviso to be made. To draw any valid conclusions, the technically feasible substitution of labor for equipment would have to be examined for these other industries as well; the inefficiency costs of manualization of techniques would have to be established and compared with those for road construction to assess the comparative advantage or disadvantage of implementing labor intensive techniques of production. While this is clearly beyond the scope of this report, it is however worth pointing out that such calculations should be attempted: if the cost of equipment-intensive techniques versus optimal techniques are evaluated quite routinely, we should also look at the relative cost of labor intensive techniques compared with optimal techniques in an effort to assess the cost of creating employment in less developed countries with a high surplus of unskilled labor.

D. The Labor Surplus Problem in Less Developed Countries

29. In the less developed economies, a labour surplus may manifest itself in several ways. There is unemployment narrowly defined: this is usually taken to include only those out of work but actively seeking it at going wage rates, and able to work as efficiently as those already occupied. If chances of obtaining work are small however, as is often true in less developed countries, people may be discouraged from actively seeking it. Thus it is useful to extend the definition of unemployment to those who would seek work if the chances of obtaining it were higher. Even in this expanded sense, unemployment includes only those without work. Since for most people in less developed countries, being without work for any length of time means being without income, it is a disaster which somehow has to be avoided. Unemployment in the conventional sense is therefore often confined to particular groups for whom the immediate need to earn enough for subsistence is in some way less pressing - for example, young people and married women who are able to rely on others for support. This means that differences in the dimension of the employment problem from one country to another are to a very limited extent, if at all, picked up as differences in measured unemployment rates. For example, it would be absurd to suggest that, because rates of unemployment in India are as low as three or four percent, while they are around twelve percent in Puerto Rico, labour is more fully utilized in India than it is in Puerto Rico. This does not mean that conventional unemployment is unimportant in less developed countries: rates of between eight and fifteen percent unemployment are not atypical for the cities. But it does mean that unemployment and the circumstances in which it arises needs special and to some extent separate treatment from the general problem of underutilized labour.

30. For the great bulk of the people in less developed countries, the employment problem shows up as one of underemployment, i.e. employment potential which is not fully utilized. Underemployment occurs in two different ways. The first occurs where the work available is spread thinly over those available, so that the withdrawal of marginal workers would not cause output to fall. It is found in the agricultural sector, where the farm is the traditional work place of the whole family. In the urban areas, petty

retailing at stalls and casual labouring work both involve much waiting between tasks; even large employers may, by custom, retain staff who are truly redundant. The second is the case of employees whose efficiency while working is quite high, but who cannot find sufficient hours or days of that work, although they do perform some. This type of underemployment is often associated with irregular availability of work (harvesting, crop processing and transport, tourist seasons, etc.) where workers are fully employed by any definition during a peak season, but at other times cannot find any work at all. This seasonality aspect of the problem is particularly important for consideration of the possibility of substituting labour for equipment in road construction, since road construction is often quite seasonal itself, depending primarily on the level, intensity, and duration of rainy seasons. If the peak of the agricultural season coincides with a limited construction season there may be small scope for substitution in road construction.

31. Worthwhile information on the extent of the labour problem is very scarce. The problems of measuring a labour surplus are discussed fully in Turnham 1/, but it can be noted here that the traditions in some less developed countries of women and children working at busy times, the extended family in the traditional sector sharing the work available among all those who join it, and the large proportion of the work force who consider themselves as self-employed on a jobbing basis, make the problem even more difficult in these countries than in the developed countries. To avoid misleading conclusions, statistics need to be classified by occupational category, for not all categories are in surplus, and they must also give details of seasonality. Somewhat paradoxically, while underemployment is probably most significant in less developed countries taken together, and certainly so in most of the poorest countries of Africa and Asia, it is for unemployment that we have the most reliable information since this is comparatively speaking less difficult to measure. Table V-11 provides estimates of unemployment in rural and urban areas for various countries.

32. Finally, drawing on this and other information, the following points concerning unemployment can be made with reasonable confidence:

a) Unemployment would appear to be rising; even where the data indicate a reasonably constant rate, this involves a rapidly rising number, especially in urban areas. Up to 20% of urban work forces may be unemployed, and in most cities examined, the proportion falls in the range 11 to 17%.

1/ D. Turnham: "The Employment Problem in Less Developed Countries", OECD, Paris, 1971.

Table V-11: Urban and Rural Rates of Unemployment[1/]

(Percent of Labour Force)

		Urban Rate	Rural Rate	Notes
Africa:				
Cameroons	1964 Males	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
China (Taiwan)	1968	3.5	1.4	Survey
Korea	1965	12.7	3.1	Survey
India[a]	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
West Malaysia	1967	11.6	7.4	Survey
America:				
Argentine (Buenos Aires)	1966	5.6 (overall)		
Chile	1968	6.1	2.0	Survey
Honduras	1961	13.9	3.4	Census
Jamaica	1960	19.0[b]	12.4[c]	Census
Panama	1960	15.5	3.6	Census
	1967	9.3	2.8	Survey
Uruguay	1963	10.9	2.3	Census
Venezuela	1961	17.5	4.3	Census
Colombia (Bogota)	1968	6.5	3.1	Survey
	1963	8.7[d]		
	1960	11.6[d]		

a. The unemployed "available" but "not seeking" work are included in rural areas but not in urban areas. Deducting this group might reduce the rural percentage rate by about one third. The urban figure relates to the age group 15-60.

b. Kingston.

c. All Jamaica less Kingston.

d. Bogota.

1/ D. Turnham: op. cit, Tables III.1 and III.7.

b) Open unemployment in rural areas is generally much less, however. To some extent this may reflect that the rural labour surplus migrates to the city, but more generally the rural surplus may be underemployed rather than unemployed.

c) Young, inexperienced persons and those with middle levels of education are represented among the unemployed in greater proportion than in the work force as a whole. Many of these are apparently unemployed for long periods: it would seem that those with jobs cling to them, and that the educated young take care and time in selecting jobs, preferring to remain unemployed rather than accepting unskilled jobs which may be available but offer lower wages and less prestige.

33. Despite the difficulties, there have been some attempts to measure the extent of underemployment. One of the most comprehensive surveys appears to be that undertaken in Thailand in 1967-68. This suggested that 26 percent of the rural labour force and 5 percent of the urban labour force worked less than 30 hours per week.1/ Table V-12 presents other statistics assembled by Oshima 2/ for selected Asian countries. Where shortfalls in hours worked are expressed in terms of equivalent full-time unemployment, we see that underemployment is estimated to have accounted for two-thirds of the Philippines employment problem and one-third or more in Ceylon, India, Malaya, and South Korea in various years.

Table V-12: Estimates of Open and Full-Time Equivalent Unemployment as Percent of Labor Force, Selected Asian Countries

	Year	Open Unemployment	Underemployment in Equivalent Full-Time Unemployment	Total Equivalent Full-Time Unempl.
India	1965	6%	3%	9%
Ceylon	1960	10%	6%	16%
Pakistan	1964/65	n.a.	-	20%
Singapore	1966	9%	1%	10%
Malaya	1962	6%	3%	9%
Philippines	1957/65	4%	8%	12%
Thailand	1963 (urban)	4%	4%	8%
S. Korea	1967	6%	3%	9%
Taiwan	1963/66	1%	4%	5%
Hongkong		2%	-	n.a.

1/ Thailand, National Statistical Office: "Report of Labour Force Survey, 1967-1968", Bangkok, 1969.

2/ H. T. Oshima: "Labour Force 'Explosion' and the Labor Intensive Sector in Asian Growth," University of Hawaii, April 1969 (mimeo).

34. But shortfalls in hours worked are only one indicator and it may be that the previously mentioned disguised unemployment is the major form of underutilization. For this dimension of the problem, productivity or income measurement seems required. But here again only very general indicators - whole economy income distributions or sectoral averages of productivity - are usually to be found. In any event, as there is no standard or widely accepted method of dealing with the measurement of disguised unemployment, knowledge of underemployment is, in quantitative terms, grossly incomplete. But even the most limited field experience is sufficient to convince most people of the size of the problem; for most policy purposes, including those under discussion here, whether twenty or forty per cent of the labour force is underutilized is perhaps not an issue of overriding consequence.

35. Probably the basic problem has been and continues to be the very rapid growth of population and therefore of labour force. Some statistics about this are shown in Table V-13. On this score the forward estimates to 1980 provide no reassurance about the future: job creation will remain a major problem for many developing countries for the foreseeable future. Indeed, the projections (which are reasonably reliable since people entering the labour force over this period are already born) indicate a worsening situation as labour force growth continues to accelerate.

36. Finally, the problem is being exacerbated by heavy migration to the urban areas. Reasons for this are many and varied. The modern sector industries are located in the towns: they pay relatively high wages to the scarce skilled labour and even the unskilled tend to be paid well above rural subsistence wages. Improvements in communications have caused a rapid spread of knowledge about the higher wages and better amenities available in the towns. Further, the rapid spread of education in rural areas has raised the aspirations of many people, leading to their dissatisfaction with rural conditions, and adding to their desire to migrate to towns, where previous savings or support from the extended family enables them to wait in pools of unemployment until work fitting their aspirations or expectations becomes available. The modern industrial sector, however, tends to be equipment intensive and creates few jobs. Furthermore, mechanization of traditional crafts displaces workers in those fields. Hence, in most of the less developed countries there will be in the next decades a growing surplus of labor, a modern sector incapable of using it, and a traditional sector with diminishing possibilities to use it.

Table V-13: Estimates of Growth of the Labour Force in Less Developed Countries

(Lines (1) in millions; Lines (2) Decennial Rate of Increase in Percentage)

Major Areas		1950	1960	1970	1980
East Asia[a]	1.	339.3	378.5	436.0	508.6
	2.	-	11.6	15.2	16.7
South Asia	1.	302.0	349.1	419.8	520.1
	2.	-	15.6	20.3	23.9
India[b]	1.	-	162.2	203.4	263.2
	2.	-	-	25.4	29.4
Europe[c]	1.	270.8	302.1	327.2	356.9
	2.	-	11.6	8.3	9.1
Africa	1.	98.5	112.1	136.3	168.4
	2.	-	13.8	21.6	23.6
North America	1.	65.7	77.0	90.6	107.6
	2.	-	17.2	17.7	18.8
Latin America	1.	56.5	71.3	92.2	121.6
	2.	-	26.2	29.3	31.9
Oceania[d]	1.	4.9	5.9	7.2	8.3
	2.	-	20.4	22.0	15.3

a. Including Japan.

b. The figures for India are for 1961, 1971, and 1981, respectively.

c. Including the USSR.

d. Excludes Polynesia and Micronesia.

Sources: India: K. N. Raj, "Prospects for Employment Opportunities in the 1970's," University of Cambridge Studies Committee Conference, 1970 (mimeo).
All other countries: Ypsilantis as quoted by Turnham, op. cit.

37. Conclusions: Given the lack of reliable data both on specific road construction expenditures and on employment in road construction, conclusions on employment potential offered by manualization of techniques must necessarily be highly tentative. The above analyses would seem to indicate that:

(i) the adoption of technically practicable labour intensive methods of road construction will significantly increase employment in this sector.

(ii) However, the increase in employment possible by manualization of road construction techniques will not significantly lower unemployment in countries with a high surplus of unskilled labor.

(iii) Employment provided in road construction is better suited to alleviate rural underemployment than urban unemployment.

(iv) Institutional and organizational factors influence productivity of unskilled labor in road construction significantly.

(v) The data currently available do not permit the comparative evaluation of the employment potential in road construction and in other industries.

Chapter VI

Recommendations for Further Work

1. The aim of the Phase II field studies is primarily to collect reliable productivity data which can be used to prepare production functions for the basic construction activities. It is recommended that research be carried out in the following fields:

(1) the productivity of labour and equipment and the effect on productivity of environment;

(2) the costs of employing labour;

(3) the costs of owning and operating equipment;

(4) mobilisation, supervision and other fixed costs incurred in road construction and their relation to labour-intensive and equipment-intensive techniques;

(5) the development of a model to simulate the highway construction process which will be capable of analysing the relevant data. (This work will be done by IBRD staff.)

2. In view of the widespread effects of environment on productivity and the differences in costs and practices between countries, and to obtain maximum benefit from the Stage II studies, it is recommended that the research should be restricted to one or two countries. In formulating proposals for the collection of productivity data, it is felt that it would be wise to concentrate on those countries where the need for, and acceptability of, the concept of labour substitution is greatest. Another major consideration is the opportunity to observe ongoing labour intensive operations, which are not present in many countries. It is therefore proposed that a considerable proportion of the data collection effort shoulc take place in India. It is a large country with a wide range of environmental conditions and there should be little difficulty in adequately covering the labour-intensive range of construction activities. To widen the scope of the study, field work in Indonesia is also suggested, mainly in the island of Java. The Bank's involvement in this country should facilitate the collection of data, though it seems that it may be some time before major construction projects are undertaken. It is recommended that the active support of the government of India and Indonesia be sought to facilitate the operation of the staff engaged in data collection.

3. It is recommended that the following methods of data collection should be used:

(1) direct observation on current projects (not necessarily restricted to road construction work) supplemented by an analysis of project records;

(2) interviews with PWD and other supervisory staff, including those engaged on maintenance;

(3) interviews with contractors and other organisations concerned with road construction (e.g., materials suppliers, equipment suppliers, army schools of engineering, road research laboratories, local consulting engineers, etc.);

Further thought should be given to the possibility of collecting additional data by a postal questionnaire system, supplemented by visits from the field staff. In order to carry out fully the observations needed we recommend that the engineer in charge be aided by a local engineer and three assistants.

4. The local engineer will be in charge of relations with the contractors and the administration, (i.e. he will find the sort of projects likely to present an interest for the study and the people whom it would be interesting to interview and carry out project record studies, especially in the case where a knowledge of the local language was needed), and he will supervise and participate in the site observations. The assistants (as well as the engineers) will observe the progression of the construction work to record the work rates and to list the methods used, (i.e. number of labourers, tools, mechanical plant, etc.) and to describe the climatic and environmental conditions.

5. To carry out correctly the studies described above, the study team will have to stay for a fairly long time on each site. We do not think that it will be possible to analyze more than three sites per month in this detail. To broaden the data, this in-depth analysis will be followed by brief observations on a large number of sites. This analysis will be done after the in-depth studies and will be concentrated on certain activities which have been judged to be especially important. Certainly a major effort will be made to determine productivity rates and labour/equipment costs in earthmoving operations.

6. To assess the quality of the work carried out by the various teams, laboratory tests must be carried out. If the administration responsible for execution of the project has allowed for quality verification testing, the role of the study team will be limited to assuring that the tests are correctly carried out and to analyzing the results. However, if the administration has not allowed for this testing, the study team must do it. Problems could arise in this case between the contractor and the study team. It would therefore be better if these observations were done on a site where the administration already has close quality control of the work. If it does not prove possible to find a controlled site, a control must be organized and executed by the administration, with the aid of the study team.

The main tests to be done are:

- In situ water content
- Proctor test
- In situ dry density
- Identification tests (sieve analysis, Atterberg tests)
- Aggregate grading.

Considering that the study team will not stay a very long time on any one construction site, and that the administration may not have the necessary testing equipment on the site, we recommend that the engineer bring with him a densitometer (membrane type) and equipment for water content measurement. This equipment could be left with the local administration when the team leaves.

Suggested Procedures

7. We would suggest that the implementation of the above recommendations be carried out in four phases, viz.:

Phase I : A short pre-planning period for consultations with the Bank and the finalisation of data collection procedures.

Phase II : A planning period in India and Indonesia to consult with the appropriate Government officials, to devise programmes and itineraries, and to set up the field teams.

Phase III : Data collection in India and Indonesia and the processing of the data.

Phase IV : Analysis of the data and the writing of the report.

8. The main work to be undertaken in Phase I would be to determine the form and extent to which data is to be collected and recorded. It would be necessary to ensure that:

(1) data are adequate and time is not wasted in recording and processing unwanted information;

(2) all members of the field staff follow identical procedures, particularly where qualitative assessments are involved.

Close consultation will be necessary with those responsible for the development of the computerised model before the first aspect can be finalised. The second aspect will entail thorough briefing of (and subsequent close liaison with and between) the field teams.

9. Some advance thought has been given to the use of standard data collection forms for the recording of environmental and productivity data. The former would need to record not only the physical factors which can be quantified (e.g., temperature, rainfall) but also data pertaining to most (if not all) of the factors listed in Chapter III. Many of these factors (such as nutritional standards, social attitudes, etc.) would have to be assessed qualitatively in the field by reference to a rating system which would need to be carefully defined.

10. For the recording of productivity data, a different data collection form would probably be needed for each of the activity groups. The list of basic construction activities would be elaborated and further disaggregated in the light of the experience gained during the analyses of the hypothetical road projects. The latter suggested the following six-field categorisation of activities:

(1) activity group;
(2) sub-activity;

The above correspond to the list of basic construction activities.

(3) the location of the activity within the work where this might have some effect on productivity (e.g., rock excavation in earthworks and in quarries);
(4) the type and size of equipment used in the activity;
(5) the type and size of equipment associated with the activity (e.g., the haulage vehicle);
(6) the level of quality.

11. The standard forms would be devised to cover all possible circumstances and activities (and groups of interdependent activities) and to permit the direct coding of the recorded data. A period of about one month would be required for this pre-planning phase.

12. Time and the lack of recent detailed knowledge of the two countries has not permitted the preparation of detailed programmes and itineraries for the fieldwork. It is therefore proposed that a senior engineer fully conversant with the study should visit India/Indonesia accompanied by Bank officials and the leaders of the field teams. They would consult jointly with the appropriate government officials whose advice and assistance would be sought before arrangements for the field work could be finalised. A period of about three weeks would be needed to complete these arrangements and to establish the teams in the field.

13. In Phase III there would be one field team in India and another in Indonesia. Each team would consist of a fairly senior experienced engineer accompanied by a locally recruited junior assistant engineer, together with counterpart personnel. To minimise costs, it is suggested that the teams should travel between main centres by air (or other public transport), relying on the government for official transport locally. Much travel would be involved since it is envisaged that the majority of projects (particularly the labour-intensive ones) would be small and it should be possible to cover such projects in some 2-3 days. Longer stays, possibly up to 2-3 weeks, would be required for large projects, particularly since these would offer greater possibilities for research into all aspects of the study.

14. The field teams would submit detailed reports on their progress at regular intervals, together with completed data sheets. The latter would be coded, transferred to punched cards, edited and processed into a form suitable for subsequent use. The data would be analysed from time to time so that guidance could be given to the field staff on the areas in which they should concentrate their efforts and to correct any inadequacies in collecting procedures, etc.

15. Concurrently with the fieldwork, it is suggested that there would be scope for extending the searches of recorded data, particularly those pertaining to India and Indonesia. Any such data would be recorded in a format identical to that collected by the field teams.

16. Phase III of the study would probably extend over a period not exceeding six months. It is emphasized that during this time it would not be possible to cover the full range of construction activities in all environments but a reasonably representative sample of the most significant activities should be achieved provided that the active support of the appropriate government departments is obtained.

17. The analysis of the data and the writing of the report, Phase IV, would take about two months. Allowing for consideration of draft reports and including a reasonable margin for contingencies, the time required for the whole of the Stage II studies should not exceed 12 months. The report would include proposals for any subsequent studies which might appear to be necessary.

Bibliography

BIBLIOGRAPHY - ENGINEERING

B.C.E.O.M.

1 - " Methodes manuelles et methodes mecanisees pour la construction et l'entretien des routes."
(a report of the Low Cost Road Committee to the Road Congress of Tokyo, 1967).

A general statement about the problem of substitution of labour for equipment which contains many interesting ideas but does not give any quantification.

2 - " Men who Move Mountains."
an ILO report - 1963

An in depth study of manual earthworks. This report gives large quantities of productivity data and a very interesting comparison between several ways of hauling, (wheelbarrow, tipping trucks pushed by hand, head basket).

3 - " Price analysis of earthworks and structures on the Poitiers crossing of Tours-Bordeaux railway."

An analysis made in 1850, which gives many productivity data related to labour intensive earthworks, masonry and wooden framework. These productivity data have not been directly used in our report, because the training, the tradition and incentives of French labourers of the middle of the 19th century led, in our opinion, to higher output than those which can be obtained from unemployed people used as labourers in the second half of the 20th century.

4 - " Madagascar 1930."

An estimating handbook prepared by the French administration in Madagascar in 1930. The rates of output used for these estimates are lower than those used in the price analysis of 1850 (source 3) but they seem to be more acceptable for work undertaken by unemployed men.

5 - Bigolet R.A.L.L. " Sur le chantier 1970."

An estimating handbook for small operations. This document has been used in order to complete the data of source 4 and to verify their coherence.

6 - Handbook for Artillery Officers.

7 - Handbook for Infantry Officers.

These documents give productivity data about earthworks completed by un-trained labourers. The rates of output given by these sources and by Madagascar 1930 (source 5) are similar, but Madagascar 1930 gives much more detail. Sources 6 and 7 therefore have only been used for verification.

8 - Galabru "Equipement general des chantiers de terrassements."

This document gives data both for manual earthworks and for mechanized earthmoving operation. For manual operations, the variations of output with the quality of the soil and the height of loading are clearly shown. For mechanized work, elementary data are given for the calculation of outputs. This source has been used directly, and also for verifying, interpolating and dissaggregating data from other sources.

9 - Breakdown of prices of the following projects:

- Bangui M'Baiki road in the Central African Republic (1969)
- Construction of roads in Ruanda (1965)
- Feeder roads in Cameroon (Cocoa plantation)

These breakdowns have been prepared by contractors in order to justify their price list. They lead to a disaggregation somewhat different from that of this report. Therefore the data from these sources have been interpreted and corrected before use.

10 - "Management of mechanized highway maintenance by the Bureau of Public Roads" (Washington D.C.).

11 - " La route en terre - Structure et entretien" by Gerard Mellier

These two documents mainly relate to maintenance problems. However, they give interesting information about the estimation of depreciation costs, operating costs and maintenance costs of equipment.

12 - " Cours de terrassements par un groupe d'ingenieurs " (Eyrolles)

This source gives much information about the methods used for calculating the output of earthwork equipment and some productivity data about manual earthworks.

13 - " Cours d'engins mecaniques de l'Ecole d'Application du Genie Militaire."

14 - " Earth moving guide to profit " by Caterpillar Tractor Co.

These documents have been used as sources of productivity data for the equipment-intensive alternative. Document 14 gives very sophisticated tables for the calculation of output. But all this information must be corrected for developing countries. On many sites, a contractor said, the actual output is only a third or a quarter of that calculated from the earthmoving guide, In our calculations we have followed the output given by contractors, and only used these documents for interpolation or extrapolation.

15 - "Bareme pour la determination des charges d'emploi pour les principaux materiels de Genie Civil," (Federation Nationale des Travaux Publics).

This document gives the depreciation cost and the maintenance cost of civil engineering machines. It has been used for the estimation of the hourly costs in the equipment intensive alternative.

16 - "Strictly Handmade" by Fu Hua Chin
Engineering New Record 29 Dec. 1938 - page 817.

This document gives interesting information about a cement-processed earthroad made manually in China. It describes carefully the work and the time schedule and shows the possibility of carrying out by labour such activities as mixing, watering, and compacting natural soils and cement processed soils.

17 - "A general appraisal of the suitability of manual/mechanical methods for various highway construction operations for adoption in developing countries," S.R.Mehra - A communication to the Low Cost Road Committee of the Permanent International Association of the Road Congresses (Macon 1966).

This document gives the opinion of a very experienced engineer about the technical and economical possibilities of substitution of labour for equipment in road construction. It provides interesting ideas about semi-mechanized operations (i.e.,operations done manually with the help of light machinery), and indicates what is, in the opinion of the author, the desirable method to be adopted in developing countries for the principal activities in road construction.

18 - "Construction and Maintenance Equipment," (Highway Research Board 1968).

A compilation of data on time utilization, performance and costs. This report gives much basic data, very useful for the calculation of outputs.

19 - "Economic Choice of Human and Physical Factors in Production," by Gerard Karel Boon of Stanford University)
(North Holland Publishing Company - Amsterdam).

This document analyses the possibilities of substituting labour for equipment, in the case of trench digging. The methodology is carefully described.

20 - "Etude de chaussees economiques en Afrique."
Communaute Economique Europeenne - Serie developpement de l'Outre-Mer no.5 (Bruxelles 1967).

21 - "Rapport sur une mission en Afrique Noire" by Peltier and Bonnenfant, (B.C.E.O.M., 1952).

22 - "Roads in Developing Countries - Design, Construction, Maintenance," Odier, Millard, Dos Santos, Pimental Mehra: compiled under the direction of UNESCO, 1968.

These documents give much technical information on road construction in developing countries - (methods of construction, environmental factors,etc.).

BIBLIOGRAPHY - ENGINEERING

Scott Wilson Kirkpatrick & Partners

Serial No.	Reference	Subject(1)	Usefulness(2)
1.	ECAFE Report: "Manual Labour & its More Effective Use in Competition with Machines for Earthwork in the ECAFE Region" - Report of the Working Party on Earthmoving Operations, E.C.A.F.E. (UNO). Early 1960's.	P, also unit rates	1
2.	ILO Report: "Men Who Move Mountains" published by I.L.O. Management & Productivity Mission to India, 1963.	P	1
3.	U.S. Dept. of the Army:		
	(1) Technical Manual TM5-250 "Roads & Airfields", published by U.S. Dept. of the Army, 1957.	P	1
	(2) Technical Manual	P	3
4.	British Army (Royal Engineers),	P	1
	(1) Supplementary Pocket Books No's. 5A "Roads", 1960, 5B "Airfields" 1960, 5C "Earthmoving Plant", 1951, 5E "Quarries & Gravel Pits", 1959, also Royal Engineers' Reconnaissance Pocket Book, 1944.		
	(2) "Military Engineering"Vol.V Part I "Roads & Airfields", 1957 Vol. XVI "Engineer Construction Equipment", 1962, published by British War Office.	P	1
	(3) Pamphlets from Civil Engineering School, Chatham.	P	3
5.	Ghana Feeder Roads Programme: "Memorandum on Rate of Progress of Works when Hand-loading Gravel"Mr. Adedevoh, Kofuridua, Ghana.	P	2
6.	"M6 Motorway, Lancaster By-Pass to Penrith By-Pass: Report on Ground Investigation, Trial Embankment", published by Dept. of the Environment, London.	P	1

Notes: (1) P = Productivity Data.
(2) Usefulness: 1: Used for Hypothetical Road Project.
2: Consulted elsewhere during study.
3: Not consulted but may be useful.
4: Consulted but not useful.
5: Not consulted, probably not useful.

Serial No.	Reference	Subject	Usefulness
7.	Company pamphlets:		
	(1) Euclid Corp.	P	1
	(2) Caterpillar Co.	P	1
	(3) A-B Vibroverken, Solna 1, Sweden	P account of methods	2
	(4) Libu Co.	P	2
8.	<u>ILO Management Development Series No.8</u> - Report of Technical Meeting on Productive Employment in Construction in Asia, Bangkok, 1968.	P	2
9.	"<u>Economic Choice of Human & Physical Factors in Production</u>", G.K. Boon, Stanford University, published by North Holland Publishing Co., Amsterdam, 1964.	P	2
10.	"<u>Report on the Recent River Valley Project in China</u>", K. Sain & K.L.Rao 1955. Library of Central Water & Power Commission, Delhi, (not available for lending or copying).	P methods of organising manual labour for earthwork project	2
11.	Field study on substitution of equipment for labour on concrete finishing - Dr. M.L. Puri & N.R. Srinivasan, Central Road Research Institute, New Delhi. Journal of the Institution of Engineers (India) Sept. 1963.	P	2
12.	"<u>Soil Compaction by Vibroflotation</u>", Vibroflotation Co., 930 Fort Duquesne Boulevard, Pittsburgh 22.	P account of method	2
13.	<u>Project & Proposal for Yorks/Lancs M.62 Motorway</u>, Chief Engineer, West Riding County Council, 1966.	P	2
14.	M6 Motorway, Killington-Tebay - Contractor's estimating sheet.	Operator hourly costs	1
15.	<u>Schedules of Dayworks Carried Out Incidental to Contract Work</u>, The Federation of Civil Engineering Contractors (Britain), June 1968.	Daywork rates for equipment	1

Serial No.	Reference	Subject	Usefulness
16.	Building & Public Works Administration, Estimating & Costing, Spence Geddes 1948 - Newnes, London.	P	1
17.	"Strictly Handmade", Fu-Hua Chen, Engineering News-Record 29-Dec-38, p.817.	P	2
18.	"Field Studies on the Pulverisation of Black Cotton Soil for the Construction of Stabilized Road Bases" H.L. Uppal, L.R. Chadda, P.K. Dhawan, Journal of the Highway Research Board, Jan. 1970.	Construction methods, possibly productivity data.	3
19.	"A General Appraisal of the Suitability of Manual/Mechanical Methods for Various Highway Construction Operations for Adoption in Developing Countries", S.R. Mehra, presented at the Low Cost Roads Committee of the Permanent International Association of the Road Congresses, Macon, 23rd/24th May, 1966.	Comparisons of methods, possibly productivity data	3
20.	Report of the Rates & Costs Committee, Ministry of Irrigation & Power, Government of India, 1956.	P	3
21.	Trends in the Design & Construction of Dams & Power houses, Kanwar Sain, 1962, Atma Ram & Sons, Kashmere Gate, Delhi 6.	P	3
22.	"Capital-Labor Substitution in Manufacturing in Underdeveloped Countries", Clague, Econometrica (New Haven) July 1969.	Production functions in manufacturing	2
23.	"The Factor Proportion Problem in Underdeveloped Areas", R.S. Eckhaus, American Economic Review, Sept. 1955.	Production Function	2
24.	"Cost Functions & Optimum Technology for Inter-City Highway Systems in Developing Countries", A. Lago, Traffic Quarterly, October 1968.	Cost model for complete transport system, Costa Rica	2

Serial No.	Reference	Subject	Usefulness
25.	"Technological Transfer, Labour Absorbtion & Economic Development", Howard, Dack & M.Jodaro, Oxford Economic Papers (London) Nov. 1969, p.p. 395-403	Rates of factor substitution & discussion of various technologies	2
26.	"The Dual Nature of Industrial Development in Japan", United Nations, Industrialisation & Productivity (New York) 1964	Co-existence of labour & capital intensive methods in same economy	2
27.	Earthmoving by Manual Labour & Machines, ECAFE (UN). 1961	P (more or less duplicates Ref. No. 1 above)	2
28.	Construction & Maintenance Equipment: A Compilation of Data on Time Utilization, Performance & Costs, 1949-1965, Highway Research Board Special Report 68. Highway Employment Trends and Requirements, HRB Bulletin 296	P, possibly unit rates	3
29.	A Cost Comparison Study of Force Account & Contract Construction on Five Secondary Projects in North Carolina, F.B.Farrell & M.J.Kilpatrick, HRB Proceedings 35th Annual Meeting 1956	Proportion of labour by construction activity, USA	3
30.	Etude de Chaussees Economiques en Afrique, Communaute Economique Europeenne Serie Developpement de l'Outre-Mer, No. 5, Brussels, 1967	Economic road studies in Africa	3
31.	Technical Meeting on Productivity & Employment in Public Works in African Countries, Lagos 19-21 Dec. 1963. ILO: Conclusions & Papers Management Development Series No. 1, Geneva, 1964	P, scope for employing labour	2
32.	Labour-Intensive Methods in Low-Cost Road Construction - A Case Study, J.Mueller, International Labour Review, Vol.101, No. 41, April 1970	P, also study of of methods	2

Serial No.	Reference	Subject	Usefulness
33.	Roads in Developing Countries - Design, Construction, Maintenance, Odier, Millard, Dos Santos, Pimental Mehra: Compiled under the direction of UNESCO, 1968	Manual of construction methods, discussing environmental factors	2
34.	Transport Technology for Developing Regions, A Study in Road Transportation in Venezuela, R.M. Soberman, MIT Press, Cambridge, Mass., 1966	Model for construction & maintenance costs. Environmental factors	2
35.	Economic Analysis of Highway Design in Developing Countries, R.M.Soberman, Highway Research Record, No. 115	Production function, optimisation of technology	2
36.	Industrialization and Productivity, UN, Bureau of Economic Affairs, "Capital Intensity in Heavy Engineering Construction" Bulletin No. 1, April 1958	Comparison of labour & capital intensive methods	2
37.	"Capital Intensity & Costs in Earthmoving Operations", Industrialization & Productivity, UN Department of Economic & Social Affairs, Bulletin No. 3, March 1960	P, unit rates	2
38.	Construction Productivity & Employment in Developing Countries, W.P.Strassmann, International Labour Review, Vol. 101, May 1970, p.p. 503-518	P	3
39.	"Measuring Labour Productivity", ILO, 1969, Studies & Reports, New Series N75	P	3
40.	Estimating for Buildings and Public Works, B. Price Davies, The Building Estimator Publications, Western Mail Office, Cardiff, 1932.	P	1
41.	Spon's Architects' and Builders' Price Book, E.& F.N. Spon Ltd., London, 1963.	Unit rates	4
42.	Laxton's Building Price Book, Kelly's Directories Limited, Kingston upon Thames, Surrey, 1969/70.	Unit rates	4

Serial No.	Reference	Subject	Usefulness
43.	Molesworth's Handbook of Engineering Formulae and Data, E.& F.N. Spon Ltd., London, 1950.	P (for blasting)	1
44.	Schedule of Rates of Hire, The Contractors' Plant Association, London, 1971.	Hire rates for equipment	1
45.	Shiftwork and Employment Expansion, M. Kabaj, in ILR Vol. 91, No.1, London, 1971.	Production functions	3
46.	Technological Change and Economic Development, W.P. Strassman, Cornell University Press, Ithaca, N.Y., 1968.	Production functions	3
47.	A Theoretical Note on Labour as an 'Inferior' Factor in Less Developed Economies, M.P. Todaro, in Journal of Development Studies, July, 1969.	Production functions	3
48.	Cost Functions for Comparison of Low-Cost Transportation Technologies, L.L.Vance, Jr., Institute of Transportation and Traffic Engineering - Dissertation Series, University of California, Berkeley, April 1967.	Production functions	3

BIBLIOGRAPHY - ECONOMIC

1. G. Ardant: "A Plan for Full Employment in Developing Countries," International Labour Review, July 1963, p.15.

2. Ove Arup and Partners, London, on E.I.U. files.

3. W. Baer and M.E.A.Herve, "Employment and Industrialization in Developing Countries," Quarterly Journal of Economics, February 1966.

4. G.Beier, M.S.Ahluwalia and E.M.Schebeck, "Fiscal Intervention and Employment," Meeting of Experts on Fiscal Policies for Employment Promotion, Geneva, International Labour Office, 1970.

5. S.S.Berry: "Economic Development with Surplus Labour: Further Complications Suggested by Contemporary African Experience," Oxford Economic Papers, July 1970, p.275.

6. P.Blacque Belair: "Promotion Nationale au Maroc Delegation Generale a la Promotion Nationale et au Plan, Rabat 1964.

7. R.N. Bhargava: "Indian Public Finances," London, Allen and Unwin, 1962.

8. Bureau Central d'Etudes pour les Equipements d'Outre-Mer, "The Moroccan Transportation Plan," Preliminary Report, Paris, February 1971.

9. S.Chakravarty: "The Use of Shadow Prices in Programme Evaluation," in P.N.Rosenstein-Rodan (editor), "Capital Formation and Economic Development: Studies in the Economic Development in India," London, Allen and Unwin,1964.

10. R.J.Chelliah: "Fiscal Policy in Underdeveloped Countries, with Special Reference to India," London, Allen and Unwin, 1960.

11. Conference on National Reconstruction and Development in Nigeria, March 1969, published papers.

12. W.G.Demas: "The Economics of Development in Small Countries, with Special Reference to the Caribbean," Montreal, McGill University Press, 1965.

13. Economist Intelligence Unit files.

14. W.P. Falcon: "Agricultural Development in Less Developed Countries: General Situation, Research Approaches, and Policy Palliatives," International Bank for Reconstruction and Development, 1971.

15. F.Forte: "Fiscal and Credit Policies to Promote 'Labour' Full Employment in a World of Imperfections," Meeting of Experts on Fiscal Policies for Employment Promotion, Geneva, International Labour Office, 1970.

16. C.Frank: "Urban Unemployment and Economic Growth in Africa," Oxford Economic Papers, March 1968.

17. R.V.Gilbert: "The Works Programme in East Pakistan," International Labour Review, March 1964, p.213.

18. Government of France, Moroccan Embassy: "Economic and Financial Bulletins."

19. Government of Morocco, Ministry of Economic Affairs, Planning and Promotion of Executives: "The Five-Year Plan 1968 - 1972" (3 volumes).

20. Government of Morocco, Ministry of Public Works and Communications: "Brief on the Organization and Operation of Road Services," June 1969.

21 Government of Morocco: "National Promotion Statistics 1961-1969."

22. A.C.Harberger: " The Opportunity Cost of Labour," International Labour Review, Geneva, June 1971.

23. F.H.Harbison: "The Generation of Employment in Newly Developing Countries," in J.Sheffield (editor): "Education, Employment and Rural Development," Nairobi, East Africa Publishing House, 1967.

24. R.H.Haveman and J.V. Krutilla: "Employment, Idle Capacity and the Evaluation of Public Expenditures," Baltimore, Johns Hopkins, 1968.

25. E.K.Hawkins: "Roads and Road Transport in an Underdeveloped Country," London, H.M.S.O., 1962.

26. R.B. Heflebower: "Characteristics of Transport Modes," in G.Fromm (editor): "Transport Investment and Economic Development," Washington,D.C., Brookings Institution, 1965.

27. India, All India Agricultural Labour Enquiry Committee, quoted in R.J.Chelliah, source 10.

28. International Bank for Reconstruction and Development, Annual Report, 1970.

29. International Labour Office: "Employment Objectives in Economic Development: Report of a Meeting of Experts," Geneva 1961.

30. International Labour Office: " Technical Meeting on Productivity and Employment in Public Works in African Countries," Lagos 1963.

31. International Labour Office: Management Development and Productivity Mission to India, "Men Who Move Mountains," New Delhi, 1963.

32. International Labour Office: "Employment and Economic Growth," Geneva 1964.

33. International Labour Office: "Problems of Employment in Economic Development," International Labour Review, March 1964, p.213.

34. International Labour Office: "The World Employment Programme," Report of the Director General to the International Labour Conference, Geneva 1969.

35. International Labour Office: "Towards Full Employment: A Programme for Colombia," Geneva 1970.

36. B.F.Johnston: "Consequences of Rapid Population Growth: Unemployment and Underemployment," California Institute of Technology Conference on Technological Change and Population Growth, May 1970 (mimeo).

37. J.A.King Jr.: "Economic Development Projects and their Evaluation," Baltimore, Johns Hopkins, 1967.

38. W.A.Lewis: "Development Planning: The Essentials of Economic Policy," London, Allen and Unwin, 1966.

39. I.M.D.Little and J.A.Mirrlees: "Manual of Project Analysis in Developing Countries, Volume II," Paris, Organisation for Economic Cooperation and Development, 1969.

40. R.Luders and N.Cabero: "Employment and Technology in Industry: the Chilean Case," Meeting of Experts on Fiscal Policies for Employment Promotion, Geneva, International Labour Organisation, 1970.

41. J.E. Mende: "Mauritius: A Case Study in Malthusion Economics," The Economic Economic Journal, Vol.71, 1961.

42. E.J.Mishan: "Cost-Benefit Rules for Poorer Countries," Canadian Journal of Economics, 1971.

43. H.Mueller: "Labour Intensive Methods in Low-Cost Road Construction - a Case Study," International Labour Review, April 1970, p.359.

44. R.B.Nugent: "Programming the Optimal Development of the Greek Economy 1954-61," Athens, Centre of Planning and Economic Research, Monograph No.15, 1966.

45. H.T.Oshima : "Labour Force 'Explosion' and the Labor Intensive Sector in Asian Growth," University of Hawaii, April 1969 (mimeo).

46. Pakistan, Ministry of Finance, "Pakistan Economic Survey," 1966-67, 1967-68, 1969-70 editions, Islamabad.

47. R.Perlman: "Labour Theory," New York, Wiley, 1969.

48. A.R.Prest: "The Role of Labour Taxes and Subsidies in Promoting Employment in Developing Countries," Meeting of Experts on Fiscal Policies for Employment Promotion, International Labour Office, Geneva, 1970.

49. C.Prou and M.Chervel: "Etablissement des Programmes en Economie Sous-Developee," Paris, Dunod, 1970.

50. A. Quayum: "The Theory and Policy of Accounting Prices," Amsterdam, North Holland, 1960.

51. K.N.Raj: "Prospects for Employment Opportunities in the 1970s," University of Cambridge Studies Committee Conference, 1970 (mimeo).

52. G.Ranis: "Employment and Income Distribution in Developing Countries," International Bank for Reconstruction and Development, Economic Staff Working Paper No.115, September 1971.

53. W.B.Reddaway: "Effects of the Selective Employment Tax; First Report- The Distributive Trades," London, H.M.S.O., 1970.

54. L.G.Reynolds: "Wages and Employment in a Labour - Surplus Economy," American Economic Review, March 1965.

55. --- "Economic Development with Surplus Labor: Some Complications," Oxford Economic Papers, 1969.

56. Y.Sabolo: "Sectoral Employment Growth: the Outlook for 1980," International Labour Review, November 1969.

57. Scott, Wilson, Kirkpatrick and Partners, London.

58. D.Seers: "New Approaches Suggested by the Colombian Employment Programme," International Labour Review, October 1970, p.377.

59. A.K.Sen: "Choice of Techniques," Oxford, Blackwell, 3rd edition, 1968.

60. Senegal C.C.T.A., Fondement Economique et Social Du Developpement, Bulletin, August 1962.

61. R.D.Sleeper: "Manpower Redeployment and SET," Bulletin of Oxford University Institute of Economics and Statistics, Nov. 1970.

62. Societe d'Etudes pour le Developemment Economique et Social, Paris.

63. W.P.Strassmann: "Technical Change and Economic Development," Cornell University Press, 1968.

64. W.P.Strassmann: "Construction Productivity and Employment in Developing Countries," International Labour Review, May 1970, p.503.

65. Tanzania, Central Statistical Bureau: "Employment and Earnings, 1966," Dar-es-Salaam, 1966.

66. Thailand, National Statistical Office: "Report of Labour Force Survey, 1967-1968," Bangkok, 1969.

67. J.W.Thomas: " Rural Public Works and East Pakistan's Development," Centre for International Affairs, Harvard University, Economic Development Report No.112, September 1968.

68. A. Tiano: "Promotion Nationale au Maroc," Cahiers de l'I.S.E.A., No.122, February 1962 (Economie du Travail).

69. --- "Le Maghreb entre les Mythes", P.U.F., 1967.

70. D.Turnham: "The Employment Problem in Less Developed Countries," Paris, OECD, 1971.

71. United Nations, Department of Economic and Social Affairs: "Capital Intensity in Heavy Engineering Construction," Industrialisation and Productivity Bulletin No.1, April 1958.

72. United Nations, Department of Economic and Social Affairs: "Capital Intensity and Costs in Earth Moving Operations," Industrialisation and Productivity Bulletin No.3., March 1960.

73. United Nations, Department of Economic and Social Affairs: "Working Party on Earthmoving Operations," Industrialisation and Productivity Bulletin No. 3, March 1960.

74. United Nations, Economic Commission for Asia and the Far East: "Earthmoving by Manual Labour and Machines," Bangkok, 1961.

75. United Nations, Economic Commission for Asia and the Far East: "Economic Survey of Asia and the Far East," 1968.

76. J.N. Ypsilantis: "World and Regional Estimates and Projections of Labour Force," U.N.Document ISLEP/A/VII/64, 1966 (mimeo).

Appendix A

CONTENTS

Appendix A. Details of the Engineering Analyses

APPENDIX A

1. Data Utilized in the Analyses of the Scope for Substitution

a. Productivity Rates

BCEOM Sources. For each elementary activity, the quantification of equipment-time and labor time has been derived from the following documents as referenced in the bibliography:

Equipment-Intensive Methods

(a) Estimating handbooks prepared by public works departments and equipment manufacturers' manuals in particular "Caterpillar" (see however comments in the bibliography, item 14).

(b) Breakdown of prices for operations similar to those of the hypothetical road projects, which have been completed recently in various African countries (see item 9 in the bibliography).

(c) Information from Contractors G.T.E. ("Grands Travaux de l'Est") who have carried out numerous projects in Madagascar.

(d) BCEOM reports and data and personal experience.

Labor-Intensive Methods

(a) Breakdown of prices for road works completed in the past by labor-intensive methods

(b) Interview with contractors who have carried out roadworks by labor-intensive methods

(c) Personal experience

In many cases we have not found the accurate breakdown required by our study in these documents, and so we have been obliged to estimate the quantities by interpolating the available data. For example, having only a price breakdown for a hauling distance of 200 metres, we have extrapolated the breakdowns for 100 metres and 400 metres with the help of estimating handbooks for public works and contractors' data. In many cases the source in Appendix B is shown as "BCEOM's estimate". For these activities general indications have been gathered from many different sources. This information was then considered within the general perspective of the environmental conditions pertaining for the main sources consulted by BCEOM, i.e. the study of the Bangui M' Baike road for the equipment intensive method and the estimating handbook prepared by the French administration in Madagascar in 1930 for the labour intensive method.

<u>SWKP Sources</u>. The main sources of productivity data used in the analyses were the following:

(a) British and US Army Engineers' handbooks.
(b) The ILO Report, "Men Who Move Mountains".
(c) The ECAFE Report of the working Party on Earthmoving Operations.

These were supplemented by:-

(d) "Building and Public Works Administration, Estimating and Costing", by Spence Geddes.
(e) "Estimating for Building and Public Works" by B. Price-Davies (1932 Edition).
(f) Euclid and Caterpillar estimating booklets.
(g) Molesworth engineering handbook.
(h) The ILO Report of the Technical Meeting on Productive Employment in Construction in Asia, Bangkok 1968.

The various sources are fully documented in Appendix B and the bibliography.

Wherever possible, several sources of data were used to estimate productivity for a particular activity. For equipment-intensive operations, British Army rates were generally given the greatest weight. Figures from "Men Who Move Mountains" were accepted as being most reliable for manual earthmoving operations. For other activities by hand, British Army figures were given preference. Since the latter give lower output rates for earthmoving operations than the former, it may be that labour productivity figures are somewhat inconsistent as between the various activities.

Where necessary, data was adjusted to allow for a 50-minute working hour and an 8-hour working day, otherwise working conditions were assumed to be good and no allowance was made for hold-ups. Haul roads and paths were assumed to be in good condition and of a size adequate for efficient use of the vehicles. Where daily outputs were given in the sources, an 8-hour working day was assumed.

It has been assumed that all equipment and labour would be fully occupied throughout the day and that there would be no idle time or spare capacity. This is clearly an unrealistic assumption for which allowance must be made in interpreting the results of the analyses. For instance, it is very difficult to exactly match the number of hauling vehicles to the output of a loading machine and some idle time is unavoidable in practice.

Further assumptions made in relation to equipment include the following:-

(1) Stouck loads have been assumed where calculations of theoretical output have been used for scrapers, shovels, vehicles, etc., except in the case of loading excavated rock where 75% of the rated load has been used for shovels and for wheelbarrows.

(2) For the analyses of cost per kilometre of road, the output rate of the combined excavating/loading/hauling/unloading/spreading operation performed by a motor scraper (push loaded by a D8 dozer) was **arbitrarily** divided into the individual activities based on the time cycle of the operation.

Assumptions made in regard to activities carried out by labour include:-

(1) Short hauls of the order of 10m. such as from stream to water bowser, or rock pile to vehicle, have been included as part of the loading operation.

(2) The height for loading vehicles by hand has been taken as 1.5m. and gangs have been assumed to consist of 6 men for trucks, 3 men for $3m^3$ trailers, 2 men for $1m^3$ carts.

(3) The operation for stripping topsoil has been taken to include loading into baskets, hauling 10m. and unloading.

(4) The spreading operation for chippings and bitumen has included loading and a short haul.

b. Unit Costs for Equipment

The SWKP and BCEOM analyses used the same unit costs or prices for the same or similar pieces of equipment and labour as described herebelow and in section c.

The time available for the study did not permit a detailed analysis of the cost of owning, operating and maintaining equipment. The sources immediately available were:-

(1) The Schedule of Daywork Rates published by the Federation of (British) Civil Engineering Contractors.

(2) The Schedule of Rates of Hire published by the (British) Contractors' Plant Association.

(3) French daywork rates from Bareme pour la determination des charges d'emploi pour les principaux materiels de Genie Civil, publie par la Federation Nationale des Travaux Publics.

(4) Daywork schedules incorporated in current and recent contracts for road construction in the United Kingdom and in various overseas countries.

These basic rates are not directly comparable since some include such items as operators' wages and fuel, whereas others do not. They have therefore been adjusted to be inclusive of all running costs (operators' wages, fuel,maintenance etc.) but to exclude supervision and mobilisation costs. It was not possible to exclude the profit element which the owner of the equipment would expect to make. On the other hand, a contractor hiring equipment (and its operator) at these rates would also expect to make his own profit in operating it, and this is not reflected in the rates (which also exclude any profit on operators' wages, fuel and lubricants).

Two examples in the variations in rates which occur in practice are shown below. The rates have been adjusted as described in 1.21.

Motor Scraper, $11m^3$ Struck Capacity

1	French daywork	US $33.08/hour
2	UK plant hire	21.51
3	UK daywork	19.87
4	Contract daywork rate in Jordan (1966)	11.20

D8 Crawler Tractor with Dozer Blade

1	French daywork	US $33.33/hour
2	Airport contract in Brunei (current)	26.88
3	UK plant hire	19.89
4	UK daywork	14.55

French daywork rates were adopted in the analyses. These rates include depreciation, the cost of fuel (except for trucks and bowsers), maintenance and consumable stores, and insurance and tax for vehicles using public roads. They do not include mobilization costs, supervision of operation, or operating staff. These rates, which are shown in Table A1, are levied for the whole period of hire, irrespective of whether or not the equipment is working. For earthmoving plant these appeared to be high in relation to rates in other countries, but the differences for other equipment were not so great.

To appreciate the limitations in their use, it is necessary to understand the basis on which hire rates are normally calculated. First the life of the equipment is estimated in terms of working hours, which vary with the nature of the work and the conditions under which it is carried out. It could range from some 8,000-10,000 hours for a bulldozer to many times this figure for static stone crushing plant. The anticipated annual hiring period is estimated and the corresponding life of the equipment is calculated in years. The cost of the equipment, in terms of original or estimated replacement cost, is written off over this period, usually on a straight-line basis with no allowance for residual value at the end of the period. To this depreciation charge is added such annual costs as insurance, financing charges, overheads, profit etc.

Table A.1: Equipment Costs and Fuel Consumption per hour, French daywork rates

Equipment	Hourly US$ (a)	Hourly consumption		Hourly rate including fuel and oil US$
		Gas-oil (litres)	Oil (litres)	
Bulldozer, 270 hp (D.8.4)	25.98	45	0.80	31.68
D8 II + Ripper	28.88	45	0.80	34.58
Bulldozer, 185 hp (D7+)	19.12	30	0.45	22.80
D7 E Bull + Ripper	21.02	30	0.45	24.70
Spreader box for bulldozer	1.52(b)	-	-	1.52
Motorscraper 621, 11 or 15.3m³	25.43	48	0.80	31.43
Motorgrader MG 12, 120 hp	6.06	22	0.25	8.64
Motorgrader, MG 14	9.18	29	0.45	12.76
Shovel "Traxcavator", 1 m³ or 1000 litres	10.18	19	0.25	12.45
Motor tractor, 75 hp	1.26	19	0.25	3.53
Compressor, 120 hp	2.68	23	0.30	5.43
Compressor, 80 hp	2.02	15	0.25	3.89
Compressor, 60 hp	1.48	11.5	0.20	2.93
Pneumatic pick or drill	0.10	-	-	0.10
Wagon drill	0.91	-	-	0.91
Truck, 6 m³ capacity	3.86	0.60 (c) litres/km	0.04 litres/km	3.86 + 0.12/km
Water bowser, 10,000 litres	3.40	0.60 (c) litres/km	0.04 litres/km	3.40 + 0.12/km
Water pump, 10 hp, 60 m³/hr	0.14	2	-	0.34
Bitumen spreader or boiler, 600 litres	0.48	included	included	0.48
Bitumen spreader, 10,000 litres	5.42	80	0.5	14.17
Bitumen heater, 5000 litres	4.10(d)	included	included	4.10
Mechanical broom, towed	0.18	-	-	0.18
Paving machine	18.00 (e)	included	included	18.00
Chipping spreader	0.42	-	-	0.42

Table A.1 continued -

Pneumatic tired self-propelled roller or compactor, 20 t	4.45	21	0.25	6.92
Pneumatic tired roller or compactor, towed 10 t	0.43	-	-	0.43
Steel-wheeled road roller, 14/18 t.	2.24	8	0.15	3.26
Tandem steel-wheeled road roller, 8/10 t	2.11	5	0.10	2.76
Vibrating trailer roller, 5 t	3.73	8.5	0.15	4.81
Hand-vibrator, 5 hp	0.77	1	0.05	0.95
Stone crushing plant 500 m^3/day No.1	16.81	150	2.00	34.81
Stone crushing plant 500 m^3/day No.2	23.67	150	2.00	41.67
Granulator, 30 m^3/day	4.74	30	0.25	8.11
3 m^3 capacity cart or trailer	0.15	-	-	0.15
1 m3 capacity cart	0.10	-	-	0.10
Driver and animals	2.00	-	-	2.00

Notes to Table A.1:

a) Net of overhead expenses and idle time but including depreciation, running and maintenance costs other than labor and fuel.
b) Assuming cost of spreader box is 5% of total hourly cost of 270 HP bulldozer including fuel and oil.
c) 0.70 litres per km. in hilly terrain.
d) UK daywork rate.
e) There is no figure for a paver in the BCEOM report, so SWKP assumed rate for paver twice the UK daywork rate to make compatible with BCEOM figures for other heavy equipment.
f) Assuming gas oil = $0.10 per litre, and oil = $1.50 per litre.

Source: Bareme de la Federation Nationale des Travaux Publics, except as otherwise noted.

The annual costs are converted into hourly costs on the basis of expected utilisation and to these are added the hourly operating costs of maintenance, fuel, operators' wages etc. to arrive at the hire rate. In practice the calculations are complicated by the need to take into account taxation regulations, investment allowances, plant obsolescence, and the like.

The unit rates for equipment are very dependent on the utilisation rate. With the utilisation normally achievable in road construction, the fixed annual charges are much greater than the hourly operating and maintenance costs, and overall costs can be reduced substantially by increasing utilisation. Thus, equipment charges can be expected to vary substantially from country to country and will be dependent on the nature of work and the environment in which it is carried out. On the basis of a 50-week year and a 40-hour week, the maximum utilisation of equipment is 2,000 hours per year. In the United Kingdom, motor scrapers on roadworks are seldom utilised for more than 800-1,000 hours per year. At the other extreme, it is not uncommon on large earthmoving projects such as open-cast mining to achieve annual utilisation rates with shift-working in excess of 4,000 hours. In the United Kingdom quite substantial discounts are offered for long-term hire which, in effect, increases the utilisation rate from the equipment owners' viewpoint.

Insofar as the analyses of the hypothetical road projects given below are concerned, the equipment hire rates used contain an allowance for unavoidable under-utilisation due to such factors as climatic conditions (insofar as they are similar to those prevailing in France). On the other hand, shorter-term lack of utilisation due, for example to sequencing difficulties, break downs and poor organisation would not be covered. This problem is treated further in paras. 3.16-3.28 below, where a sensitivity analysis of the effect of varying utilisation rates on the cost per hour of a road scraper and the corresponding breakeven wage rate for labor substitution is given.

In comparing labour- and equipment-intensive methods of construction in the developing countries, more precise data on the costs of owning and operating equipment will be needed. While this would probably be available in respect of haulage vehicles, proper rates would also have to be established for most other items of equipment.

c. Unit Costs for Labour.

The following daily wage rates for an 8-hour working day were assumed in the analyses of the hypothetical road projects:

	US $/day	US $/hour
Unskilled (labour-orientated)		
General labour	2.00	0.25
Animal cart with driver	16.00	2.00
Skilled (equipment-orientated)		
Equipment operator	10.80	1.35
Truck driver	6.00	0.75
Operators' assistant	2.40	0.30

Certain alternative analyses (clearly identified in the text) were done at wage rates of US$0.20 per day for purposes of comparison.

The skilled rates were deemed to apply to all but the simplest of equipment. With certain machines doing certain activities, both a skilled operator and a semi-skilled assistant were assumed (e.g, a dozer working on clearing operations).

In the analyses by Scott Wilson Kirkpatrick headmen (or gangers) have been treated as unskilled labour since they are essentially working members of the group (see Chapter IV 3.1), since in the British experience the premium paid to headmen, perhaps 20% above that of other labourers, would not constitute a significant part of the cost of unskilled labour. On the other hand, BCEOM has adopted a rate for headmen some 250% greater than that for unskilled labour which presumably reflects a different tradition of organisation of unskilled labour.

No allowances have been made for associated payroll costs such as paid holidays, workman's compensation insurance, overtime and the like. These would all have to be taken into account in practice as well as the costs of mobilisation, administration, supervision, provision and maintenance of hand tools, camps and associated facilities and other similar expenses.

Certain of the foregoing items could be covered by marking-up the wage rate, while others would be independent, within limits, of the labour employed and could be treated as a fixed cost.

d. Unit Costs for Materials.

The following unit rates were assumed for materials delivered, unloaded and stacked at the base camp:-

Bitumen	US $70.00 per metric ton
Gas Oil	0.10 per litre
Engine Oil	1.50 per litre
Explosives (including fues and detonators)	2.00 per kg.

Distribution on the site has been allowed for in the case of bitumen as part of the general construction activities. The cost of explosives includes an allowance for fuses and detonators.

No allowance have been made for storage facilities for materials, nor for any other camp buildings and facilities.

2. The Hypothetical Road Projects

Analyses were made of the principal quantities of work involved in one kilometre of a typical road construction project, varying the following:-

(i) Quality at high and intermediate levels
(ii) Type of terrain, defined at three levels as flat, rolling and hilly
(iii) Pavement construction, three types:-

A - Gravel sub-base, gravel base with two-coat surface dressing;
B - Gravel sub-base, penetration macadam base with single coat surface dressing;
C - Gravel sub-base, crushed rock base with two-coat surface dressing.

a. Basic Specification

The basic specification for the hypothetical road was:-

Width of surfacing (pavement)	-	7.00m.
Width of upper surface of base	-	7.50m.
Width of shoulder	-	1.25m.
Width of formation	-	10.00m.
Side slopes of earthworks	-	1:2
Thickness of sub-base	-	15cm.
Thickness of base	-	15cm.

The following quantities of work applied in all cases for each kilometre of road:-

Clearing and grubbing in medium vegetation, including an allowance for borrow areas	-	25,000m^2
Stripping topsoil 10cm. thick	-	15,000m^2
Volume of sub-base	-	1,700m^3
Volume of base	-	1,200m^3
Average haul distance of sub-base material	-	1 km.
Volume of water required for compacting sub-base	-	100,000 litres
Average haul distance for all water	-	2 km.

b. Variations to Simulate Terrain

The quantities of drainage excavation per kilometre were varied as below:

	Volume	% Rock	Average Haul
Flat	5,000m^3	Nil	100m.
Rolling	10,000	2	400
Hilly	15,000	5	200

All excavation was assumed to be soft except:

(1) gravel for sub-bases and bases, taken as hard material
(2) rock

Twice as much explosive was assumed for rock excavation in ditches as in bulk earthworks. For road type A (gravel base) where the only rock product required is for chippings, the amount of explosives was increased 50 per cent above those assumed for rock excavation in quarries for the other types of road.

The placing of material in embankments, whether originating from cuttings or borrow pits, was assumed to be at the following rates per kilometre:

Flat	5,000m^3
Rolling	7,500
Hilly	10,000

All rock excavated in bulk earthworks was assumed to be dumped and not incorporated in embankments, and it was further assumed that no water would be required for compaction of earthworks.

The quantities for topsoiling and grassing (15 cm. thick) per kilometre were assumed to be:

Flat	4,000m^2
Rolling	5,000
Hilly	6,000

c. Variations to Simulate Road (Pavement) Type

Average haulage distances for base material were assumed to be:-

Gravel	2 km.
Macadam	5
Crushed rock	10

The quantities of water required per kilometre for compaction of the base material were assessed at:-

Gravel	70,000 litres
Macadam	35,000
Crushed rock	70,000

The rate of application of bitumen for the surface dressing was assumed to be 2.4 kg/m^2 and for the penetration macadam, 2.2 kg/m^2. In the former case, the bitumen would be applied in two equal coats. The average haul distance for bitumen was taken at 10 km., it being delivered to site in 160 litre drums.

Stone sizes were assumed to be:-

Aggregate for macadam	40/70 mm.
Crushed rock for base	0/30
Chippings for macadam dressing	15/25
Chippings for surface dressing	10/15

The rates of spread of chippings were:-

Macadam dressing	20 litre/m^2
Surface dressing	12

The average haulage distance for the above stone products was taken to be 10 km, except for macadam base and dressing for which the distance is 5 km.

d. Quantities of Work

The quantities of work, in terms of bill items, were calculated on the basis of the above assumptions. No other items of work other than those specifically referred to were taken into account; in particular, culverting and bridgeworks were excluded.

In calculating the appropriate quantities, it was necessary to make further assumptions and these are listed below:

(1) Bulking factors for excavated soils were not taken into account and the quantities for loading, hauling, spreading and compacting are in terms of volume of undisturbed material.

(2) For gravel the volume excavated was taken to be equal to the volume of compacted material.

(3) For stone products, it was assumed that the volume remained constant from the point immediately following the excavation through the crushing activity to the final spreading and compacting activities. The expansion of rock during excavation was allowed for by calculating output figures by weight and then converting to volume by assuming a density for the loose material.

(4) No allowances were made for loss of material during crushing activities.

(5) The average haul distance between the quarry face and the crushing (or hand-breaking) point was assumed to be 200m.

(6) It was assumed that $1m^3$ of grass roots would cover $200m^2$ and that the average haul distance would be 5 km. The activities required for watering grass after planting were not taken into account.

(7) The topsoiling operation was assumed to consist of:-

Activity 4.1	Loading
12.3	Laying, trimming and compacting

and no allowance was made for hauling.

(8) The heating of bitumen was included under the loading operation. This gave a large equipment content to the loading operation (and in future work it would probably be best to define this operation as a separate activity).

(9) It was assumed that crushing plant would be so arranged as to permit gravity feeding from unit to unit and to the stockpile.

On the above assumptions, the bill items were broken down into the basic construction activities. The degree of disaggregation was greater than that shown in the list of basic construction activities. Firstly, to facilitate the checking of calculations, further sub-division of the basic activities was desirable and, secondly, it became necessary to allow for differing productivity rates within the same activity. Examples of the more important instances of the latter are given below:-

(1) Rock excavation in a quarry is markedly different from the smaller quantities encountered in bulk excavation.

(2) Labour productivity rates for loading excavated materials into baskets or wheelbarrows are much higher than for loading into vehicles.

(3) Hauling was further disaggregated by length of haul since haulage time (and hence cost) is not directly proportional to the length of haul, particularly with the shorter hauls.

(4) Differing types of base material were considered separately since the type of compaction plant and the effort required for compaction varies accordingly.

e. Selection of Equipment

To simplify the analyses, a standard list of equipment was drawn up and the most suitable item for carrying out each activity was selected. It must be emphasized that the equipment assumed is not necessarily the most efficient for carrying out the particular operation and the analyses are limited in this respect. Wherever possible, the same equipment was assumed irrespective of the construction technique. Several types of haulage vehicle were considered in the analyses.

The list of equipment employed by SWKP in the analyses and the activities carried out by each item are given below. The equipment employed by BCEOM was quite similar, though not identical; those items which do not precisely correspond with BCEOM items are marked with an asterisk.

(1) D8 dozer - clearing and grubbing, stripping topsoil, excavating gravel.

* (2) D8 dozer with spreader box - spreading sub-base and base materials for intermediate quality (BCEOM used M12 grader).

* (3) M12 grader - excavating ditches, finishing earthworks, sub-bases and bases. (BCEOM also used M14 grader.)

(4) 11m^3 scraper (push loaded by D8 dozer) - excavating soft materials in bulk, hauling and spreading.

(5) 80 hp (8m^3/min) compressor with tools and explosives - for excavating rock.

* (6) 1.0m^3 tracked shovel "Traxcavator" - all loading activities except water and bitumen. (BCEOM used "1m^3 shovel", not stating whether tracked or not.)

(7) 60m^3/hr water pump - loading water.

(8) 6m^3 truck - hauling all bulk solid materials and bitumen.

(9) 75hp tractor and 3m^3 trailer - hauling all materials.

(10) Bullocks and 1m^3 carts - hauling all materials up to 5 km for labour-intensive methods (categorised as labour).

(11) 10,000 litre water bowser - hauling and spreading water.

*(12) 60/75 hp paving machine - spreading sub-base and base material for high quality. (BCEOM used M12 grader.)

*(13) 5,000 litre static bitumen heating unit - for equipment-intensive method. (BCEOM omitted heater.)

(14) 600 litre mobile bitumen boiler - for labour-intensive method, intermediate quality.

*(15) 10,000 litre bitumen distributor - hauling and spreading bitumen, both qualities equipment-intensive and high quality labour-intensive methods.

(16) Chipping spreader (attached to truck) - spreading chippings.

(17) 20 tonne pneumatic tyred roller, self-propelled, for compacting earthworks - both qualities equipment-intensive, high quality labour-intensive.

(18) 8-10 tonne pneumatic tyred roller, towed by 75 hp tractor - compacting gravel and surface dressing intermediate quality.

(19) 14-18 tonne steel wheeled roller, self-propelled - compacting macadam and crushed rock base and high quality surface dressing.

(20) 8-10 tonne steel wheeled roller, self-propelled - surface dressing (in addition to pneumatic-tyred roller) and topsoil.

(21) 500 m^3/day crushing plant - crushing rock for bases.

(22) 30m^3/day crushing plant - crushing chippings for surface dressings.

(23) 75 hp tractor sweeper - brooming and cleaning surfaces.

Hand rollers and rammers were assumed for compaction at intermediate qualities for labour-intensive operations and no equipment charges have been made for these and such items of hand tools as picks, shovels, watering cans, etc.

f. Analyses of Projects

The above rates were used to determine the unit costs for carrying out each activity at both high and intermediate levels of quality. By comparing rates for labour- and equipment-intensive techniques, the break-even wage rates were determined (as given in Volume I, Chapter II.D).

Production functions were prepared for the interdependent activities - those groups of activities comprising mainly excavating, loading, hauling, unloading and spreading, where the method adopted for one activity restricts the choice of methods for other activities. Based on these functions, the most efficient haulage vehicle in relation to length of haul was selected for the subsequent analyses. These functions are given in the following section of this Appendix.

The production functions for interdependent activities were then utilised to prepare functions for groups of similar operations, combining them and the individual independent activities together in the quantities required for the construction of one kilometre of the hypothetical road projects. The grouped operations, (which are given in Volume I, Chapter II.E) are:

Earthworks at intermediate quality in differing types of terrain.
Sub-bases and bases at intermediate quality.
Surface dressings at intermediate quality.

In the last series of analyses (presented in Volume I, Chapter II.E), the work involved in one kilometre of each of the hypothetical road projects was broken down into basic construction activities and estimates of the costs of equipment and unskilled labour (at US $2.00 per day) were prepared for carrying out each activity by either equipment- or labour-intensive techniques at high and intermediate levels of quality. Costs were summarised by activity group and on a kilometre basis. The construction methods assumed were those found to be most efficient during the preceding analyses.

The effect of varying wage rates was assessed by keeping equipment costs (including skilled labour) the same and reducing the cost of unskilled labour to US $0.20 per day.

Costs were summarised by activity group and on a kilometre basis. The construction methods assumed were those found to be most efficient during the preceding analyses.

The effect of varying wage rates was assessed by keeping equipment costs (including skilled labour) the same and reducing the cost of unskilled labour to US $0.20 per day.

3. Production Functions for Road Construction Activities as Estimated by SWKP

The complete grouping of interdependent sequential activities into production functions is:

a. Bulk Excavation in Roadworks: excavating in bulk in soft material, loading, hauling (various distances), unloading and spreading.

b. Rock Excavation in Roadworks: excavating in bulk in rock, loading, hauling (various distances) and unloading.

c. Rock Excavation in Quarry (for crushing): excavating in bulk in rock, loading, hauling and unloading.

d. Gravel Sub-base: excavating in bulk in hard material, loading, hauling, unloading and spreading (at two levels of quality).

d. Gravel Base: as above.

f. Macadam Base (from crusher to site): loading, hauling, unloading and spreading (at two levels of quality).

g. Crushed Rock Base (from crusher to site): loading, hauling, unloading and spreading.

h. Water Distribution: loading, hauling, unloading and spreading.

i. Chippings for Surface Dressings (from crusher to site): loading, hauling, unloading and spreading.

j. Bitumen Distribution: loading, hauling, unloading and spreading (including heating).

Production functions for the complete set of interdependent activities, which were prepared only by SWKP, are given in the following section.

a. Bulk Excavation in Roadworks

Table A.2 shows the various combinations of methods considered for carrying out each activity. The list does not cover all technically possible combinations and for simplicity it has been assumed that the excavating and loading operations would be carried out either both by equipment or both by labour.

Table A.3 (upper portion) gives the corresponding equipment and labour inputs for these various methods of carrying out 1000 m^3 of bulk earthworks in flat terrain where the average length of haul is assumed to be 100m. Figure A.1 depicts these graphically.

The scraper operation, identified as point A, is the most efficient way of carrying out the operation wholly by equipment. Of the labour-intensive methods, point G is the most efficient, with haulage by wheelbarrow. However, the straight line A-G does not represent the production function for this operation since some of the other points lie beneath this line. Point L, which represents excavating and loading by labour, hauling by tractor/trailer and spreading by grader, is an intermediate substitution possibility and it must lie on the production function which follows the line A-L-H-G. Hence, while the slope of the line A-G gives the break-even wage rate ($1.70) for the whole operation, substitution along the slope A-L would be more advantageous with a break-even daily wage rate of $3.35, but along L-H-G the overall slope would drop to $0.73. With an actual wage rate between these two figures, substitution would be advantageous only up to point L.

Table A.3 (middle portion) and Figure A.2 give a similar production function for earthworks in hilly terrain where the average length of haul is assumed to be 200 m. In this case Method J, hauling by bullock cart, is the most efficient of the labour-intensive methods. Points L and K, both utilising tractor/trailer units for hauling, are intermediate substitution possibilities, and the production function follows the line A-L-K-J. The break-even daily wage rate for the overall operation is $1.12 while the slopes of A-L and L-K-J are 3.80 and 0.49 respectively.

In rolling terrain the average length of haul has been taken as 400 m. and this condition is presented in Table A.3 (lower portion) and Figure A.3. Methods F, G and H (hauling by basket and wheelbarrow) have been excluded in view of the length of haul. Again, the production function follows the line A-L-K-J. The average substitution slope for the overall operation is $0.92 per day while the slopes for A-L and L-K-J are 3.27 and 0.47 respectively.

These three examples demonstrate that the most efficient equipment-intensive method for bulk earthworks is by scraper but substitution for more than half of the equipment input is financially advantageous with wage rates less than about $3.25 per day by using tractor/trailer units for hauling and carrying out the other activities by hand.

Table A.2. Construction Methods for Bulk Excavation in Roadworks

Operation Method	Construction Method for Activity				
	Excavating	Loading	Hauling	Unloading	Spreading
A	Scraper	Scraper	Scraper	Scraper	Scraper
B	D8 dozer	Shovel into truck	Truck	Tipped from truck	Grader
C	D8 dozer	Shovel into truck	Truck	Tipped from truck	Labour
D	D8 dozer	Shovel into trailer	Tractor and trailer	Tipped from trailer	Grader
E	D8 dozer	Shovel into trailer	Tractor and trailer	Tipped from trailer	Labour
F	Labour	Labour into basket	Basket	Tipped from basket	Labour
G	Labour	Labour into wheelbarrow	Wheelbarrow	Tipped from wheelbarrow	Labour
H	Labour	Labour into wheelbarrow	Wheelbarrow	Tipped from wheelbarrow	Grader
J	Labour	Labour into bullock cart	Bullock cart	Labour	Labour
K	Labour	Labour into trailer	Tractor and trailer	Tipped from trailer	Labour
L	Labour	Labour into trailer	Tractor and trailer	Tipped from trailer	Grader
M	Labour	Labour into truck	Truck	Tipped from truck	Labour
N	Labour	Labour into truck	Truck	Tipped from truck	Grader

TABLE A.3 DATA FOR PRODUCTION FUNCTIONS FOR 1,000m^3 OF BULK EXCAVATION IN ROADWORKS

(U.S. Dollars)

Activity	Operation Method																									
	A		B		C		D		E		F		G		H		J		K		L		M		N	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Flat Terrain - 100m. Haul																										
Excavating	167	-	233	-	233	-	233	-	233	-	-	80	-	80	-	80	-	80	-	80	-	80	-	80	-	80
Loading	98	-	331	-	331	-	251	-	251	-	-	60	-	87	-	87	-	135	23	113	23	113	345	113	345	113
Hauling	112	-	36	-	36	-	80	-	80	-	-	500	-	313	-	313	-	280	80	-	80	-	36	-	36	-
Unloading	28	-	31	-	31	-	2	3	2	3	-	7	-	10	-	10	-	67	2	3	2	3	31	-	31	-
Spreading	28	-	10	-	-	40	10	-	-	40	-	1	-	22	5	-	-	1	-	40	10	-	-	40	10	-
Totals	433	-	641	-	631	40	576	3	566	43	-	648	-	512	5	490	-	563	105	236	115	196	412	233	422	193
Hilly Terrain - 200m. Haul																										
Excavating, loading, unloading and spreading as above	321	-	605	-	595	40	496	3	486	43	-	148	-	199	5	177	-	283	25	236	35	196	376	233	386	193
Hauling	193	-	59	-	59	-	107	-	107	-	-	1000	-	850	-	850	-	490	107	-	107	-	59	-	59	-
Totals	514	-	664	-	654	40	603	3	593	43	-	1148	-	1049	5	1027	-	773	132	236	142	196	435	233	445	193
Rolling Terrain - 400m. Haul																										
Excavating, loading, unloading and spreading as above	321	-	605	-	595	40	496	3	486	43	NA		NA		NA		-	283	25	236	35	196	376	233	386	193
Hauling	233	-	87	-	87	-	99	-	199	-	NA		NA		NA		-	910	199	-	199	-	87	-	87	-
Totals	554	-	692	-	682	40	695	3	685	43	NA		NA		NA		-	1193	224	236	234	196	463	233	473	193

Notes: Operation methods are defined in Table 5.2. Production functions are given in Figures 5.2A, 5.2B and 5.2C.
Units for E and L are US $ with daily wage rate of US $2.00 for unskilled labour.
NA = Not applicable.

Source: SWKP Estimates

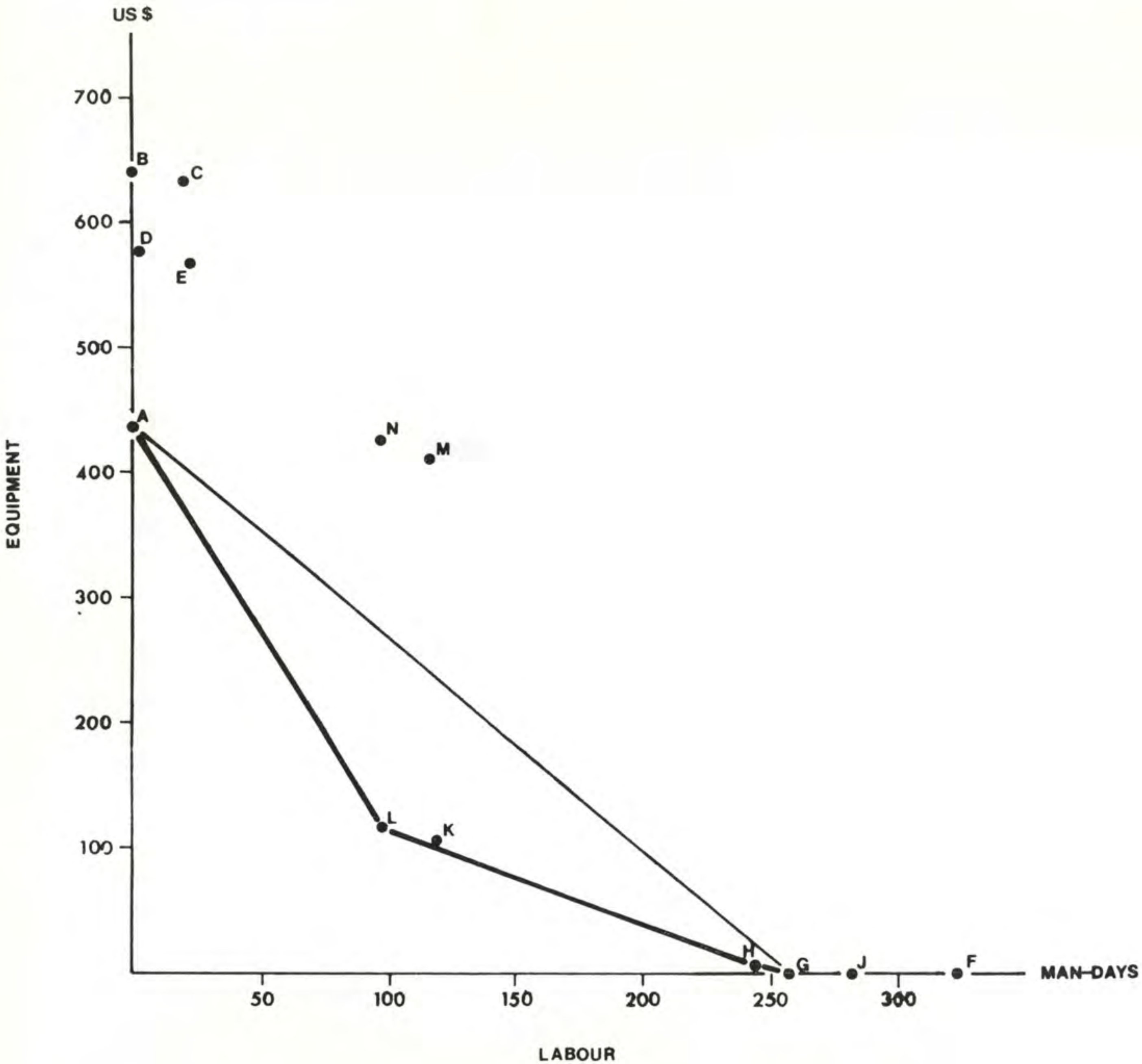


FIGURE A.1: PRODUCTION FUNCTION FOR 1000 M^3 OF BULK EXCAVATION IN ROADWORKS – FLAT TERRAIN (HAULAGE DISTANCE 100 M)

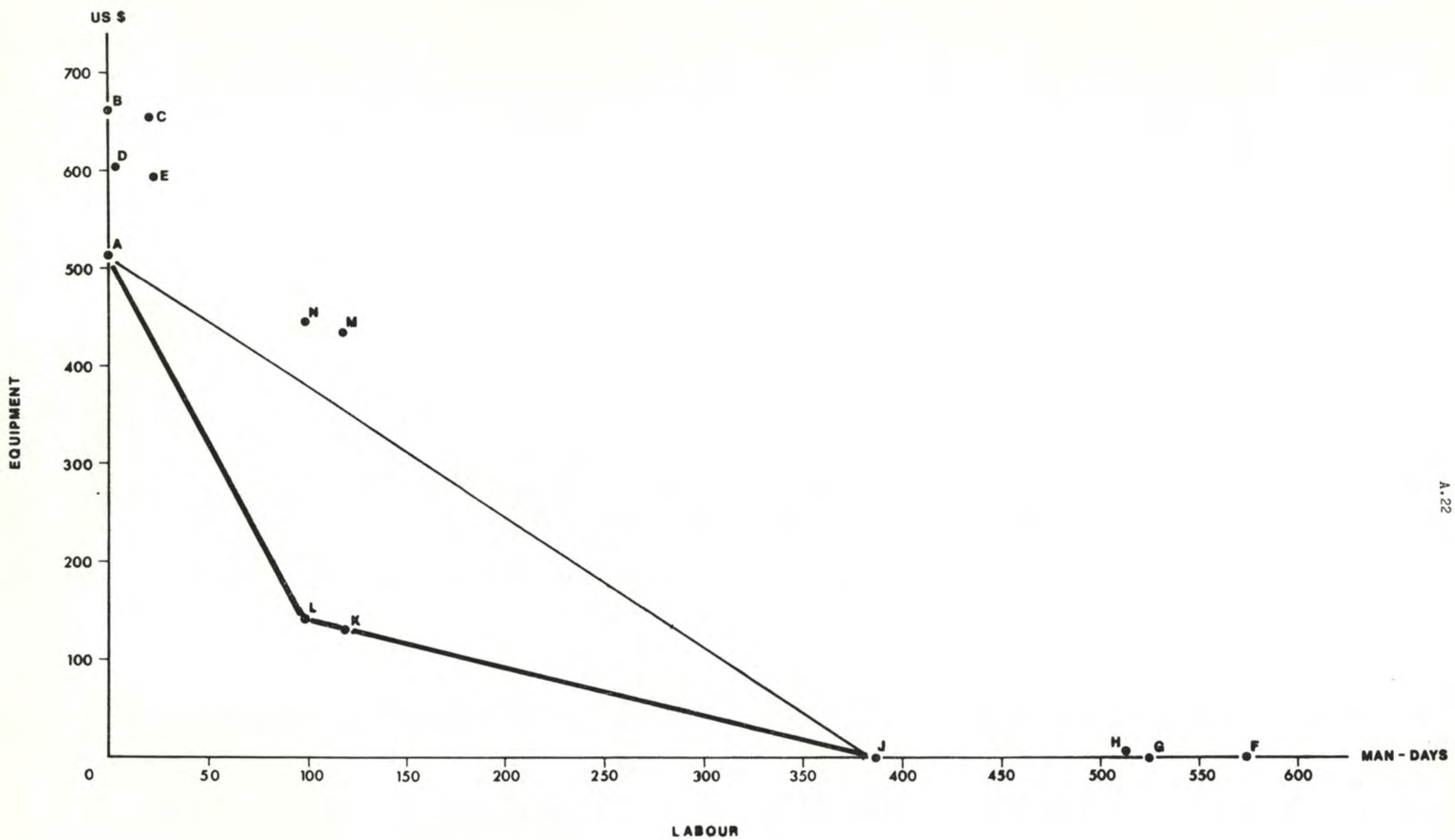


FIGURE A.2 : PRODUCTION FUNCTION FOR 1000 M^3 OF BULK EXCAVATION IN ROADWORKS - HILLY TERRAIN (HAULAGE DISTANCE 200 M)

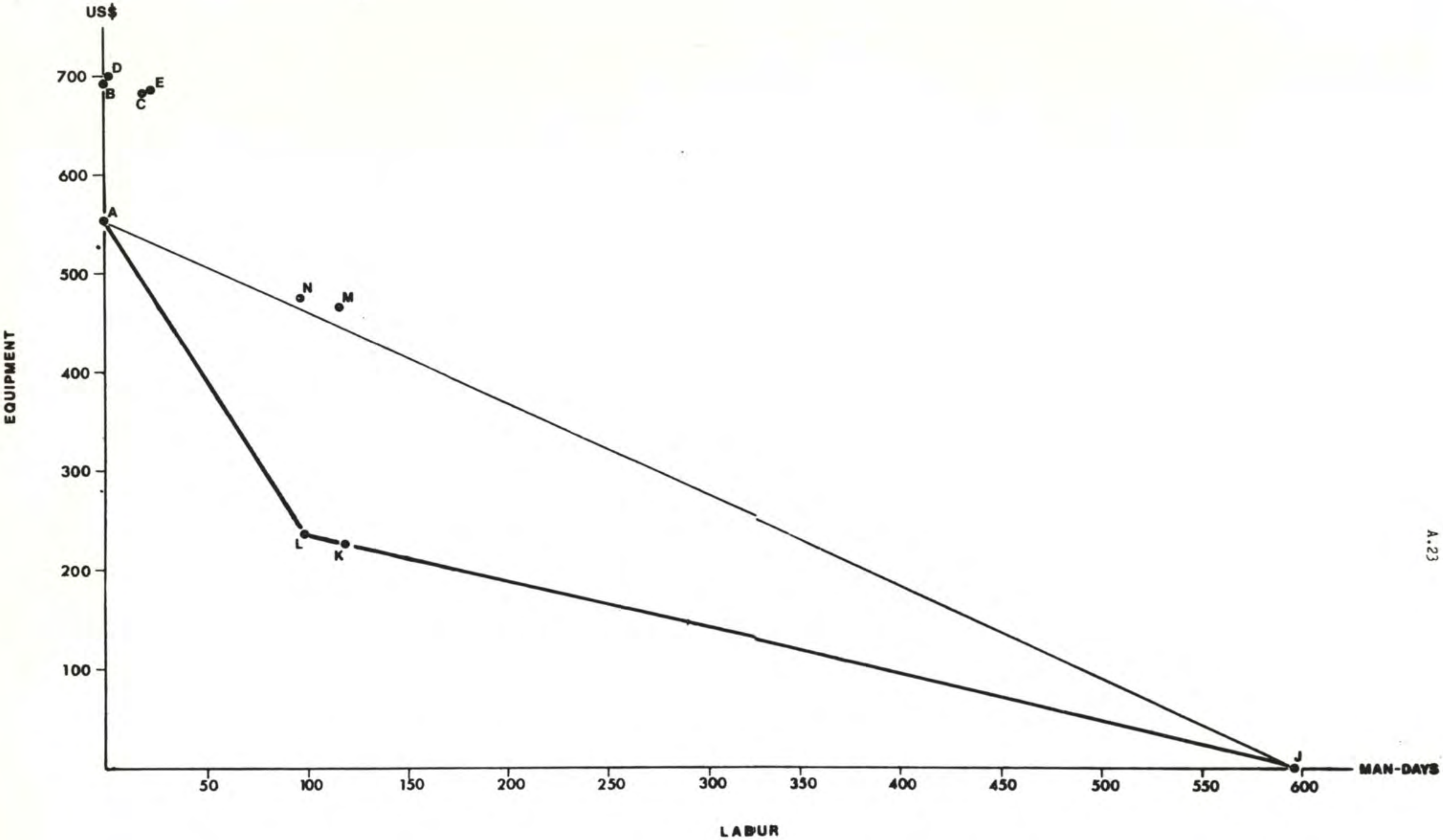


FIGURE A.3 : PRODUCTION FUNCTION FOR 1000 M^3 OF BULK EXCAVATION IN ROADWORKS – ROLLING TERRAIN (HAULAGE DISTANCE 400M)

(b) Rock Excavation in Roadworks

Table A.4 shows the various combinations of construction methods considered for carrying out each activity. Again, the list is not comprehensive and it has been assumed that equipment loading would not be combined with hand excavation.

Table A.5 and Figure A.4 give the production functions for this operation in hilly terrain, assumed haulage distance 200 m, and in rolling terrain where the distance is increased to 400 m (no rock excavation was assumed in flat terrain). Hauling by basket and wheelbarrow, methods F, G, L and M, were considered only for the shorter haul distances in hilly terrain.

In both cases hauling by bullock cart is the most efficient of the labour-intensive operations while tractor/trailer units are more efficient than trucks at the equipment-intensive end of the function. Both functions follow the lines B-D-J-K. The overall break-even wage rate in hilly terrain with the shorter haul is $1.07 per day which reduces to $0.99 per day in rolling terrain with the 400 m hauling distance. The slopes of the individual substitution lines are the same in both cases and are B-D 5.57, D-J 0.91 and J-K 0.45. Line B-D represents the change from shovel to hand loading of trailers.

TABLE A.4: CONSTRUCTION METHODS FOR ROCK EXCAVATION IN ROADWORKS

Operation Method	Construction Method for Activity			
	Excavating	Loading	Hauling	Unloading
A	Compressor, drills and explosives	Shovel into truck	Truck	Tipped from truck
B	"	Shovel into trailer	Tractor and trailer	Tipped from trailer
C	"	Labour into truck	Truck	Tipped from truck
D	"	Labour into trailer	Tractor and trailer	Tipped from trailer
E	"	Labour into bullock cart	Bullock cart	Labour
F	"	Labour into wheelbarrow	Wheelbarrow	Tipped from wheelbarrow
G	"	Labour into basket	Basket	Tipped from basket
H	Labour	Labour into truck	Truck	Tipped from truck
J	"	Labour into trailer	Tractor and trailer	Tipped from trailer
K	"	Labour into bullock cart	Bullock cart	Labour
L	"	Labour into wheelbarrow	Wheelbarrow	Tipped from wheelbarrow
M	"	Labour into basket	Basket	Tipped from basket

Note: This table also applies to the "Rock Excavation in Quarry Operation"

TABLE A.5 DATA FOR PRODUCTION FUNCTIONS FOR 1,000m^3 OF ROCK EXCAVATION IN ROADWORKS

(US dollars)

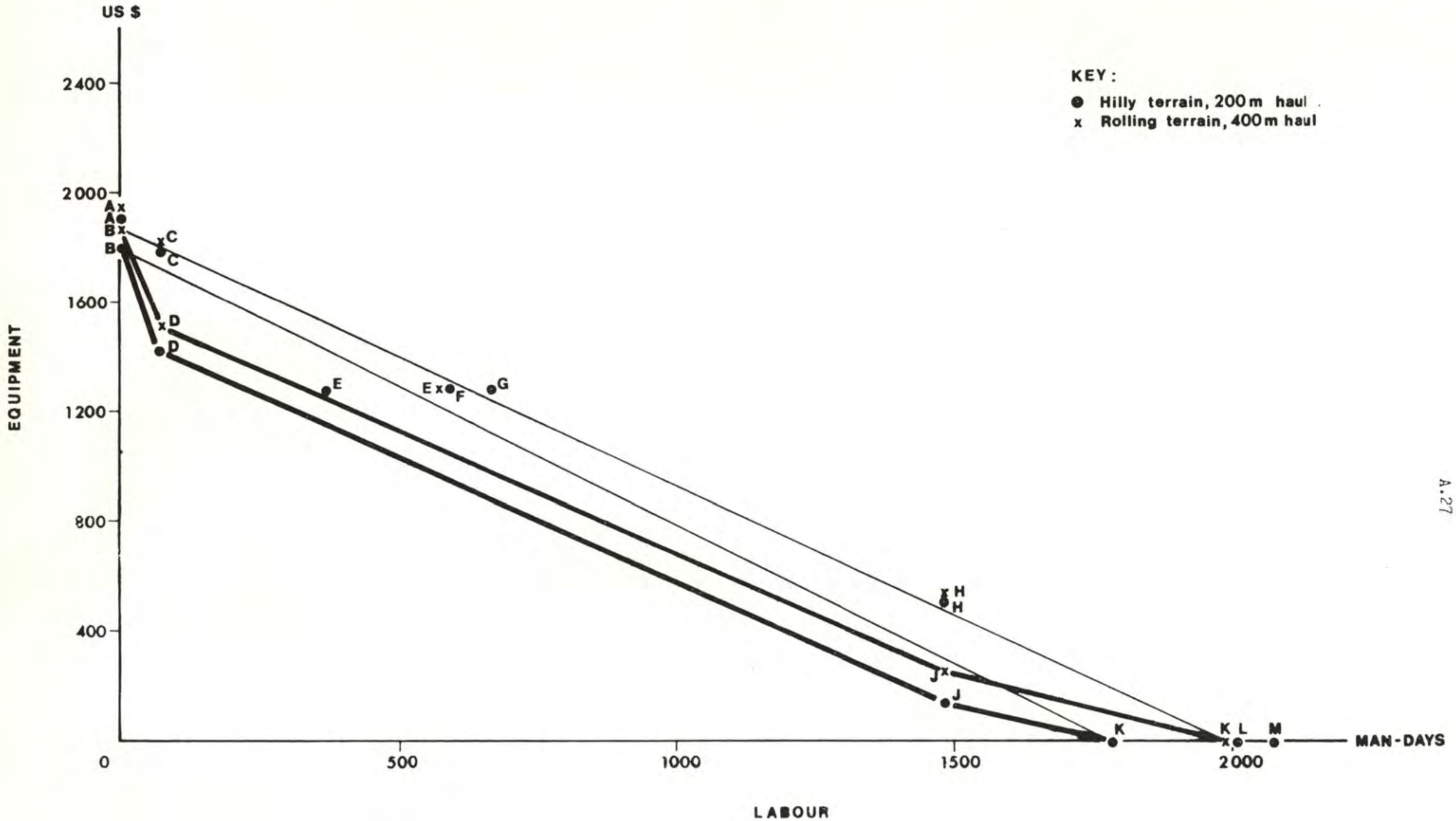
Activity	Operation Method																							
	A		B		C		D		E		F		G		H		J		K		L		M	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Hilly Terrain - 200m. Haul																								
Excavating	1280	-	1280	-	1280	-	1280	-	1280	-	1280	-	1280	-	-	2825	-	2825	-	2825	-	2825	-	2825
Loading	552	-	418	-	433	140	28	140	-	169	-	109	-	75	433	140	28	140	-	169	-	109	-	75
Hauling	59	-	107	-	59	-	107	-	-	490	-	1062	-	1250	59	-	107	-	-	490	-	1062	-	1250
Unloading	15	-	1	2	15	-	1	2	-	67	-	10	-	7	15	-	1	2	-	67	-	10	-	7
Totals	1906	-	1806	2	1787	140	1416	142	1280	726	1280	1181	1280	1332	507	2965	136	2967	-	357	-	4006	-	4157
Rolling Terrain - 400m. Haul																								
Excavating, loading and unloading as above	1847	-	1699	2	1728	140	1309	142	1280	236	NA		NA		448	2965	29	2967	-	3061	NA		NA	
Hauling	87	-	199	-	87	-	199	-	-	910	NA		NA		87	-	199	-	-	910	NA		NA	
Totals	1934	-	1898	2	1815	140	1508	142	1280	1146	NA		NA		535	2965	228	2967	-	3971	NA		NA	

Note : Operation methods are defined in Table 5.3. Production functions are given in Figure 5.3.

Units for E and L are US $ with daily wage rate of US $2.00 for unskilled labour

NA = Not applicable

Source: SWKP Estimates



A.27

FIGURE A.4 PRODUCTION FUNCTIONS FOR 1000 M^3 ROCK EXCAVATION IN ROADWORKS

c. Rock Excavation in Quarry (for crushing)

Quarrying operations are required in the hypothetical road projects to provide material for crushed rock and macadam bases and for chippings for surface dressing (including macadam). This group of sequential activities covers the excavation at the quarry face, loading, hauling an assumed distance of 200 m from the quarry face and unloading at the crushing point. The construction methods considered are identical with those listed in Table A.4 (for rock excavation in earthworks).

The two functions given in Table A.6 and Figure A.5 are a simplified treatment of the substitution possibilities. The effort required to excavate rock is related, inter alia, to the size into which it is broken and this depends on the size of the crushing plant and the method of hauling. At the equipment-intensive end of the functions, two cases have been considered:-

(1) rock for the production of bases courses, and
(2) rock for the production of chippings.

In the second case, a closer pattern of blasting has been assumed to provide smaller sized rock fragments. In the labour-intensive method, excavating includes breaking to sizes which can be carried by hand.

Hauling by bullock cart is the most efficient of the labour-intensive methods. The production functions follow the lines A-B-D-E-K in both cases. The overall break-even wage rates are $0.72 and 0.59 per day, the higher figure applying to the rock for chippings. The substitution slopes are steep, averaging $5.50 per day, between A and D, the substitution of shovel-loaded trucks by hand-loaded tractor/trailer units. For the remaining analyses the production function has been taken to start at B and the slopes of the segments of the function for basecourse rock are:

B-D	U.S.$4.36 per day
D-E	0.47
E-K	0.33

and for chippings

B-D	4.36
D-K	0.50

TABLE A.6 DATA FOR PRODUCTION FUNCTIONS FOR 1,000m^3 ROCK EXCAVATION IN QUARRY (FOR CRUSHING)

(US dollars)

Activity	Operation Method A		B		C		D		E		F		G		H		J		K		L		M	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Rock for Base Aggregates																								
Excavating	419	-	419	-	419	-	419	-	419	-	419	-	419	-	-	2500	-	2500	-	2500	-	2500	-	2500
Loading	442	-	335	-	433	141	28	141	-	169	-	109	-	75	433	141	28	141	-	169	-	109	-	75
Hauling 200m.	59	-	107	-	59	-	107	-	-	490	-	1063	-	1250	59	-	107	-	-	490	-	1063	-	1250
Unloading	31	-	2	3	31	-	2	3	-	67	-	10	-	7	31	-	2	3	-	67	-	10	-	7
Totals	951	-	863	3	942	141	556	144	419	726	419	1182	419	1332	523	2641	137	2644	-	3226	-	3682	-	3832
Rock for Chippings																								
Excavating	631	-	631	-	631	-	631	-	631	-	631	-	631	-	-	2500	-	2500	-	2500	-	2500	-	2500
Loading, hauling and unloading as above	532	-	444	3	523	141	137	144	-	726	-	1182	-	1332	523	141	137	144	-	726	-	1182	-	1332
Totals	1163	-	1075	3	1154	141	768	144	631	726	631	1182	631	1332	523	2641	137	2644	-	3226	-	3682	-	3832

Notes: Operation methods are defined in Table 5.3. Production functions are given in Figure 5.4.

Units for E and L are US $ with daily wage rate of US $2.00 for unskilled labour.

Source: SWKP Estimates

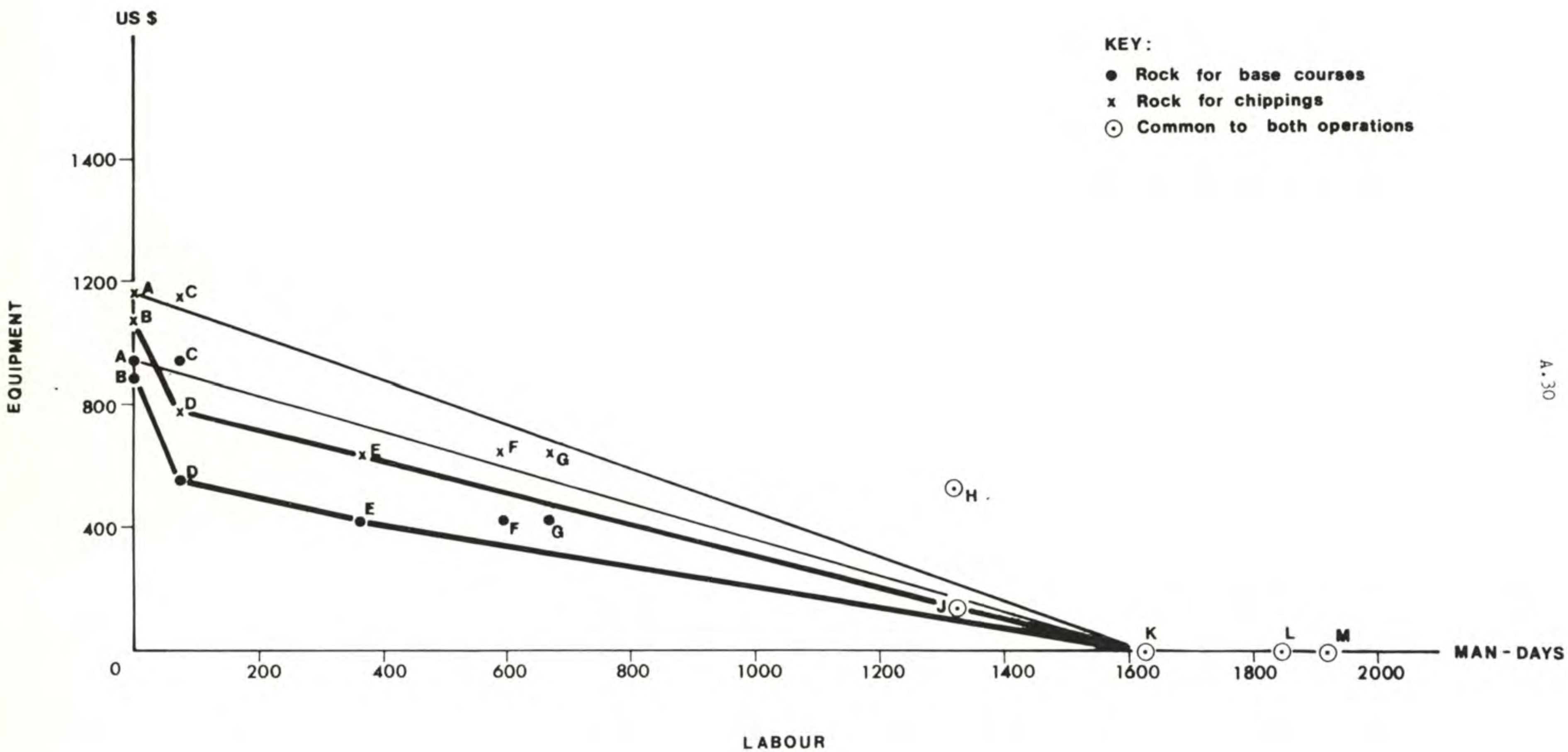


FIGURE A.5 : PRODUCTION FUNCTIONS FOR 1000 M^3 ROCK EXCAVATION IN QUARRY

(d) Gravel Sub-base

This operation covers the excavating, loading, hauling 1 km, unloading and spreading activities. The construction methods considered are listed in Table A.7. Substitution in the spreading operation at the high level of quality is not feasible since this is an 'E' category activity.

The production functions at both levels of quality are given in Table A.8 and Figure A.6. For high quality the production function follows the line A-G-J with an average daily break-even wage rate of $0.80. At intermediate quality, the function is A-B-H-K with an average slope of U.S. $0.94 per day. Substituting hand-loaded trailers (points G and H) gives average substitution slopes of $4.94 and $5.24 per day, respectively, at high and intermediate levels of quality. At the latter quality, the slopes of the segments are: -

A-B	U.S. $6.96 per day
B-H	4.94
H-K	0.28

(e) Gravel Base

The construction methods considered for the excavating, loading, hauling, unloading and spreading gravel sub-base are identical with those defined in Table A.7. For gravel base the length of haul has been assumed to be 2 km.

The production functions at high and intermediate levels of quality are given in Table A.8 and Figure A.7. The functions follow a similar pattern to those for the sub-base and substitution slopes are:-

High Quality

A-J (overall)	U.S. $0.38 per day
A-G	3.98
G-J	0.24

Intermediate Quality

A-K (overall)	0.56
A-B	6.96
B-H	3.98
H-K	0.25

Again, the substitution of hand-loaded trailers for shovel-loaded trucks is particularly advantageous.

TABLE A.7: CONSTRUCTION METHODS FOR GRAVEL SUB-BASE, GRAVEL BASE, MACADAM BASE, AND CRUSHED ROCK BASE.

eration ethod	Construction Method for Activity					
	Excavating	Loading	Hauling	Unloading	Spreading(1)	Spreading(2
A	D8	Shovel into truck	Truck	Tipped from truck	Paver	D8 with spreader box
B	"	"	"	"	N.A.	Labour
C	"	Shovel into trailer	Tractor and trailer	Tipped from trailer	Paver	D8 with spreader box
D	"	"	"	"	N.A.	Labour
E	Labour	Labour into truck	Truck	Tipped from truck	Paver	D8 with spreader box
F	"	"	"	"	N.A.	Labour
G	"	Labour into trailer	Tractor and trailer	Tipped from trailer	Paver	D8 with spreader box
H	"	"	"	"	N.A.	Labour
J	"	Labour into bullock cart	Bullock cart	Labour	Paver	D8 with spreader box
K	"	"	"	"	N.A.	Labour

Spreading (1) - High quality

Spreading (2) - Intermediate quality

N.A. - not applicable at this quality level.

TABLE A.8: DATA FOR PRODUCTION FUNCTIONS FOR 1,000m³ GRAVEL SUB-BASE AND BASE

(US dollars)

Activity	Operation Method																			
	A		B		C		D		E		F		G		H		J		K	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Gravel Sub-base																				
Excavating	467	-	467	-	467	-	467	-	-	160	-	160	-	160	-	160	-	160	-	160
Loading	331	-	331	-	251	-	251	-	345	113	345	113	22	113	22	113	-	135	-	135
Hauling - 1km.	155	-	155	-	279	-	279	-	155	-	155	-	279	-	279	-	-	2100	-	2100
Unloading	31	-	31	-	2	3	2	3	31	-	31	-	2	3	2	3	-	67	-	67
Spreading - High Quality	196	-	NA		196	-	NA		196	-	NA		196	-	NA		196	-	NA	
Spreading - Int. Quality	174	-	-	50	174	-	-	50	174	-	-	50	174	-	-	50	174	-	-	1
Totals - High Quality	1180	-	NA		1195	3	NA		727	273	NA		499	276	NA		196	2462	NA	
Totals - Int. Quality	1158	-	984	50	1173	3	999	53	705	273	531	323	477	276	303	326	174	2462	-	2463
Gravel Base																				
Excavating, loading, unloading & spreading as above																				
High Quality	1025	-	NA		916	3	NA		572	273	NA		220	276	NA		196	362	NA	
Int. Quality	1003	-	829	50	894	3	720	53	550	273	376	323	198	276	24	326	174	362	-	363
Hauling - 2km.	245	-	245	-	501	-	501	-	245	-	245	-	501	-	501	-	-	4200	-	4200
Totals - High Quality	1270	-	NA		1417	3	NA		817	273	NA		721	276	NA		196	4562	NA	
- Int. Quality	1248	-	1074	50	1395	3	1221	53	795	273	621	323	699	276	525	326	174	4562	-	4563

Notes: Operation methods are defined in Table 5.4. Production functions are given in Figures 5.5 and 5.6

Units for E and L are US $ with daily wage rate of US $2.00 for unskilled labour

NA = Not applicable

Source: SWKP Estimates

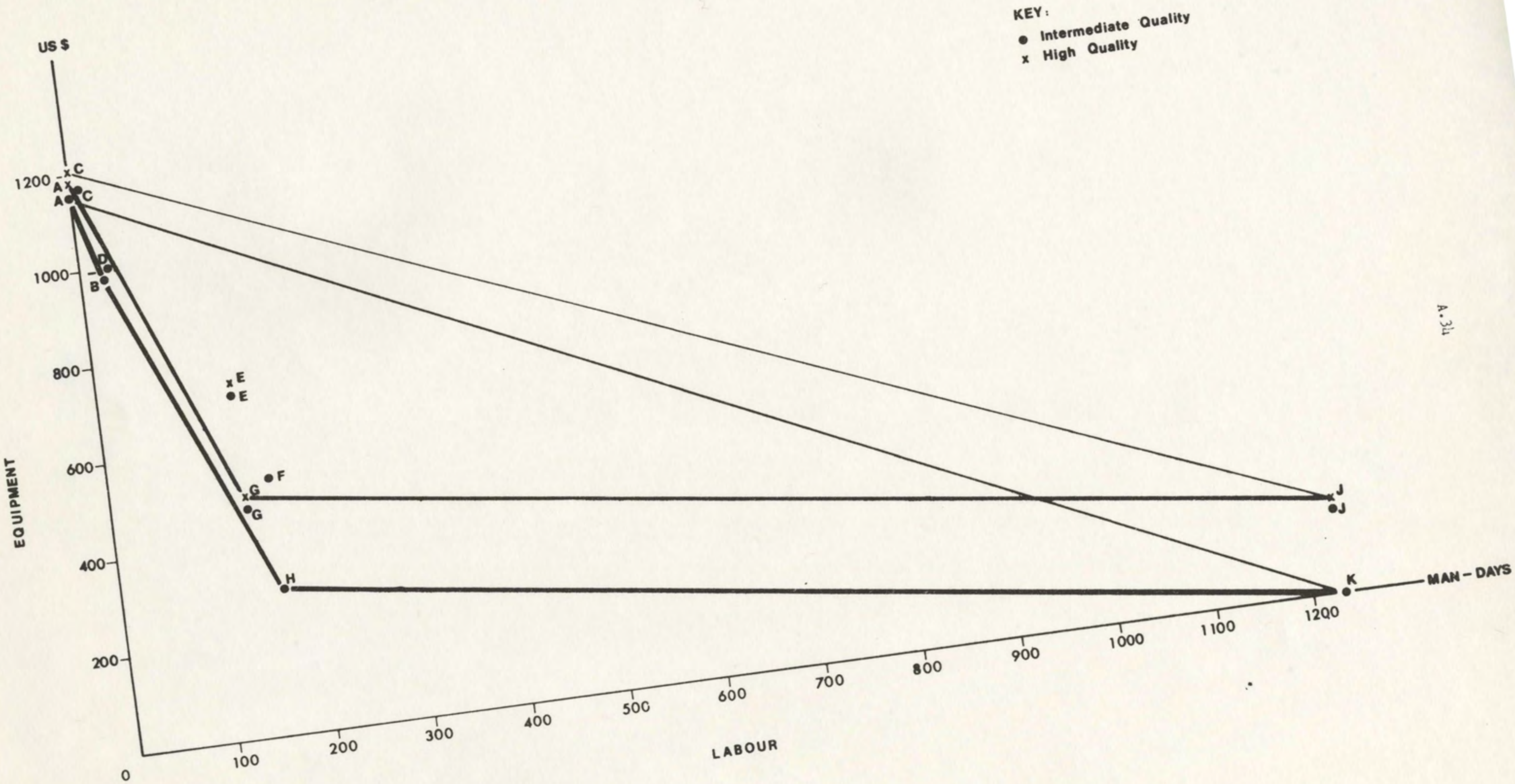


FIGURE A.6: PRODUCTION FUNCTIONS FOR 1000 M^3 GRAVEL SUB-BASE

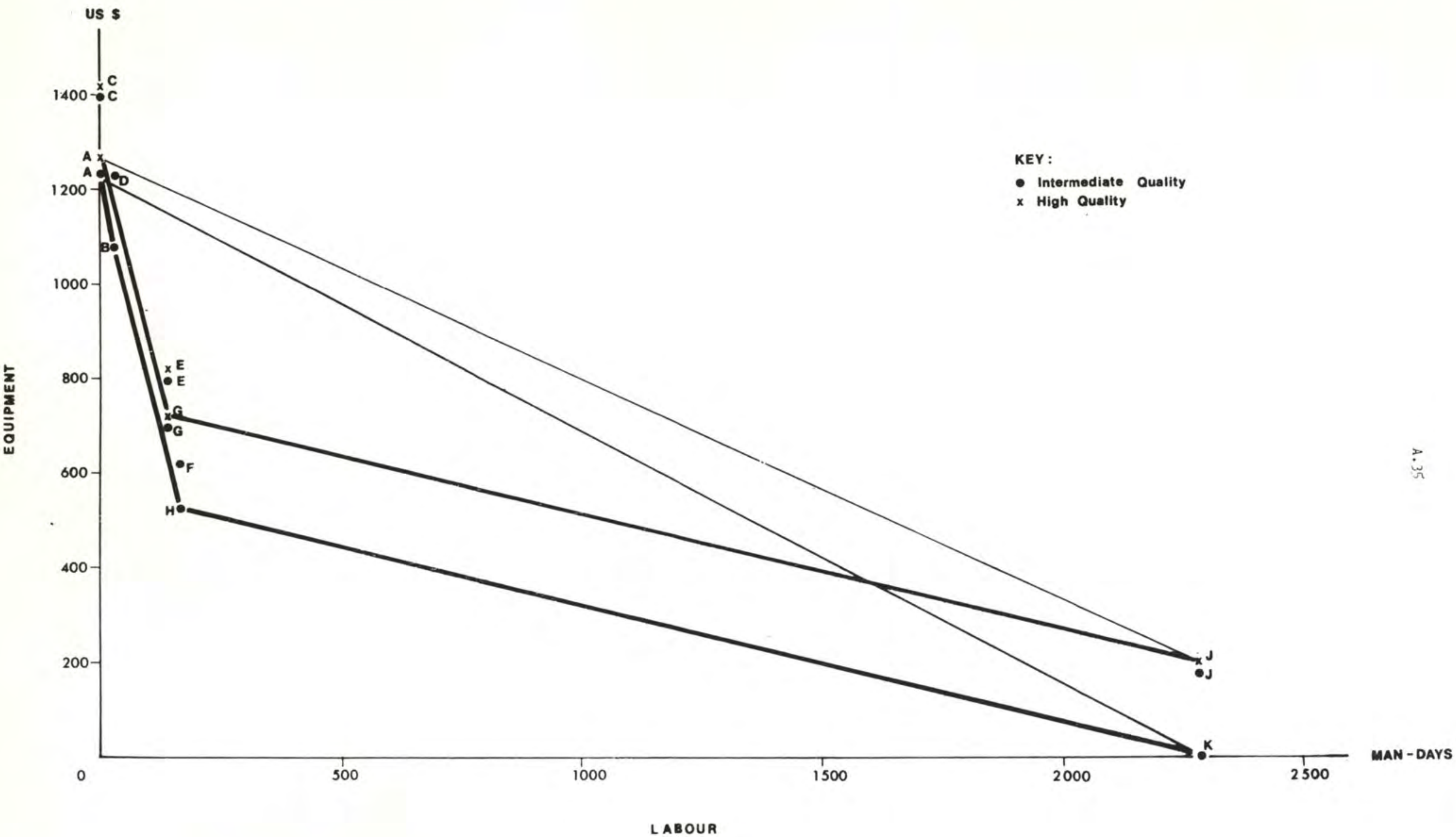


FIGURE A.7: PRODUCTION FUNCTIONS FOR 1000 M^3 GRAVEL BASE

(f) Macadam Base (from crusher to site)

The construction methods considered are again identical with those defined in Table A.7. For macadam base, the length of haul has been assumed to be 5 km. The two production functions are given in Table A.9 and Figure A.8.

For high quality, the substitution slope is the line A-J of value $0.17 per day. Since this slope is less than $0.20 per day, substitution is not practicable by our definition and hence the production function consists of a single point A on the equipment axis.

At the intermediate level of quality, the substitution slopes are:-

A-K	U.S. $0.204 per day
A-B	6.96
B-K	0.17

Hence the production function consists of the line A-B which consists of substitution of labour in only the spreading operation.

It is notable that trucks are more economic than tractor/trailer units with a 5 km. length of haul.

(g) Crushed Rock Base

For this operation, the construction methods are the same as those considered for the other basecourse materials and are defined in Table A.7. In this case the length of haul is assumed to be 10 km.

Examination of Table A.9 shows that the production functions follow a similar pattern for those for macadam base. Trucks are again the best method of haulage. For high levels of quality, no substitution is possible and the production function consists of a single point on the equipment axis. At intermediate quality levels, substitution is restricted to the spreading operation.

TABLE A.9 : DATA FOR PRODUCTION FUNCTIONS FOR 1,000m^3 MACADAM AND CRUSHED ROCK BASES (FROM CRUSHER TO SITE)

(US dollars)

Activity	Operation Method																			
	A		B		C		D		E		F		G		H		J		K	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
Macadam Base																				
Loading	331	-	331	-	251	-	251	-	345	113	345	113	22	113	22	113	-	135	-	135
Hauling - 5km.	538	-	538	-	1165	-	1165	-	538	-	538	-	1165	-	1165	-	-	10500	-	10500
Unloading	31	-	31	-	2	3	2	3	31	-	31	-	2	3	2	3	-	67	-	67
Spreading - High Quality	196	-	NA		196	-	NA		196	-	NA		196	-	NA		196	-	NA	
Spreading - Int. Quality	174	-	-	50	174	-	-	50	174	-	-	50	174	-	-	50	174	-	-	1
Totals - High Quality	1096	-	NA		1614	3	NA		1110	113	NA		1385	116	NA		196	10702	NA	
Totals - Int. Quality	1074	-	900	50	1592	3	1418	53	1088	113	914	163	1363	116	1189	166	174	10702	-	10703
Crushed Rock Base																				
Loading, unloading and spreading as above																				
High Quality	558	-	NA		449	3	NA		572	113	NA		220	116	NA		NA		NA	
Int. Quality	536	-	362	50	427	3	253	53	550	113	376	163	198	116	24	166	NA		NA	
Hauling - 10km.	1018	-	1018	-	2272	-	2272	-	1018	-	1018	-	2272	-	2272	-	NA		NA	
Totals - High Quality	1576	-	NA		2721	3	NA		1590	113	NA		2492	116	NA		NA		NA	
Totals - Int. Quality	1554	-	1380	50	2699	3	2525	53	1568	113	1394	163	2470	116	2296	116	NA		NA	

Note: Operation methods are defined in Table 5.4. The production function for macadam base is given in Figure 5.7

Units for E and L are US $ with daily wage rate of US $2.00 for unskilled labour.

NA = Not Applicable

Source: SWKP Estimates

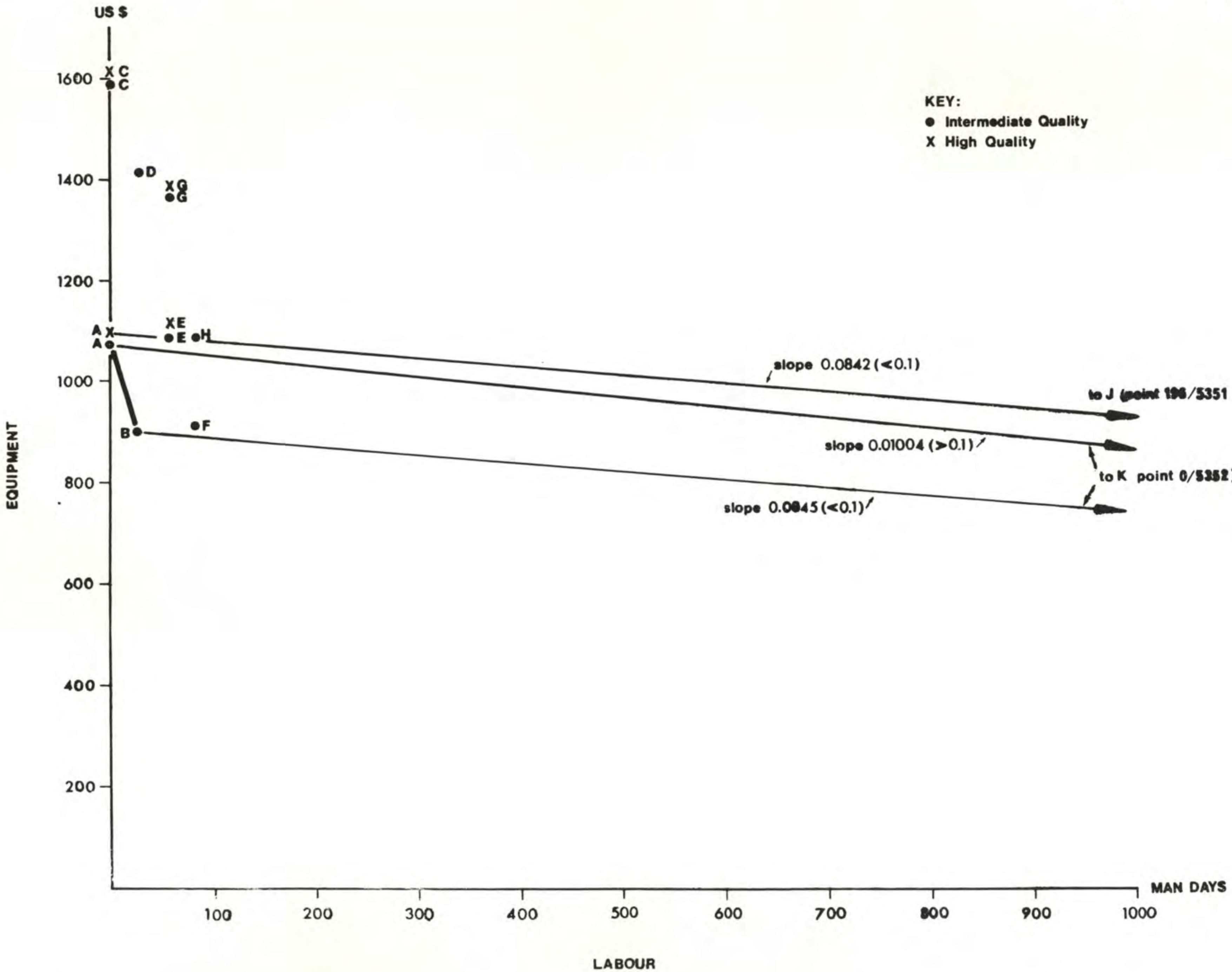


FIGURE A.8: PRODUCTION FUNCTIONS FOR 1000 M^3 MACADAM BASE

A.38

(h) Water Distribution

Table A.10 shows the various combinations of methods considered for carrying out the activities of loading, hauling (2 km), unloading and spreading water.

Examination of Table A.11 shows that substitution of either method B or method C for method A would give a negative substitution slope; and substitution of either method D or method E for method A would give a positive slope of less that $0.20 per day. Hence no substitution is practicable and the production function is a single point on the equipment axis.

(i) Chippings for Surface Dressings (from crusher to site)

The various combinations of methods considered for loading, hauling, unloading and spreading chippings for surface dressing are shown in Table A.12. The haul distance is assumed to be 5 km for surface dressing macadam base.

This production function is given in Table A.13 and Figure A.9. The substitution slopes are:-

A-G	U.S.$0.24 per day
A-C	1.13
C-G	0.17

Hence the production function consists of the line A-C, the substitution of spreading by hand for spreading by truck equipped with a chipping spreader.

There are similar substitution possibilities where the length of haul is increased to 10 km, as in the case of surface dressing for gravel and crushed rock bases. In all cases, haul by truck is more economic than haul by tractor/ trailer units and the slope of the production function is $1.18 per day.

TABLE A.10 CONSTRUCTION METHODS FOR WATER DISTRIBUTION

Operation Method	Construction Method for Activity			
	Loading	Hauling	Unloading	Spreading
A	Pump into bowser	Bowser	By bowser	By bowser
B	Pump into trailer	Tractor and trailer	Labour	Labour
C	Labour into trailer	"	"	"
D	Pump into bullock cart	Bullock cart	"	"
E	Labour into bullock cart	"	"	"

TABLE A.11: DATA FOR PRODUCTION FUNCTION FOR 1,000m³ WATER DISTRIBUTION

(US dollars)

Activity	Operation Method									
	A		B		C		D		E	
	E	L	E	L	E	L	E	L	E	L
Loading	76	-	9	-	100	500	6	2	-	600
Hauling	137	-	752	-	752	-	-	7000	-	7000
Unloading	-	-	50	250	50	250	-	300	-	300
Spreading	255	-	-	167	-	167	-	167	-	167
Totals	468	-	811	417	902	917	6	7469	-	8067

Notes: Operation methods are defined in Table 5.5

Units for E and L are US $ with daily wage rates of US $2.00 for unskilled labour

Source: SWKP Estimates

TABLE **A.12** CONSTRUCTION METHODS FOR **HAULING AND SPREADING** CHIPPINGS FOR SURFACE DRESSINGS

Operation Method	Construction Method for Activity			
	Loading	Hauling	Unloading	Spreading
A	Shovel into Truck	Truck	N.A.	Truck
B	Labour into truck	"	N.A.	Truck
C	Shovel into truck	"	Tipping from truck	Labour
D	Labour into truck	"	"	"
E	Shovel into trailer	Tractor and trailer	Tipping from trailer	"
F	Labour into trailer	"	"	"
G	Labour into bullock cart	Bullock cart	Labour	"

Note: In Methods A and B, the truck is equipped with a chipping spreader.

TABLE A.13 DATA FOR PRODUCTION FUNCTIONS FOR 1,000m^3 CHIPPINGS FOR SURFACE DRESSING (FROM CRUSHER TO SITE)

(US dollars)

Activity	Operation Method													
	A		B		C		D		E		F		G	
	E	L	E	L	E	L	E	L	E	L	E	L	E	L
For macadam bases														
Loading	339	-	353	113	331	-	345	113	251	-	22	113	-	135
Hauling - 5km.	569	-	569	-	538	-	538	-	1165	-	1165	-	-	10500
Unloading	-	-	-	-	31	-	31	-	2	3	2	3	-	67
Spreading	556	556	556	-	-	1000	-	1000	-	1000	-	1000	-	667
Totals	1464	-	1478	113	900	1000	914	1113	1418	1003	1189	1116	-	11369
For gravel and crushed rock bases														
Loading, unloading and spreading as above	895	-	909	113	362	1000	376	1113	253	1003	24	1116	-	869
Hauling - 10km.	1074	-	1074	-	1018	-	1018	-	2272	-	2272	-	-	21000
Totals	1969	-	1983	113	1380	1000	1394	1113	2523	1003	2296	1116	-	21869

Notes: Operation methods are defined in Table 5.6. The production function for chippings for macadam bases is given in Figure 5.8

Units for E and L are US $ with a daily wage rate of US $2.00 for unskilled labour.

Source: SWKP Estimates

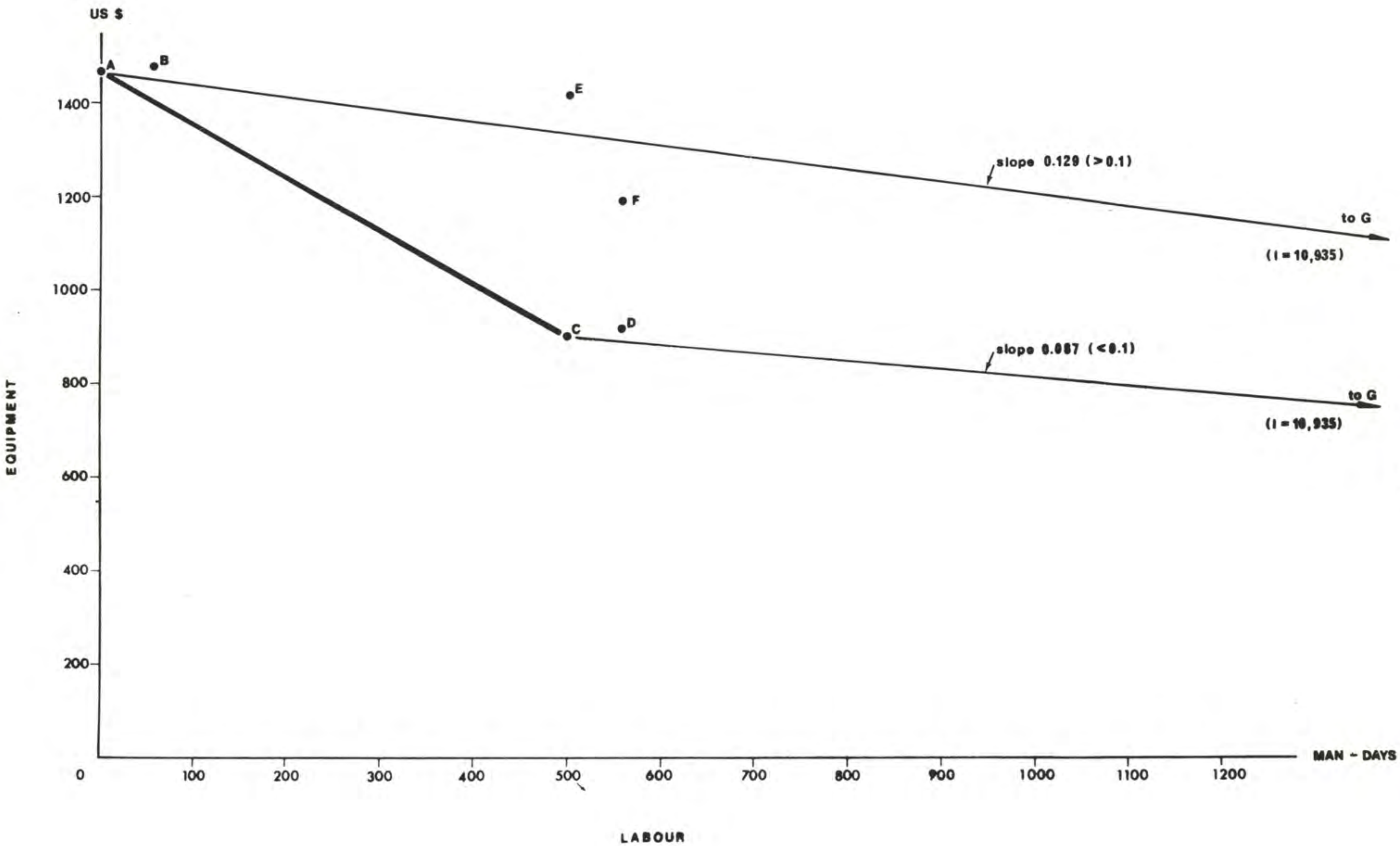


FIGURE A-9: PRODUCTION FUNCTION FOR 1000 M^3 OF CHIPPINGS FOR SURFACE DRESSING - HAUL DISTANCE 5 KM

(j) Bitumen Distribution

This operation consists of the activities needed to load, haul from the base camp, unload heat, and spread bitumen for surface dressing. Direct comparison between individual activities for labour- and equipment-intensive methods is not possible since the activities differ in themselves.

The following groups of activities have been compared:

Method A (equipment-intensive)

(1) Load bitumen by hand from drums into a static heater and heat bitumen.
(2) Pump heated bitumen from static heater to mobile distributor.
(3) Haul heated bitumen from base camp to site (10 km.)
(4) Spread heated bitumen by distributor.

This method would be the same for high and intermediate levels of quality.

Method B (labour-intensive)

(1) Load bitumen in drums into truck by hand.
(2) Haul drums in truck from base camp to site (10 Km.)
(3) Unload bitumen in drums from truck by labour at site.
(4) Load bitumen from drums into mobile heater by labour and heat.
(5) Unload and spread heated bitumen by labour.

This method would apply only for intermediate quality.

Method C (labour-intensive)

As method B but using tractor/trailer units instead of trucks.

From Table A.14, it can be seen that Method B is superior in that it entails a lower equipment cost than Method C while the labour content is the same.

There are no intermediate substitution possibilities between the two methods and the production function is a straight line connecting A to B, of slope $1.76 per day. Substitution is therefore advantageous at any lower wage.

TABLE A.14: DATA FOR PRODUCTION FUNCTION FOR 1,000 TONNE BITUMEN DISTRIBUTION - INTERMEDIATE QUALITY

(US dollars)

Activity	Operational Method					
	A		B		C	
	E	L	E	L	E	L
Loading into static heater	4360	170	NA		NA	
Loading into mobile heater	NA		3120	500	3120	500
Loading drums into vehicle	NA		460	175	26	175
Loading distributor from static heater	707	-	NA		NA	
Hauling drums in vehicle	NA		849	-	3029	-
Hauling bitumen in distributor	1069	-	NA		NA	
Unloading drums from vehicle	NA		230	88	13	88
Unloading and spreading bitumen	9960	-	-	12500	-	12500
Totals	16096	170	4659	13263	6188	13263

Notes: Operation methods are defined in Para 5.55

The heating operation is included under loading.

NA = Not applicable

Source: SWKP Estimates

4. Analysis of Costs per Kilometre for Different Road Types and Different Terrains by SWKP

In this series of analyses, the work involved in one kilometre of each of the hypothetical road projects has been broken down into basic construction activities and estimates of the costs of equipment and unskilled labour (at $2.00 per day) have been prepared for carrying out each activity by equipment- and labour-intensive methods at high and intermediate levels of quality. Substitution has been assumed to take place provided that the break-even wage rate is shown to be greater than $0.20 per day.

The methods assumed for carrying out each activity by equipment and by labour have been taken to be those found to lie on the production function in the previous analyses. Those for the independent activities are listed in Table II.3, while those for the interdependent activities are given in Table II.13.

To permit comparison between a scraper operation for excavating, loading, hauling, unloading and spreading earthworks with labour-intensive methods in which each of the interdependent activities can be costed individually, scraper costs have been allocated to each activity to accord with its cycle time.

a. High Quality Equipment-Intensive Method (Table A.16)

Taking costs in flat terrain as a base, the proportionate increases in total costs per kilometre in other terrains are given below:-

Terrain	Road Type		
	A	B	C
Flat	1.00	1.00	1.00
Rolling	1.40	1.33	1.32
Hilly	1.73	1.61	1.59

The increases in cost due to more difficult terrain are seen to be greater for the less costly road type A (gravel base) and there is little difference between types B and C.

With costs for road type A as a base, the proportionate increases in total costs per kilometre for the other road types are:-

Terrain	Road Type		
	A	B	C
Flat	1.00	1.20	1.23
Rolling	1.00	1.15	1.17
Hilly	1.00	1.12	1.14

The proportionate increases become smaller as the terrain becomes more difficult.

TABLE A.15 CONSTRUCTION METHODS FOR INTERDEPENDENT ACTIVITIES ASSUMED IN ANALYSES OF COSTS PER KILOMETRE OF THE HYPOTHETICAL ROAD PROJECTS

Operation	Quality	Equipment - Intensive					Labour - Intensive				
		Excavating	Loading	Hauling	Unloading	Spreading	Excavating	Loading	Hauling	Unloading	Spreading
Bulk excavation in roadworks - haul 100 m.	N.A.	Scraper	Scraper	Scraper	Scraper	Scraper	Labour	Labour	Wheel-Barrow	Labour	Labour
Bulk excavation in roadworks - haul 200 and 400 m	N.A.	Scraper	Scraper	Scraper	Scraper	Scraper	Labour	Labour	Bullock cart	Labour	Labour
Rock excavation in roadworks	N.A.	Compressor & explosives	Shovel	Tractor/ trailer	Tractor/ trailer	N.A.	Labour	Labour	Bullock cart	Labour	N.A.
Rock excavation in quarry (for crushing)	N.A.	Compressor & explosives	Shovel	Tractor/ trailer	Tractor/ trailer	N.A.	Labour	Labour	Bullock cart	Labour	N.A.
Gravel sub-base and base	High	Dozer	Shovel	Truck	Truck	Paver	Labour	Labour	Bullock cart	Labour	Paver
Gravel sub-base and base	Inter-mediate	Dozer	Shovel	Truck	Truck	Spreader box	Labour	Labour	Bullock cart	Labour	Labour
Macadam and crushed rock base	High	N.A.	Shovel	Truck	Truck	Paver	N.A.	Shovel	Truck	Truck	Paver
Macadam and crushed rock base	Inter-mediate	N.A.	Shovel	Truck	Truck	Spreader box	N.A.	Shovel	Truck	Truck	Labour
Water distribution	N.A.	N.A.	Pump	Bowser	N.A.	Bowser	N.A.	Pump	Bowser	N.A.	Bowser
Chippings for surface dressing (from crusher to site)	N.A.	N.A.	Shovel	Truck*	N.A.	Truck*	N.A.	Shovel	Truck	Truck	Labour
Bitumen distribution	High	N.A.	Labour into static heater Pump into distri-butor	Distri-butor	N.A.	Distri-butor	N.A.	Labour into static heater Pump into distri-butor	Distri-butor	N.A.	Distri-butor
Bitumen distribution	Inter-mediate	N.A.	Labour into static heater Pump into distri-butor	Distri-butor	N.A.	Distri-butor	N.A.	Labour into trucks and mobile heater	Truck	Labour	Labour
Replacing topsoil	N.A.	N.A.	Shovel	Shovel	Shovel	Labour	N.A.	Labour	Labour	Labour	Labour
Grass roots for sprigging	N.A.	Grader	Shovel	Truck	Truck	Labour (planting)	Labour	Shovel	Truck	Truck	Labour (planting)

N.A. – Not applicable
Source: SWKP estimates

* truck with chipping spreader

TABLE A.16 ANALYSES OF COSTS PER KILOMETRE OF HYPOTHETICAL ROAD PROJECTS

HIGH QUALITY EQUIPMENT-INTENSIVE METHODS

Activity Group		Flat Terrain			Rolling Terrain			Hilly Terrain		
		A	B	C	A	B	C	A	B	C
No	Description	E - L	E - L	E - L	E - L	E - L	E - L	E - L	E - L	E - L
1.	Site Preparation	1100 - (11.7)	1100 - (9.7)	1100 - (9.4)	1100 - (8.3)	1100 - (7.2)	1100 - (7.1)	1100 - (6.7)	1100 - (6.0)	1100 - (5.9)
2.	Excavating Small Quantities	17 - (.2)	17 - (.1)	17 - (.1)	138 - (1.0)	138 - (.9)	138 - (.9)	363 - (2.2)	363 - (2.0)	363 - (2.0)
3.	Excavating in Bulk	2239 - (23.7)	2217 - (19.6)	2182 - (18.8)	3295 - (25.0)	3273 - (21.6)	3238 - (21.0)	4741 - (29.1)	4719 - (25.9)	4684 - (25.3)
4.	Loading	1629 3 (17.3)	2060 3 (18.2)	2031 3 (17.5)	2200 3 (16.7)	2631 3 (17.4)	2602 3 (16.9)	2862 3 (17.5)	3293 3 (18.0)	3264 3 (17.6)
5.	Hauling	1272 - (13.5)	1742 - (15.4)	2329 - (20.0)	3031 - (23.0)	3501 - (23.2)	4088 - (26.5)	3551 - (21.8)	4021 - (22.0)	4608 - (24.9)
6.	Unloading	229 - (2.4)	231 4 (2.0)	231 4 (2.0)	363 - (2.7)	365 4 (2.4)	365 4 (2.4)	488 1 (3.0)	490 5 (2.7)	490 5 (2.6)
7.	Spreading	966 - (10.2)	974 - (8.6)	966 - (8.3)	1036 - (7.8)	1044 - (6.9)	1036 - (6.7)	1106 - (6.8)	1114 - (6.1)	1106 - (6.0)
9.	Compacting and Finishing	394 - (4.2)	393 - (3.5)	393 - (3.4)	440 - (3.3)	439 - (2.9)	439 - (2.8)	485 - (3.0)	484 - (2.6)	484 - (2.6)
11.	Production of Local Materials	265 - (2.8)	1416 - (12.5)	1075 - (9.2)	265 - (2.0)	1416 - (9.4)	1075 - (7.0)	265 - (1.6)	1416 - (7.8)	1075 - (5.8)
12.	Miscellaneous	41 83 (.4)	26 83 (.2)	41 83 (.3)	43 103 (.3)	28 103 (.2)	43 103 (.3)(.7)	46 124 (.3)	31 124 (.2)	46 124 (.2)(.7)
	Totals	8152 86 (86.5)(.9)	10176 90 (89.9)(.8)	10365 90 (89.1)(.8)	11911 106 (90.3)(.8)	13935 110 (92.1)(.7)	14124 110 (91.6)(.7)	15007 128 (92.0)(.8)	17031 132 (93.4)(.7)	17220 132 (92.9)(.7)
	Manufactured Materials	1176 (12.5)	1078 (9.5)	1176 (10.1)	1176 (8.9)	1078 (7.1)	1176 (7.6)	1176 (7.2)	1078 (5.9)	1176 (6.3)
	Total Cost per Km of Road	9414	11324	11631	13193	15123	15410	16311	18241	18528

Notes : Road Type A - Gravel sub-base, gravel base and 2 - coat surface dressing
B - Gravel sub-base, macadam base and single surface dressing
C - Gravel sub-base, crushed rock base and 2 - coat surface dressing
Percentage figures are given in brackets

Source: SWKP Estimates

Equipment costs as percentages of total costs per kilometre vary with terrain and road type as shown below:-

Terrain	Road Type A	Road Type B	Road Type C
Flat	86.5	89.9	89.1 %
Rolling	90.3	92.1	91.6
Hilly	92.0	93.4	92.9

The equipment proportion of total cost increases as the terrain becomes more difficult but there is not a great deal of difference between road types.

Unskilled labour forms a very small part (around 1%) of total costs, irrespective of terrain and road type. The cost of manufactured materials is much the same for all road types and is not affected by the terrain. As a proportion of total costs it decreases from 12.5% for road type A in flat terrain to around 6% for roads type B and C in hilly terrain.

The most significant activity groups are excavating in bulk, loading and hauling. Taken together, they account for 54-56% of total costs in flat terrain, 62-65% in rolling terrain and 66-68% in hilly terrain. Of the remaining groups of activities, site preparation and spreading are next in importance, together with the production of local materials for roads type B and C (due to the macadam and crushed rock bases).

b. High Quality Labour-Intensive Method (Table A.17)

With costs per kilometre in flat terrain as a base, proportionate increases in total costs in other types of terrain are:-

Terrain	Road Type A	Road Type B	Road Type C
Flat	1.00	1.00	1.00
Rolling	1.60	1.50	1.57
Hilly	1.69	1.57	1.65

There is a large increase in cost in rolling terrain but the additional costs due to hilly terrain are of much less significance. There is not a great deal of difference between the differing road types.

TABLE A.17 ANALYSES OF COSTS PER KILOMETRE OF HYPOTHETICAL ROAD PROJECTS

HIGH QUALITY LABOUR-INTENSIVE METHODS

Activity Group		Flat Terrain			Rolling Terrain			Hilly Terrain		
		A	B	C	A	B	C	A	B	C
No	Description	E - L	E - L	E - L	E - L	E - L	E - L	E - L	E - L	E - L
1.	Site Preparation	- 1162 (6.8)	- 1162 (5.7)	- 1162 (6.5)	- 1162 (4.3)	- 1162 (3.8)	- 1162 (4.1)	- 1162 (4.1)	- 1162 (3.6)	- 1162 (3.9)
2.	Excavating in Small Quantities	- 31 (.2)	- 31 (.1)	- 31 (.2)	- 166 (.6)	- 166 (.5)	- 166 (.6)	- 410 (1.4)	- 410 (1.3)	- 410 (1.4)
3.	Excavating in Bulk	- 1074 (6.3)	- 4022 (19.7)	- 3882 (21.7)	- 2023 (7.4)	- 4971 (16.2)	- 4831 (17.2)	- 3933 (13.7)	- 6881 (21.4)	- 6741 (22.8)
4.	Loading	110 889 (.6)(5.2)	517 939 (2.5)(4.6)	508 929 (2.8)(5.2)	111 1818 (.4)(6.7)	518 1868 (1.7)(6.1)	509 1858 (1.8)(6.6)	113 2520 (.4)(8.8)	520 2570 (1.6)(8.0)	511 2560 (1.7)(8.7)
5.	Hauling	135 10213 (.8)(60.1)	764 5789 (3.7)(28.2)	1357 5761 (7.6)(32.2)	137 17751 (.5)(65.4)	766 13327 (2.5)(43.5)	1359 13299 (4.8)(47.4)	140 16000 (.5)(55.8)	769 11576 (2.4)(36.0)	1362 11548 (4.6)(39.0)
6.	Unloading	8 253 (1.5)	9 337 (1.6)	8 334 (1.9)	8 878 (3.2)	9 962 (3.1)	8 959 (3.4)	8 1217 (4.2)	9 1301 (4.0)	8 1298 (4.4)
7.	Spreading	780 196 (4.6)(1.1)	757 252 (3.7)(1.2)	780 196 (4.4)(1.1)	780 91 (2.9)(.3)	757 147 (2.5)(.5)	780 91 (2.8)(.3)	780 94 (2.7)(.3)	757 150 (2.4)(.5)	780 94 (2.6)(.3)
9.	Compacting and Finishing	394 - (2.3)	393 - (1.9)	393 - (2.2)	440 - (1.6)	439 - (1.4)	439 - (1.6)	485 - (1.7)	484 - (1.5)	484 - (1.6)
11.	Production of Local Materials	- 420 (2.5)	- 4310 (21.0)	810 420 (4.5)(2.3)	- 420 (1.5)	- 4310 (14.1)	810 420 (2.9)(1.5)	- 420 (1.5)	- 4310 (13.4)	810 420 (2.7)(1.4)
12.	Miscellaneous	- 148 (.9)	- 130 (.6)	- 148 (.8)	- 175 (.6)	- 157 (.5)	- 175 (.6)	- 204 (.7)	- 186 (.6)	- 204 (.7)
	Totals	1427 14386 (8.4)(84.7)	2440 16972 (11.9)(82.8)	3856 12863 (21.5)(71.9)	1476 24484 (5.4)(90.2)	2489 27070 (8.1)(88.4)	3905 22961 (13.9)(81.9)	1526 25960 (5.3)(90.6)	2539 28546 (7.9)(88.7)	3955 24437 (13.4)(82.[illegible])
	Manufactured Materials	1176 (6.9)	1078 (5.3)	1176 (6.6)	1176 (4.3)	1078 (3.5)	1176 (4.2)	1176 (4.1)	1078 (3.3)	1176 (4.0)
	Total Cost per Km. of Road	16989	20490	17895	27136	30637	28042	28662	32163	29568

Notes : Road Type A - Gravel sub-base, gravel base and 2 - coat surface dressing
B - Gravel sub-base, macadam base and single surface dressing
C - Gravel sub-base, crushed rock base and 2 - coat surface dressing
Percentage figures are given in brackets

Source: SWKP Estimates

The proportionate increases in total costs per kilometre in relation to those for road type A are:-

Terrain	Road Type		
	A	B	C
Flat	1.00	1.21	1.05
Rolling	1.00	1.13	1.03
Hilly	1.00	1.12	1.03

Road type B gives rise to much greater increases than type C, particularly in flat terrain.

Labour (unskilled) costs as percentages of total costs per kilometre vary with terrain and road types as shown below:-

Terrain	Road Type		
	A	B	C
Flat	84.7	82.8	71.9 %
Rolling	90.2	88.4	81.9
Hilly	90.6	88.7	82.6

The labour content increases with difficulty of terrain and is greatest for the roads with gravel and macadam bases.

The equipment contents, as percentages of total costs, are:-

Terrain	Road Type		
	A	B	C
Flat	8.4	11.9	21.5 %
Rolling	5.4	8.1	13.9
Hilly	5.3	7.9	13.4

There is a significant reduction in equipment content with rolling terrain which increases only marginally in hilly terrain. Road type C needs much more equipment than either A or B.

The cost of manufactured materials forms a relatively small proportion of total costs, reducing as the difficulty of the terrain increases.

The most significant activity group is that of hauling which accounts for the following proportions of the total cost per kilometre:-

Terrain	Road Type		
	A	B	C
Flat	60.9(0.8)	31.7(3.7)	39.8(7.6) %
Rolling	65.9(0.5)	46.0(2.5)	52.2(4.8)
Hilly	56.3(0.5)	38.4(2.4))	43.6(4.6)

The figures above are for equipment and labour costs while those for equipment only are shown in the brackets. This activity is of great importance in labour-intensive work, particularly since it has a low break-even wage rate.

Excavating in bulk, particularly for road types B and C, is also of importance and the production of local materials for the macadam base type B road. All other groups of activities are of little significance compared with the above groups.

c. <u>Intermediate Quality Equipment-Intensive Method (Table A.18)</u>

The proportionate increases in total costs per kilometre, using flat terrain as a base, are:-

Terrain	Road Type		
	A	B	C
Flat	1.00	1.00	1.00
Rolling	1.41	1.34	1.33
Hilly	1.74	1.62	1.60

The increases due to terrain are seen to be greater for road type A and there is little difference between roads type B and C.

With costs per kilometre for road type A as a base, proportionate increases are:-

Terrain	Road Type		
	A	B	C
Flat	1.00	1.21	1.24
Rolling	1.00	1.15	1.17
Hilly	1.00	1.12	1.14

The increases reduce as the terrain becomes more difficult.

TABLE A.18 ANALYSES OF COSTS PER KILOMETRE OF HYPOTHETICAL ROAD PROJECTS

INTERMEDIATE QUALITY - EQUIPMENT INTENSIVE METHODS

Activity Group		Flat Terrain						Rolling Terrain						Hilly Terrain					
		A		B		C		A		B		C		A		B		C	
No.	Description	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
1.	Site Preparation	1100 (12.0)	-	1100 (9.9)	-	1100 (9.6)	-	1100 (8.5)	-	1100 (7.4)	-	1100 (7.2)	-	1100 (6.8)	-	1100 (6.1)	-	1100 (6.0)	-
2.	Excavating in Small Quantities	17 (.2)	-	17 (.1)	-	17 (.1)	-	138 (1.1)	-	138 (.9)	-	138 (.9)	-	363 (2.3)	-	363 (2.0)	-	363 (2.0)	-
3.	Excavating in Bulk	2239 (24.3)	-	2217 (19.9)	-	2182 (19.1)	-	3295 (25.4)	-	3273 (22.0)	-	3238 (21.3)	-	4741 (29.5)	-	4719 (26.2)	-	4684 (25.6)	-
4.	Loading	1629 (17.7)	3	2060 (18.5)	3	2031 (17.8)	3	2200 (17.0)	3	2631 (17.7)	3	2602 (17.1)	3	2862 (17.8)	3	3293 (18.3)	3	3264 (17.9)	3
5.	Hauling	1272 (13.8)	-	1742 (15.6)	-	2329 (20.4)	-	3031 (23.4)	-	3501 (23.5)	-	4088 (26.9)	-	3551 (22.1)	-	4021 (22.4)	-	4608 (25.2)	-
6.	Unloading	229 (2.5)	-	231 (2.1)	4	231 (2.0)	4	363 (2.8)	-	365 (2.4)	4	365 (2.4)	4	488 (3.0)	1	490 (2.7)	5	490 (2.7)	5
7.	Spreading	901 (9.7)	-	909 (8.2)	-	901 (7.9)	-	971 (7.5)	-	979 (6.6)	-	971 (6.4)	-	1041 (6.5)	-	1049 (5.8)	-	1041 (5.7)	-
9.	Compacting and Finishing	242 (2.6)	-	242 (2.2)	-	242 (2.1)	-	264 (2.0)	-	264 (1.8)	-	264 (1.7)	-	287 (1.8)	-	287 (1.6)	-	287 (1.6)	-
11.	Production of Local Materials	265 (2.9)	-	1416 (12.7)	-	1075 (9.4)	-	265 (2.0)	-	1416 (9.5)	-	1075 (7.1)	-	265 (1.6)	-	1416 (7.9)	-	1075 (6.0)	-
12.	Miscellaneous	41 (.4)	83	26 (.2)	83	41 (.4)	83	43 (.3)	103	28 (.2)	103	43 (.3)	103	46 (.3)	124	31 (.2)	124	46 (.3)	124
	Totals	7935 (86.3)	86 (.9)	9960 (89.5)	90 (.8)	10149 (88.9)	90 (.8)	11670 (90.1)	106 (.8)	13695 (92.0)	110 (.7)	13884 (91.5)	110 (.7)	14744 (91.9)	128 (.8)	16769 (93.3)	132 (.7)	16958 (92.8)	132 (.7)
	Manufactured Materials	1176 (12.8)		1078 (9.7)		1176 (10.3)		1176 (9.1)		1078 (7.2)		1176 (7.7)		1176 (7.3)		1078 (6.0)		1176 (6.4)	
	Total Cost per Km of Road	9197		11128		11415		12952		14883		15170		16048		17979		18266	

Notes : Road Type A - Gravel sub-base, gravel base and 2 - coat surface dressing
B - Gravel sub-base, macadam base and single surface dressing
C - Gravel sub-base, crushed rock base and 2 - coat surface dressing
Percentage figures are given in brackets

Source: SWKP Estimates

Variations in equipment cost, as percentages of total cost, vary with terrain and road type as follows:-

Terrain	Road Type		
	A	B	C
Flat	86.3	89.5	88.9 %
Rolling	90.1	92.0	91.5
Hilly	91.9	93.3	92.8

The equipment content increases as the terrain becomes more difficult, particularly from flat to rolling, and is greatest with roads type B and C.

The labour content, as a proportion of the total cost, is much the same in all cases and, being less than 1%, is of little significance. Total costs of manufactured materials are much the same for all types of road and are unaffected by the terrain; as a proportion of the cost per kilometre, they reduce as the terrain becomes more difficult.

As in the equipment-intensive high quality method, the most significant groups of activities are excavating in bulk, loading and hauling, which together account for the following proportions of the total costs per kilometre:-

Terrain	Road Type		
	A	B	C
Flat	55.8	54.0	57.3 %
Rolling	65.8	65.2	65.3
Hilly	69.4	66.9	68.7

There is little difference between the various types of road, but the proportions increase as the terrain becomes more difficult, particularly from flat to rolling.

Of the other activity groups, the production of local materials for roads type B and C, site preparation and the spreading of materials are of most significance.

d. Intermediate Quality Labour-Intensive Method (Table A.19)

With flat terrain as a base, the proportionate increases in total costs per kilometre are:-

Terrain	Road Type		
	A	B	C
Flat	1.00	1.00	1.00
Rolling	1.61	1.51	1.58
Hilly	1.71	1.59	1.67

Costs increase significantly between flat and rolling terrain and the additional increases due to hilly terrain are much less. The increases are greatest for road type A.

Proportionate increases using road type A as a base are:-

Terrain	Road Type		
	A	B	C
Flat	1.00	1.21	1.06
Rolling	1.00	1.13	1.04
Hilly	1.00	1.12	1.03

Road type B gives much larger increases than type C and they are greatest in flat terrain with little difference between rolling and hilly terrain.

Unskilled labour costs as percentages of total costs per kilometre vary with terrain and road type as shown below:-

Terrain	Road Type		
	A	B	C
Flat	91.2	88.2	78.0 %
Rolling	94.5	92.1	86.1
Hilly	94.8	92.5	86.8

The labour content is proportionally greater in the more difficult terrain, the greater part of the increase occuring between flat and rolling terrain, but the labour proportion decreases as pavement standards are raised.

The percentage equipment contents are:-

Terrain	Road Type		
	A	B	C
Flat	1.8	6.5	15.4 %
Rolling	1.1	4.3	9.7
Hilly	1.1	4.1	9.2

The equipment content increases substantially with the higher types of road (pavement) but in all cases reduces as the terrain becomes more difficult, particularly between flat and rolling terrain.

TABLE A.19 ANAYLSES OF COSTS PER KILOMETRE OF HYPOTHETICAL ROAD PROJECTS

INTERMEDIATE QUALITY LABOUR INTENSIVE METHODS

Activity Group		Flat Terrain						Rolling Terrain						Hilly Terrain					
		A		B		C		A		B		C		A		B		C	
No.	Description	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L	E	L
1	Site Preparation	-	1162 (6.9)	-	1162 (5.7)	-	1162 (6.5)	-	1162 (4.3)	-	1162 (3.8)	-	1162 (4.1)	-	1162 (4.0)	-	1162 (3.6)	-	1162 (3.9)
2	Excavating Small Quantities	-	31 (.2)	-	31 (.2)	-	31 (.2)	-	166 (.6)	-	166 (.5)	-	166 (.6)	-	410 (1.4)	-	410 (1.3)	-	410 (1.4)
3	Excavating in Bulk	-	1074 (6.4)	-	4022 (19.8)	-	3882 (21.9)	-	2023 (7.5)	-	4971 (16.2)	-	4831 (17.2)	-	3933 (13.7)	-	6881 (21.3)	-	6741 (22.7)
4	Loading	110 (.6)	889 (5.3)	517 (2.5)	939 (4.6)	508 (2.9)	929 (5.2)	111 (.4)	1818 (6.7)	518 (1.7)	1868 (6.1)	509 (1.8)	1858 (6.6)	113 (.4)	2520 (8.8)	520 (1.6)	2570 (7.9)	511 (1.7)	2560 (8.6)
5	Hauling	135 (.8)	10213 (60.8)	764 (3.8)	5789 (28.5)	1357 (7.6)	5761 (32.5)	137 (.5)	17751 (65.6)	766 (2.5)	13327 (43.5)	1359 (4.8)	13299 (47.4)	140 (.5)	16000 (55.7)	769 (2.4)	11576 (35.8)	1362 (4.6)	11548 (38.9)
6	Unloading	8	253 (1.5)	9	337 (1.7)	8	334 (1.9)	8	878 (3.2)	9	962 (3.1)	8	959 (3.4)	8	1217 (4.2)	9	1301 (4.0)	8	1298 (4.4)
7	Spreading	43 (.3)	409 (2.4)	34 (.2)	506 (2.5)	43 (.2)	468 (2.6)	43 (.2)	304 (1.1)	34 (.1)	401 (1.3)	43 (.2)	363 (1.3)	43 (.1)	307 (1.1)	34 (.1)	404 (1.2)	43 (.1)	366 (1.2)
9	Compacting and Finishing	-	715 (4.3)	-	715 (3.5)	-	715 (4.0)	-	902 (3.3)	-	902 (2.9)	-	902 (3.2)	-	1090 (3.8)	-	1090 (3.4)	-	1090 (3.7)
11	Production of Local Materials	-	420 (2.5)	-	4310 (21.2)	810 (4.6)	420 (2.4)	-	420 (1.6)	-	4310 (14.1)	810 (2.9)	420 (1.5)	-	420 (1.5)	-	4310 (13.3)	810 (2.7)	420 (1.4)
12	Miscellaneous	-	148 (.9)	-	130 (.6)	-	148 (.8)	-	175 (.6)	-	157 (.5)	-	175 (.6)	-	204 (.7)	-	186 (.6)	-	204 (.7)
	Totals	296 (1.8)	15314 (91.2)	1324 (6.5)	17941 (88.2)	2726 (15.4)	13850 (78.0)	299 (1.1)	25599 (94.5)	1327 (4.3)	28226 (92.1)	2729 (9.7)	24135 (86.1)	304 (1.1)	27263 (94.8)	1332 (4.1)	29890 (92.5)	2734 (9.2)	25799 (86.8)
	Manufactured Materials	1176 (7.0)		1078 (5.3)		1176 (6.6)		1176 (4.3)		1078 (3.5)		1176 (4.2)		1176 (4.1)		1078 (3.3)		1176 (4.0)	
	Total Cost per Km of Road	16786		20343		17752		27074		30631		28040		28743		32300		29709	

Notes : Road Type A - Gravel sub-base, gravel base and 2 - coat surface dressing
B - Gravel sub-base, macadam base and single surface dressing
C - Gravel sub-base, crushed rock base and 2 - coat surface dressing
Percentage figures are given in brackets

Source: C&P Estimates

Costs of manufactured materials account for between 7.0 and 3.3% of the total costs per kilometre, reducing as the terrain becomes more difficult.

By far the most important of the activity groups is hauling, which accounts for the following proportions of the costs per kilometre:-

Terrain	Road Type		
	A	B	C
Flat	70.0(0.8)	32.3(3.8)	40.1(7.6)
Rolling	66.1(0.5)	46.0(2.5))	52.2(4.8)
Hilly	56.2(0.5)	38.2(2.4)	43.5(4.6)

The figures above are for equipment and labour costs combined while those in brackets are for equipment only. Again, this activity is of great importance in carrying out work by labour-intensive methods.

Other important groups of activities are excavating in bulk for roads type A and B (13.7 to 22.7%) and production of local materials for road type B with the macadam base (13.3-21.2%).

e. Comparison between High Quality Equipment-Intensive and Labour-Intensive Methods

Comparing the total costs per kilometre given in Tables A.16 and A.17 the percentage increases in total cost arising from maximum practicable labour substitution are given below:-

Terrain	Road Type		
	A	B	C
Flat	80	81	54 %
Rolling	106	103	82
Hilly	76	76	59

The increases are much the same for roads type A and B and are greater than those for road type C. The greatest increases occur in rolling terrain while those in flat and hilly terrain are much the same.

The above comparisons are based on a daily wage rate of U.S.$2.00 for unskilled labour. For total costs to remain the same, the break-even wage rates (U.S.$ per day) for unskilled labour would need to be:-

Terrain	Road Type		
	A	B	C
Flat	0.94	0.92	1.02
Rolling	0.86	0.85	0.89
Hilly	1.04	1.02	1.09

Hence the financial advantage of labour substitution (to the maximum practicable extent) is greatest in hilly terrain and least in rolling terrain. Road type C offers the greatest advantage while type B offers the least. Partial substitution would undoubtedly affect these rankings.

f. Comparison between Intermediate Quality Equipment-Intensive and Labour-Intensive Methods

The percentage increase in total costs per kilometre arising from labour substitution at the intermediate level of quality are:-

Terrain	Road Type		
	A	B	C
Flat	82	83	55 %
Rolling	109	106	85
Hilly	79	80	63

The increases are much the same for roads type A and B but they are significantly less with road type C. The greatest increases occur in rolling terrain. In all cases, these increases are higher than the corresponding figures for high levels of quality (see para 5.102)

For total costs per kilometre to remain the same, the break-even wage rates (U.S.$ per day) for unskilled labour would need to be:-

Terrain	Road Type		
	A	B	C
Flat	1.00	0.97	1.08
Rolling	0.89	0.88	0.93
Hilly	1.06	1.04	1.11

Hence hilly terrain offers the greatest and rolling terrain the least financial advantage in labour substitution to the maximum practicable extent. Road type C offers the greatest advantage and type B the least. However, partial substitution would undoubtedly affect these rankings. In all cases, the break-even wage rates are higher than the corresponding figures for the high level of quality

g. Comparison between Equipment-Intensive High Quality and Intermediate Quality Methods

Lowering quality standards for the equipment intensive methods reduces the total costs per kilometre by the percentages shown below:-

Terrain	Road Type		
	A	B	C
Flat	2.3	1.7	1.9 %
Rolling	1.8	1.6	1.6
Hilly	1.6	1.4	1.4

The proportionate reductions in cost are very small but are greatest in flat terrain and for the gravel-based road type A.

Lowering quality does not affect the total labour costs but reduces the costs of equipment by around U.S.$220,240 and 260 per kilometre, respectively, in flat, rolling and hilly terrain.

h. Comparison between Labour-Intensive High Quality and Intermediate Quality Methods

Lowering quality standards with labour intensive methods affects total costs per kilometre by the following amounts:-

Terrain	Road Type		
	A	B	C
Flat	-1.1	-0.7	-0.7 %
Rolling	-0.2	C	0
Hilly	+0.3	+0.4	+0.5

The effects on total costs are very small and are less than with equipment intensive methods

The decreases in equipment cost per kilometre are:-

Terrain	Road Type		
	A	B	C
Flat	$1131	$1116	$1130
Rolling	1177	1162	1176
Hilly	1222	1207	1221

which are offset by the following increases in labour cost:-

Terrain	Road Type		
	A	B	C
Flat	$ 928	969	987
Rolling	1415	1156	1194
Hilly	1303	1134	1362

The slight increases in total costs arising from lowering quality standards in rolling and hilly terrain are due to the higher cost of labour needed to replace the savings in equipment.

i. Effect of Differing Rates for Labour and Equipment

The analyses of costs per kilometre of road have been based on a daily wage rate of U.S.$2.00 for unskilled labour. Also included in the labour category are bullock carts at a daily rate, inclusive of the driver, of U.S.$16.80 of which U.S.$0.80 represents the cost of the cart. While these rates might correspond to actual wages paid in the developing labour-surplus countries, the resource cost of labour might be considerably lower.

French daywork rates have been assumed for equipment together with rates for skilled and semi-skilled operators which would be representative of actual wages in many developing countries. In practice actual equipment rates (including operators) might be marginally higher, in financial terms, than those assumed but economic costs could be greater.

To assess the effects of varying the relative costs of equipment and labour, an extreme case of reducing unskilled labour costs to U.S. 20 cents per day has been taken while keeping equipment rates the same. The effect on individual activity groups in Tables A.16,A.17,A.18 and A.19 can be seen by dividing the labour costs by ten. The effect on total costs per kilometre is summarised in Table A.20

At high levels of quality, the percentage reductions in total cost arising from maximum practicable substitution are given below:-

Terrain	Road Type		
	A	B	C
Flat	57	54	45 %
Rolling	61	58	52
Hilly	67	64	59

TABLE A.20 TOTAL COSTS PER KILOMETRE OF HYPOTHETICAL ROAD PROJECTS

UNSKILLED LABOUR COST US $0.20 PER DAY

	Flat Terrain			Rolling Terrain			Hilly Terrain		
Road Type	A	B	C	A	B	C	A	B	C
Equipment-Intensive, High Quality									
Equipment	8152	10176	10365	11911	13935	14124	15007	17031	17220
Labour	9	9	9	11	11	11	13	13	13
Materials	1176	1078	1176	1176	1078	1176	1176	1078	1176
Totals	9337	11263	11550	13098	15024	15311	16196	18122	18409
Labour-Intensive, High Quality									
Equipment	1427	2440	3856	1476	2489	3905	1526	2539	3955
Labour	1439	1697	1286	2448	2707	2296	2596	2855	2444
Materials	1176	1078	1176	1176	1078	1176	1176	1078	1176
Totals	4042	5215	6318	5100	6274	7377	5298	6472	7575
Equipment-Intensive, Intermediate Quality									
Equipment	7935	9960	10149	11670	13695	13884	14744	16769	16958
Labour	9	9	9	11	11	11	13	13	13
Materials	1176	1078	1176	1176	1078	1176	1176	1078	1176
Totals	9120	11047	11334	12857	14784	15071	15933	17860	18147
Labour-Intensive, Intermediate Quality									
Equipment	296	1324	2726	299	1327	2729	304	1332	2734
Labour	1531	1794	1385	2560	2823	2413	2726	2989	2580
Materials	1176	1078	1176	1176	1078	1176	1176	1078	1176
Totals	3003	4196	5287	4035	5228	6318	4206	5399	6490

Source : SWKP Estimates

The proportionate reductions in total cost become greater as the terrain becomes more difficult but become less with the more costly road types.

These reductions should be compared with the increases scheduled in para 5.102 at a wage rate of U.S.$2.00 per day.

At intermediate levels of quality, the percentage reductions in total cost per kilometre arising from labour substitution are:-

Terrain	Road Type		
	A	B	C
Flat	67	62	53 %
Rolling	69	65	58
Hilly	74	70	64

Again the proportionate reductions are greater with increasingly difficult terrain and with the less costly road types.

These reductions should be compared with the increases scheduled in para 5.104.

With equipment-intensive methods, lowering the levels of quality from high to intermediate reduces total costs per kilometre by the percentages shown below:-

Terrain	Road Type		
	A	B	C
Flat	2.5	1.9	1.8 %
Rolling	1.8	1.5	1.5
Hilly	1.6	1.4	1.4

The reductions are small and vary only slightly from those listed in para 5.106.

Lowering quality standards for labour-intensive methods reduces the costs per kilometre as follows:-

Terrain	Road Type		
	A	B	C
Flat	26	20	16
Rolling	21	17	14
Hilly	21	17	14

These reductions are substantially greater than those listed in para 5.108 (which are based on a U.S.$2.00 per day wage rate). The proportionate reductions are greatest in flat terrain and are less with the more costly road types.

5. Tables Giving Comparative Cost of Equipment, Optimal and Labor-Intensive Methods

Table A.21 Comparative Cost of Equipment, Optimal and Labor-Intensive Methods for 1 Km. of Road Type A (Rolling Terrain) for wage = $1/day Intermediate Quality

Estimates Based on SAKP Data

(U.S. Dollars)

Activity	Equipment Solution		Optimal Mix		Labor-Intensive Solution	
	E1	L1	Eo	Lo	E2	L2
Earthworks						
Clearing and grubbing	1,000	-	-	281	-	281
Stripping topsoil	100	-	100	-	-	300
Excavating in bulk-soft materials, loading, hauling, unloading, spreading	5,422	-	2,293	960	-	5,845
Compacting and finishing	68	-	68	-	-	281
Excavating in bulk rock	380	-	302	14	-	397
Excavating ditches in soft materials	30	-	-	25	-	25
Excavating ditches in rock	107	-	-	56	-	56
Laying, trimming, compacting topsoil	199	10	-	51	-	51
	7,306	10	2,736	1,387	-	7,236
Total Earthworks	7,316		4,123		7,236	
Gravel Subbase						
Excavating, loading, hauling, unloading, spreading gravel	1,969	-	515	277	-	2,093
Loading, hauling, unloading, spreading water	47	-	47	-	47	-
Compacting and finishing	90	-	-	84	-	84
	2,106	-	562	361	47	2,177
Total Gravel Subbase	2,106		923		2,224	
Gravel Base						
Excavating, loading, hauling, unloading, spreading gravel	1,498	-	630	195	-	2,738
Loading, hauling, unloading, spreading water	33	-	33	-	33	-
Compacting and finishing	64	-	-	60	-	60
	1,595	-	663	255	33	2,798
Total Gravel Base	1,595		918		2,831	
Surface Dressing						
Excavating, loading, hauling, unloading rock in quarry	90	-	65	5	-	135
Production of chippings	264	-	-	210	-	210
Loading, hauling, heating, unloading, spreading bitumen	270	1	77	114	77	114
Loading, hauling, unloading, spreading chippings	165	-	116	42	116	42
Compacting and finishing	42	-	-	26	-	26
Brooming and cleaning surface	31	-	-	17	-	17
	862	1	258	415	193	544
Total Surface Dressing	863		673		737	
Subtotal Equipment/Labour	11,869	11	4,219	2,418	273	12,755
TOTAL COST PER KILOMETER	11,880		6,637		13,028	

(Excluding structures, engineering, supervision, mobilization, administrative and miscellaneous costs).

Eo, E2 Equipment Cost in U.S.$.
Lo, L2 Labor Cost (also labor days at $1/day).

Table A.22 Comparative Cost of Equipment, Optimal and Labor-Intensive Methods for 1 Km. of Road Type A (Rolling Terrain) for Wage = $1/day High Quality

Estimates Based on SWKP Data

(U.S. Dollars)

Activity	Equipment Solution		Optimal Mix		Labor Intensive Solution	
	E1	L1	Eo	Lo	E2	L2
Earthworks						
Clearing and grubbing	1,000	-	-	281	-	281
Stripping topsoil	100	-	100	-	-	300
Excavating in bulk-soft materials, loading, hauling, unloading, spreading	5,422	-	2,293	960	-	5,845
Compacting and finishing	136	-	137	-	137	-
Excavating in bulk rock	380	-	302	14	-	397
Excavating ditches in soft materials	30	-	-	25	-	25
Excavating ditches in rock	107	-	-	56	-	56
Laying, trimming, compacting topsoil	199	10	-	51	-	51
	7,374	10	2,832	1,387	137	6,955
Total Earthworks:	7,384		4,219		7,092	
Gravel Subbase						
Excavating, loading, hauling, unloading, spreading gravel	2,006	-	848	235	333	2,093
Loading, hauling, unloading, spreading water	47	-	47	-	47	-
Compacting and finishing	128	-	128	-	128	-
	2,181	-	1,023	235	508	2,093
Total Gravel Subbase	2,181		1,258		2,601	
Gravel Base						
Excavating, loading, hauling, unloading, spreading gravel	1,525	-	865	166	333	2,737
Loading, hauling, unloading, spreading water	33	-	33	-	33	-
Compacting and finishing	91	-	91	-	91	-
	1,649	-	989	166	457	2,737
Total Gravel Base	1,649		1,155		3,194	
Surface Dressing						
Excavating, loading, hauling, unloading rock in quarry	90	-	65	6	-	135
Production of chippings	264	-	-	210	-	210
Loading, hauling, unloading, spreading chippings	165	-	116	42	116	42
Loading, hauling, heating, unloading, spreading bitumen	270	1	270	1	270	1
Compacting and finishing	80	-	84	-	84	-
Brooming and cleaning surface	31	-	-	17	-	17
	900	1	535	276	470	405
Total Surface Dressing	901		811		875	
Subtotal Equipment/Labour	12,104	11	5,379	2,064	1,572	12,190
TOTAL Cost per Kilometre	12,115		7,443		13,762	

(Excluding structures, engineering supervision, mobilization, administrative and miscellaneous costs.)

Eo, E2 Equipment Cost in U.S.$.
Lo, L2 Labor Cost (also labor days at $1/day).

Table A.23: Comparative Cost of Equipment, Optimal and Labor Intensive Methods for One Kilometre of Road Type A (Rolling Terrain) for Wage = $1 per day Intermediate Quality

Estimates Based on BCEOM Data

(U.S. Dollars)

Activity	Equipment Solution		Optimal Solution		Labor Intensive Solution	
	E1	L1	Eo	Lo	E2	L2
Earthworks						
Clearing and grubbing	1,140	21	1,140	21	-	1,751
Stripping topsoil	915	-	915	-	-	1,266
Excavating, loading, hauling, unloading in bulk-soft materials	6,896	-	6,896	-	2,146	10,640
Spreading	403	-	403	-	-	2,481
Compacting and finishing	449	-	449	-	-	2,072
Excavation in bulk rock	312	37	312	37	234	702
Excavating soft in small quantities	137	2	137	2		270
Excavating rock in small quantities	61	19	61	19		149
Laying, trimming, compacting topsoil	1,512	40	-	469		469
	11,825	119	10,313	548	2,380	19,800
Total Earthworks	11,944		10,861		22,180	
Gravel Subbase						
Excavating, loading, hauling, unloading gravel	2,668	-	2,668	-	1,456	1,341
Spreading	123	9	123	9	-	516
Loading, hauling, unloading, spreading water	53	1	53	1	53	1
Compacting and finishing	87	4	43	25	43	25
	2,931	14	2,887	35	1,552	1,883
Total Gravel Subbase	2,945		2,922		3,435	
Gravel Base						
Excavating and loading	829	-	829	-	273	921
Hauling and unloading	422	-	422	-	204	2,295
Spreading	82	9	82	9	-	365
Loading, hauling, spreading water	37	1	37	1	37	1
Compacting and finishing	140	7	40	24	40	24
	1,510	17	1,409	34	554	3,605
Total Gravel Base	1,527		1,443		4,159	
Surface Dressing						
Production stones	166	184	52	270	52	270
Loading stones	38	-	-	6	-	6
Hauling and unloading stones	17	1	17	1	-	318
Production 10/15 chippings	318	32	318	32	318	32
Bitumen spreading	102	2	102	2	102	2
Loading chippings) Haul (10 km.) chippings) Spread chippings)	117	1	117	1	117	1
Compacting and finishing	7	-	7	-	7	-
	765	220	613	312	596	629
Total Surface Dressing	985		925		1,225	
Subtotal Equipment/Labour	17,031	370	15,222	929	5,082	25,917
TOTAL Cost per Kilometre	17,401		16,151		30,999	

(Excluding structures engineering, supervision, mobilization, administrative, and miscellaneous costs.)

Table A.24 : Comparative Cost of Equipment, Optimal and Labor Intensive Methods for one Kilometre of Road Type A (Rolling Terrain) for Wage = $1/Day High Quality

Estimates Based on BCEOM Data

(U.S. Dollars)

Activity	Equipment Solution E1	Equipment Solution L1	Optimal Solution Eo	Optimal Solution Lo	Labor Intensive Solution E2	Labor Intensive Solution L2
Earthworks						
Clearing and grubbing	1,140	21	1,140	21	-	1,751
Stripping topsoil	915	-	915	-	-	1,266
Excavating soft bulk, loading, hauling, unloading	6,896	-	6,896	-	2,146	10,640
Spreading	403	-	403	-	-	2,481
Compacting and finishing	707	-	707	-	707	-
Excavating rock bulk, loading, hauling, unloading	312	37	312	37	234	702
Excavating soft small quantities	137	2	137	2	-	270
Excavating rock small quantities	61	19	61	19	-	149
Laying, trimming, compacting topsoil	1,512	40	-	469	-	469
	12,083	119	10,571	548	3,087	17,728
Total Earthworks	12,202		11,119		20,815	
Gravel Subbase						
Excavating, loading, hauling, unloading gravel	2,668	-	2,668	-	1,456	1,341
Spreading	164	12	164	12	-	600
Watering, loading, hauling, unloading, spreading	53	1	53	1	53	1
Compacting and finishing	140	37	140	37	140	37
	3,025	50	3,025	50	1,649	1,979
Total Gravel Subbase	3,075		3,075		3,628	
Gravel Base						
Excavating gravel)		-				
Loading)	828	-	828	-	273	921
Hauling and unloading	422	-	422	-	204	2,295
Spreading	103	11	103	11	-	425
Loading, hauling, spreading water	37	1	37	1	37	1
Compacting and finishing	175	8	175	8	175	65
	1,565	20	1,565	20	689	3,707
Total Gravel Base	1,585		1,585		4,396	
Surface Dressing						
Production stones	166	184	52	270	52	270
Loading stones	38	-	-	6	-	6
Hauling and unloading stones	17	1	17	1	-	318
Production 10/15 chippings	318	32	318	32	318	32
Bitumen spreading	142	3	142	3	142	3
Load chippings)						
Haul (10 km.) chippings)	117	1	117	1	117	1
Spread chippings)						
Compacting and finishing	9	-	9	-	9	-
	807	221	655	313	638	630
Total Surface Dressing	1,028		968		1,268	
Subtotal Equipment/Labour	17,481	410	15,816	931	6,063	24,044
TOTAL Costs per Kilometre	17,891		16,747		30,107	

(Excluding structures engineering, supervision, mobilization, administrative, and miscellaneous costs.)