Scope for the substitution of labor and equipment in civil construction

A Progress Report

by

C. G. HARRAL, I. K. SUD and B. P. COUKIS

World Bank

INTRODUCTION

Widespread unemployment and underemployment in many developing countries has been a cause of increasing concern in recent years. It is generally acknowledged that productive employment opportunities must be created for large segments of population to foster economic development with distributional equity. In this regard, the present dominance of highly capital-intensive technologies in capital-scarce, labor-abundant economies has brought into question the appropriateness of the technology being transferred from the developed to the developing countries. It is argued that the pool of unemployed and underemployed labor is an important resource which could contribute to real capital formation and income if only "appropriate technologies" could be found which employ this resource productively.

Since 1971 the World Bank, in conjunction with several governments and other agencies, has undertaken to investigate the prospects for appropriate technologies in civil construction. [1] Although the question of appropriate technologies has been raised for a number of different sectors, the Bank study has been focused on civil construction for two main reasons. First, the need for appropriate technology is perhaps most apparent in civil construction, where a pronounced dichotomy exists between the modern capital-intensive technology and the traditional labor-intensive technology of civil construction. The output of a modern machine, typically costing in excess of US$100,000, is equivalent to the output of several hundred laborers. Second, civil works in the form of roads, irrigation channels, dams, reservoirs, etc., account for a major part of real domestic capital formation, and thus account for a significant part of lending by the World Bank and bilateral aid agencies. The employment potential of these investments is indeed substantial.

The initial phase of the study confirmed the technical feasibility of the substitution of labor for equipment for a wide range of construction activities. However, economic feasibility, which depends on relative factor prices and productivities, could not be assessed bacause of a lack of adequate information on the productivity of labor under different conditions. The second phase of the study, therefore, focused on collecting field observations of ongoing construction activities on 30 road, irrigation and dam construction sites in India and Indonesia to obtain the production relationships between varying inputs of equipment and labor and the output of different tasks of civil construction.

Based on the evidence on hand at the end of the second phase of the study, it was concluded that the traditional labor-intensive methods of construction that were being observed were not economically competitive with modern equipment even at extremely low wage rates. The reasons for this were believed to be:

a. the inefficiency of the technology employed;

b. a lack of proper organization and management; and

c. the fact that labor-intensive methods were observed under conditions where the primary emphasis was on employment creation rather than the productive use of labor.

Phase III of the study was initiated in late 1973 to examine ways in which the efficiency of labor-intensive methods could be enhanced by the introduction of improved hardware, project organization, management and incentives. The research is now sufficiently far-advanced so that the main conclusions have been established, which are significant enough to warrant a review at this stage. In future work the focus will be more on implementation and demonstration of the results rather than on research *per se.* This report is intended as a summary of the findings. For greater detail the reader is referred to the numerous technical memoranda and other reports listed in Appendix 1.

MAIN CONCLUSIONS

The following are the main conclusions of the work completed so far:

a. Labor-intensive methods are technically feasible for a wide range of construction activities and can generally produce the same quality of product as equipment-intensive methods.

b. Traditional labor-intensive civil works as observed in the course of this study are inefficient and economically inferior to [2] capital-intensive works except at extremely low wage levels. However, labor productivity can be improved very significantly by the introduction of certain organizational, management and mechanical improvements.

c. With superior tools, high incentives, and good management labor productivity can be improved to the point that labor-intensive methods can be fully competitive with equipment-intensive methods for wages under US$1.00 per day at present (1976) prices for equipment and fuel. For base wages above US$2.00 per day, labor-intensive methods are unlikely to be economically justifiable; for wages between US$1.00 and US$2.00 per day the economic viability will depend on various factors. Of course, these "break-even wages" would change with changes in the price of equipment and fuel.

d. Although there is considerable scope for increasing labor productivity by the use of available off-the-shelf hardware and improvements in the quality of tools, the prospect for developing new "intermediate technologies" for civil construction may be limited.

e. Prevalence of low wage rates (under US$1.00 per day) merely indicates the *potential* for the use of labor-intensive methods. Adequate organization and management particularly designed for labor-intensive projects is a critical consideration in adopting labor-intensive methods on a large scale.

f. The availability of adequate labor supply during the construction season is a much more significant factor than has generally been considered even in labor-abundant economies. Labor requirement for civil works is specific in time and space dimensions and it is therefore not sufficient to have an aggregate stock of surplus labor in a region. The required flow of labor at the construction site is the relevant consideration.

g. The health and nutrition status of construction workers has a significant effect on worker productivity. Several health/nutritional improvements at relatively low costs can result in major improvements in productivity and earnings of the workers. However, mechanisms available for large scale interventions in this area need to be further investigated.

h. Alteration of project design, can in some circumstances improve the feasibility of using labor-intensive technologies, but any resulting change or deferral in project benefits must be explicitly accounted for.

As is evident from the conclusions given above, the scope for using labor-intensive methods for civil construction is determined by a number of conditions, of which low wage rates is only one. Selection of tools of appropriate type and design can effect labor productivity, and therefore the economic viability of labor-intensive technologies. Organization and management considerations of labor recruitment, supervision and motivation are of critical importance.

The remainder of the paper is devoted to an elaboration of these and other considerations. In many developing countries with low wage rates, where labor-intensive methods could potentially be economical, many of the conditions given above are not met. The last section of the paper discusses the approach which will be followed in the future work program of the study which has as aim the development of the capacity for undertaking efficient labor-intensive projects. Areas which require further research are also discussed.

TECHNICAL AND ECONOMIC FEASIBILITY OF LABOR-INTENSIVE TECHNOLOGIES

Technical Feasibility

Civil construction basically consists of the integration of a small number of repetitive tasks, which in turn are comprised of a number of activities. Although the range of feasible technologies is large for some tasks and restricted for others, most of these tasks can be accomplished using a wide range of technology, from the most labor-intensive to the most capital-intensive. In theory any combination of technologies may be specified for the various tasks, but in practice the use of certain technology (say equipment) for any one task may indicate the use of a similar technology for some or all of the other tasks in the project.

Earthworks, including haulage of aggregates and other materials, is overall the single most important task of civil construction and typically accounts for up to 50 percent of expenditures on civil construction. Earthworks can be broken down into the activities of ripping (if required), excavation, loading of excavated material into a haulage vehicle, hauling, unloading, spreading and compaction, although more than one of these activities may be combined into a single operation in different technologies. Manual excavation and loading can be combined with a variety of haulage modes - headbaskets, wheelbarrows of different types, various types of animals, agricultural tractor/trailer combinations and flatbed trucks - and manual unloading and spreading as necessary. Equipment-intensive methods of earthworks include bulldozers, excavators with haulage vehicles, and towed and motorized scrapers of various sizes and specifications. Compaction may be carried out by self-propelled and tractor or animal-towed rollers of various designs; although the compaction standards normally achieved by the latter are not comparable to those by fully mechanized rollers. Thus, it is often necessary to specify mechanical means of compaction on labor-intensive projects, even though the output of the compaction equipment is considerably higher than the labor gangs generally engaged on any one site, resulting in a low utilization of equipment.

Besides earthworks, production of aggregates and pavement construction are other major tasks of civil construction. Aggregate production can be carried out entirely by manual methods or by mechanical crushers of varying sizes, but hand crushing cannot economically achieve gradation standards comparable to those achieved by mechanical crushers. Although the larger crushing plants can be highly automated, a significant number of laborers can be employed with small-scale crushers for such activities as loading and hauling of stock piles. Pavement construction involves two main tasks which require a significant labor input. These are the laying of the base, e.g. water-bound macadam (WBM), and the laying of the surface, either premix carpet or bituminous surface dressing. The laying of WBM is peculiar to labor-intensive road construction and therefore no strictly comparable equipment-intensive methods are available. Most premix carpet can be laid either by conventional mechanical pavers, which have relatively high output rates, or by manual methods which may be suitable for working with smaller size hot-mix plants. However, the quality of machine-laid surface is normally superior as measured by its surface roughness.

Thus, from a technical point of view, most major tasks of civil construction can be carried out by various labor-intensive methods working generally to the same tolerances as machines. But for a few selected activities changes in design standard may be necessary to off-set the advantage of machinery with some loss of benefit (see the section 'Project Design' for further elaboration of this point).

Economic Feasibility

Whether or not labor-intensive methods are economically feasible depends on the productivity of different technologies and the relative prices of labor and equipment. For the different tasks of civil construction, productivity of different labor-intensive methods with alternative assumptions of wage rages can be compared with the cost of the same task by equipment-intensive methods to determine the economic 'break-even' wages for labor. The lower the productivity of labor, the lower would be the break-even wage, and vice versa. Early conclusions of the study (Phase II) indicated extremely low productivity of traditional labor-intensive technologies, which, at the prices for equipment and fuel then prevailing (1973), could not be economically competitive with equipment except at extremely low wages. Clearly the economic feasibility of labor-intensive techniques rests on increasing the productivity of labor.

Field work carried out in the study indicates that substantial improvements in labor productivity in certain tasks are achievable by improvements in basic tools, worker incentives and site management. Labor productivity in excavating hard soils, for example, can very from $2m^3$ per man-day to $5m^3$ per man-day with high incentives and better quality shovels. Further increases of 50-100 percent can be achieved by pre-ripping of soil by animal-drawn ploughs (see Technical Memorandum No. 19). Labor productivity in haulage by wheelbarrows can be up to twice the productivity of haulage by head-baskets depending on the length of haul, and productivity with a better designed wheelbarrow with ball-bearings can be 50 percent more than that with many conventionally available wheelbarrows (see Technical Memoranda No. 1 and 13). Use of rail wagons and aerial ropeways can increase labor productivity significantly in specific site conditions where large quantities of material are to be moved or where a substantial lift is involved (see Technical Memoranda No. 6, 22 and 23). Production of aggregates by manual methods can be improved by the use of specially designed hammers. With the types of productivity increases indicated above, the economic break-even wages for labor-intensive methods are much higher at current (1976) prices of equipment and fuel than were indicated in the earlier phase of the study. [3]

For generalized comparisons, break-even wages have been calculated by using international prices for equipment and fuel, while local labor costs have been expressed in US dollars. Obviously, the break-even wages will increase or decrease with any future variations in the price of equipment and fuel. Broadly speaking, base wage rates of US$1.00 to US$1.80 per day combined with and effective incentive system represent the upper limit (in 1976 prices) at which labor-intensive methods can be economically attractive. For base labor wages of over US$2.00 or US$2.50 per day, there is little prospect for labor-intensive methods being economically competitive with equipment. These wage rates represent the boundary conditions. Between the two, factors such as the nature of work, special site conditions, magnitude of the work, and set-up costs, will determine the economic feasibility of labor-intensive technologies.

Typical unit cost of earthworks for a few selected technologies at varying wage rates and alternative haul lengths is depicted in Figure 1. For each method, a lower and upper bound is given, reflecting the range of productivities under favorable conditions (high incentive wages and good supervision) and poor conditions (daily wages and poor supervision). Comparing extremes, it can be seen from the figures for all haul distances that the unimproved labor-intensive method is not economically competitive with efficient equipment-intensive methods except at wage rates of the order of US$0.40 to US$0.50 per day or less. However, by introducing small scale equipment, improved supervision and high wage incentives, productivity can be increased several fold and labor-intensive methods become economical at base wage rates up to about US$1.20 per day when compared to the more efficient equipment-intensive operation, or as high as US$1.60 to US$1.80 per day when compared to less efficient equipment operations. This comparison includes allowances for the cost of the equipment, for wage incentive supplements equal to the base daily wage (to compensate for additional effort and skills), and an additional overhead allowance of thirty percent for the cost of superior supervision, as consistent with field observations. [4]

Technical considerations would dictate the use of mechanical compaction even on labor-intensive projects. On a larger project this would pose no special difficulties as the cost of compaction would generally be only a small part of the total project cost. However, on many smaller and scattered labor-intensive jobs (e.g. feeder road construction), such compaction equipment would have a very low utilization because of the small quantities of work involved and it may be more economical to use animal-or tractor-towed rollers with an acceptable reduction of compaction standards (see Technical Memorandum No. 17). These are explicit tradeoffs which must be considered in the design and organization of the project, as discussed below.

Break-even wages have also been computed for other important tasks. For aggregate production, larger size aggregates (greater than 25 mm) can be produced more economically by labor with proper incentives at wages under US$1.00 per day, whereas small aggregates for shippings, etc. are produced more economically by mechanical crushers. However, limited evidence from the study suggests that at low wage rates, smaller size aggregates may be produced more economically by first pre-breaking of larger stones by hand to about 50 mm size and then crushing by machine. It should be noted that manual stone breaking itself is a semi-skilled task. Using hammers of improved design can increase productivities as much as 50 percent, but there appears little prospect for increasing productivity by further altering the technology short of switching to a mechanical crusher.

Laying of hot premix carpet can be accomplished much more economically by labor for typical project conditions in developing countries where the quantity of work and the output rate required may be relatively small. This is because the available paving machines are of high capacity (70-80 tons per hour) and consequently entail considerable idle time. In one instance in India, the cost of laying premix carpet by hand was estimated to be US$0.06 per ton and by mechanical paver to be US$0.85 per ton when both methods were used in conjunction with a 25-30 ton/hour capacity hot mix plant (see Technical Memorandum No. 5). However, the quality of machine-laid surface was markedly superior. In this case, the increased user costs resulting from lowered surface standard had to be weighed against the reduction in the cost of surfacing. User cost considerations may be significant for highly trafficked roads but are less important for feeder roads or roads with heavy volumes of slow moving traffic.

The conclusions about the relative costs of different technologies should, of course, be recognized as being boundary conditions. Each individual situation has to be analyzed to determine any deviations from these conditions Factors such as available skills both in the use of machines and labor, set-up costs and site conditions, would determine these deviations. Moreover, project management considerations will influence the overall economic feasibility of labor-intensive methods, as will be discussed in the section below.

Prospects for 'Intermediate' Technologies

The extreme dichotomy between the available labor-intensive technologies and the modern equipment-intensive technologies has prompted the study to focus attention on the development of 'intermediate' technologies. It was believed that technologies could be developed between the two extremes which require considerably less capital per unit of output, a smaller investment per machine (less lumpiness), and which would enhance labor productivity such that these technologies would be economically efficient at higher labor wage rates than the traditional labor-intensive technologies.

Development of intermediate technologies can be envisaged in two ways. Starting with the equipment-intensive end of the spectrum the size and production capacity of equipment can be reduced in steps thereby decreasing the capital content and increasing the labor content of any given task. Various earthmoving machines, for example, can be replaced by smaller size equipment. Alternatively, starting from the labor-intensive end, capital can be substituted for labor in small increments for some of the activities of a task in such a way that the overall labor productivity is enhanced, which can more than offset the incremental increase in the capital cost. For example, labor productivity in earthworks can be increased by the use of superior excavating and loading tools, substituting wheelbarrows for headbaskets, introduction of improved design wheelbarrows, use of rail carts, animal-drawn carts, etc. The latter approach was pursued in the Bank study which has explored the development of intermediate technologies principally from the labor-intensive end of the spectrum. Field trials were carried out not only with the available off-the-shelf hardware and tools with improved designs, but also innovations in hand and animal carts, winches, animal and tractor-drawn scrapers, lever cranes, monorails, etc. However, while substantial improvements in labor productivity were obtained by the proper selection and adaptation of conventional hardware, the more innovative devices did not prove to be very successful. It appears that for most tasks of civil construction and under the general site conditions encountered on civil works projects, the available hardware may represent the practical limit of intermediate technologies and the prospects for any new intermediate technologies is not clear.

Two factors support this conclusion. First, output of

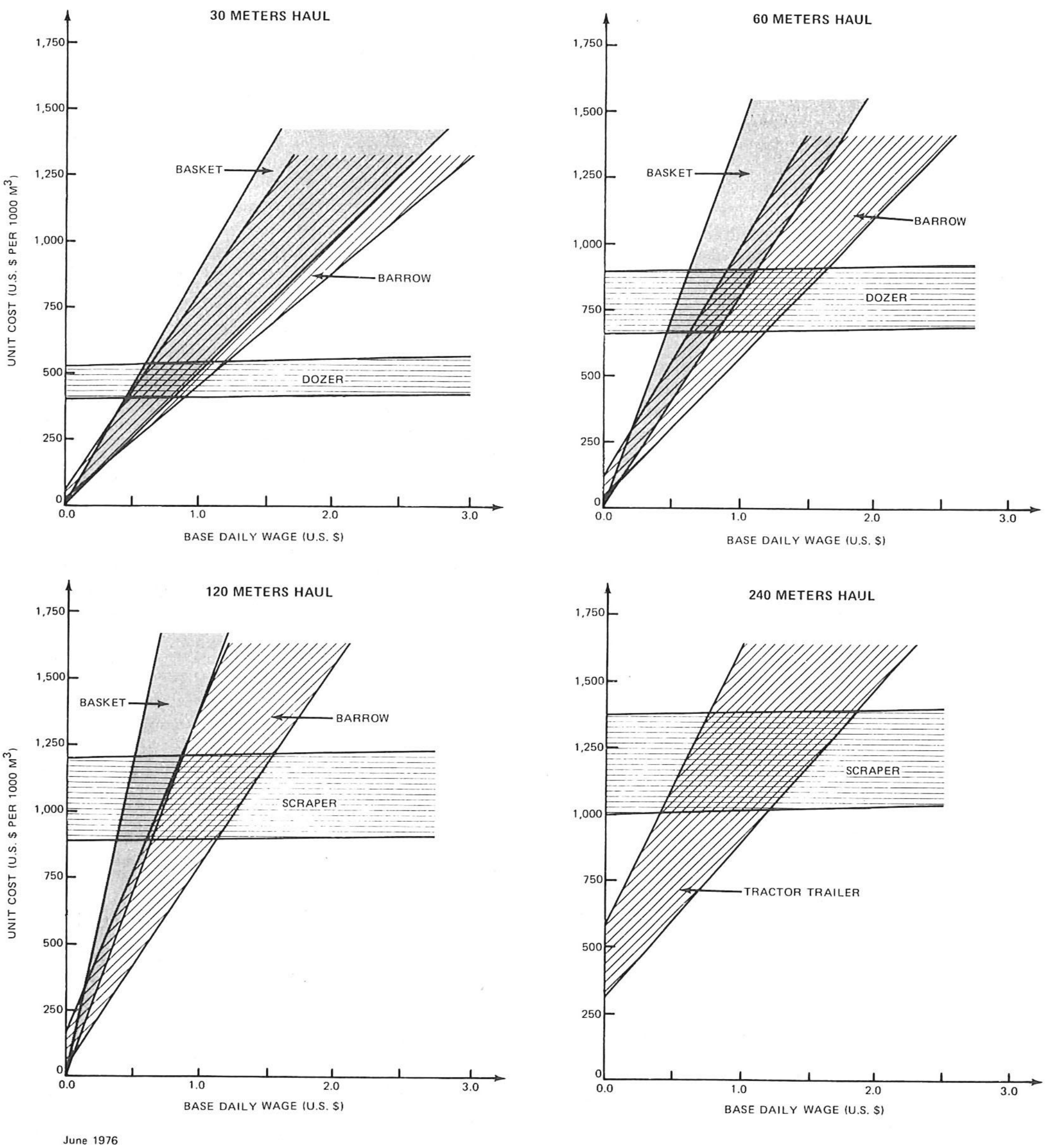

Figure 1 - Comparative unit costs of earthworks by different methods as a function of haul distance and wage rate

labor based technologies is limited by the physical constraints of energy of a worker (see Technical Memorandum No. 11). Various types of mechanical advantages (wheels, levers, inclined planes, etc.) can be provided to an individual to ensure that only a minimum of energy is wasted. The conventional hardware generally serves this purpose. Further increases in productivity are only possible by switching to a machine generated source of power, which in turn entails a major jump in labor productivity and a major increase in capital intensity of the task. Once a switch is made to machine-based technologies, there is a minimum size of machines below which the machine operation is not economical. Thus, although a farm tractor could be used in excavation, its cost per unit of output is considerably higher than that of a conventional dozer, because it does not have the horsepower and weight necessary for ripping or shearing the soil efficiently.

The second reason for the lack of success with new intermediate technologies seems to be the complexity they introduce in the execution of the task. Introduction of these technologies for one or more activities of a task requires a close coordination with the remaining activities to be able to realize the expected gains in productivity. For example, haulage by wheelbarrows and carts, which already represents a major improvement on haulage by headbaskets, could be further improved in some circumstances by resorting to a fixed rail system. But this requires a proper set-up of the rails and the balancing of loaders and unloaders at the two ends of the system to match the haulage cycle of the rail, without which the rail haulage becomes much less efficient. Such close coordination is often not achievable under typical site conditions in civil construction projects. Similary, switching to machine based technologies for any one part of a task generally dictates the use of machines for all other activities of the task because of the large imbalances between men and machine productivities.

Thus the prospect for developing intermediate technologies between the limits of an efficient labor-intensive technology based on human muscle and modern equipment technologies based on other sources of energy are not very encouraging. Such a technology would hinge on the development of small scale equipment which could efficiently substitute other sources of energy for human muscle. However, the evidence to date suggests that there are limits on the degree to which equipment can be fragmented without experiencing losses due to the inherent economies of scale to be found in fossil produced sources of energy. The employment effects of using such a technology will also be small compared to human muscle based technologies and will primarily involve the use of skilled labor. Undoubtedly there are some improvements that can be made in adapting modern machine based technologies to conditions found in developing countries and it will certainly be worthwhile to do so; but their employment effects are likely to be marginal.

ORGANIZATION AND MANAGEMENT REQUIREMENTS

Much of the discussion on the economic efficiency of labor-intensive methods has in the past been primarily based on the type of micro-level cost comparisons of alternative technologies described above. However, such comparisons merely indicate the range of wage rates (and other factor costs) for which labor-intensive methods can be economical. Whether labor-intensive methods can be economically implemented at the project and program level is determined by the organization and management capabilities of the public works authority or contractor concerned to recruit, mobilize, organize and supervise large numbers of labor. Without effective project organization and management, inefficiencies in the form of multiple handling of materials, long project gestation periods and low labor productivity are commonly observed. Thus prevalence of labor wage rates at or below the economic break-even wage is a necessary but not sufficient condition for the adoption of labor-intensive technologies.

Of course, the need for effective project organization and management exists irrespective of the technology employed. However, what is often not appreciated is the fact that the organization and management requirements of labor-intensive projects are quite different from those of equipment-intensive projects. There are unique problems associated with recruitment, supervision and motivation of labor which call for different supervision skills and a different framework for project organization. These factors are often overlooked by many public works authorities thereby resulting in a mismatch of supervisory skills and an inappropriate project organization. This may well be the major cause of the inefficiencies which are often observed in labor-intensive works. [5] These issues are discussed in more detail in the following.

Labor Mobilization

Availability of an adequate supply of labor at the project site is obiously a critical consideration in the planning and execution of labor-intensive projects. The labor supply conditions determine not only the relative economics of labor-intensive methods but also the length of time required for project completion. Even in the most labor abundant economies, the supply of labor to civil construction projects is often inadequate, contributing to long project delays. This is particularly true during the seasons when earnings opportunities in agriculture rise sharply. The tradeoffs between higher wages necessary to attract an adequate labor force and the economic loss from deferred project benefits caused by insufficient labor must be explicitly accounted for.

Most of the arguments in favor of using labor-intensive methods in construction (as in other sectors) are based on the assumption of the existence of surplus labor in agriculture. It has been hypothesized that a stock of surplus labor exists, particularly in the slack agricultural season, which could be diverted to other productive activities without a significant loss in agricultural production. However, the existence of a stock of surplus labor during certain seasons does not ensure labor will be available for employment in civil construction at the specific times when it is required. The willingness of labor to work in civil construction depends on earning differentials (both short-term and long-term) relative to alternative employment, on the "wealth" of the individual (e.g. extent of landholdings, if any), any additional work-related costs of food, housing and transport, and on the disutility of work in terms of leisure foregone. In addition, substantial underemployment may be interspersed with essential part-time employment such that it is difficult to utilize productively the time that is available.

Limited empirical evidence has been collected in the Bank studies on the determinants of labor supply for civil construction, [6] but the importance of seasonal variations in agriculture is clearly established. In India agricultural wages typically increase from 30 to 80 percent or more during peak seasons, which are encountered about four months out of the year in rainfed cultivation but may extend to eight months in irrigated areas. Because of the shortage of labor during this period, and because of climatic factors, civil construction is normally halted from sometime in June until October, and periodic interruptions of work occur during the rest of the year. An important fact to be determined is the extent to which labor may be more freely available on a part-time basis more suitable for periodic activities (such as maintenance) near to their homes than for construction activities which demand full time and require substantial travel.

Labor demand for construction also fluctuates as the work progresses over the construction season. This consideration normally dictates employing labor on a casual basis, i.e. labor is employed as and when necessary. The ability of the project authorities to recruit labor in this context is governed by their sensitivity and responsiveness to the changing labor market conditions. Unless wage rates can be revised in response to changing site conditions or seasonal considerations, wide fluctuations in labor availability can occur. On many sites, it becomes necessary to import labor from other labor surplus regions, which may sometimes be located several hundred miles from the site. In order to attract labor from such distant places, it is generally necessary to provide labor with mobilization advances, travel fares and sometimes even food supplies and shelter for their assignment. Government construction authorities are not well suited to perform such functions as they often require long and personal contacts with these communities. Intermediaries or special contractors are commonly used to perform such functions, as discussed below.

In India large migratory labor populations have emerged which provide the bulk of the labor force for large scale civil works projects. Migration of hundreds of thousands of workers and their families for construction work, usually in response to specific recruitment drives by contractors, is an annual phenomenon. The existence of this large mobile population, combined with relatively low costs of migration in India [7] tends to limit wage differentials between regions. The propensity to seasonal migration is higher in those areas and among those classes which have been relatively impoverished over a long term; notable reluctance to migrate has been observed among those affected even severely by temporary or recent events such as drought or floods. Field investigations in northern and central India in fact show that almost all migrant laborers on construction work are either landless or possess very small holdings. The investigations also confirm that contractors have a strong preference for migrant laborers whom they consider more productive, reliable and disciplined. Migrant workers tend to specialize in particular activities, developing skills and often much higher productivities and earnings than casual laborers recruited locally.

The important point to be stressed is that even in seemingly labor-abundant areas, the availability of an adequate supply of labor for civil works cannot be assumed without a careful investigation of the local labor market conditions. Examples of labor-intensive projects which have remained uncompleted for years are unfortunately all too common. The cost of having large sums of capital tied-up in unfinished projects does not seem to be fully recognized. An explicit recognition of labor supply constraints may well dictate a redesign of the project or the selection of a more capital-intensive technology.

Labor Management

Supervisory Skill Requirements

For the same rate of output, supervision requirements of labor-intensive projects are much greater than those for equipment-intensive projects. The output of a single piece of equipment is generally equivalent to the output of several hundred laborers working in several small gangs. For example, the output of a bulldozer employed in earthworks can be as high as 1,000 cubic meters per day, which may be equivalent to the output of 200-300 laborers working in groups of 20-30 each. The work of the bulldozer may be carried out by one or two skilled workers, but it would require more than a dozen supervisors to supervise the work of the equivalent number of labor. In addition, labor is often deployed over a wider geographical area requiring a dispersal of supervision, which further increases supervision requirements.

The skills needed for the supervision of labor rather than machines are also quite different; the former requiring the leadership qualities to motivate large groups of human beings over long periods. Labor is more heterogenous in its characteristics than equipment and therefore the "style" of supervision is likely to vary widely for labor-intensive projects. Moreover, a task which can be performed in one machine operation may require several gangs of labor working in the different component activities. This imposes an important responsibility on the supervisor to coordinate and sequence the different activities efficiently. For instance, on a road construction project in India it was found that with a proper balance of excavators and haulers and with a more appropriate sequence of performing the excavation, labor productivity could be more than doubled. (See Technical Memorandum No. 2). In another instance of canal construction in Indonesia, when wheelbarrows were introduced for haulage instead of headbaskets, the expected increase in productivity could not be realized because of the site supervisor's apparent inability to understand the need for a proper balance between the excavators, loaders and haulers -- the haulers speeded up, but only to be delayed in queues because the rate of excavation and loading was inadequate. Other aspects of site supervision of labor-intensive projects which have a major bearing on productivity are the proper selection and maintenance of work tools, which require a good understanding by the supervisors of the principles of manual work.

Unfortunately, such supervision skills require a certain inclination and training for the site supervisors which often do not exist. Even in countries like India and Indonesia, where labor-intensive methods of construction have been traditionally used, many of the site supervisors are graduates of polytechnics or engineering schools where the education tends to be oriented towards design engineering and the use of equipment. Frequently these supervisors possess no prior experience in working with labor, and they rarely (if ever) come up from the labor ranks. Indeed, labor-intensive civil works are often seen by governments as a way to absorb the unemployed technical graduates. Under these conditions, the role of these site supervisors in project execution is more like the measurement and checking of work done by 'quantity surveyors' rather than the labor management and supervision work done by a 'foreman'.

Thus, for labor-intensive projects to be implemented on a wide scale, it is essential that sufficient numbers of site supervisors be available who are specifically trained in labor supervision and management. In most countries availability of such skilled staff will be a critical constraint in the adoption of labor-intensive methods. A substantial effort is required to develop and implement training programs specifically oriented to labor-intensive works. The nature of the work suggests that on the job training would be the most suitable approach.

Wage and Incentive Systems

As indicated earlier in the paper, management systems which provide incentives for efficiency are of paramount concern in labor-intensive works programs. The evidence indicated that incentive payment methods may result in labor productivities up to three times greater than daily wage systems. (See Technical Memoranda No. 12, 19). However, the development and administration of incentive systems is a large and difficult task; at a minimum, job analyses must be carried out and a schedule of productivity norms established. The payment basis must be fully understood and felt to be fair by the labor force, and wage payments must be made regularly and promptly. There must be flexibility so that rates can be revised to reflect particular site conditions. In the case of the Chinese sponsored road projects in Nepal, elaborate piece rate systems were developed which provided different rates for each task under varying conditions. Development and administration of such incentive schemes can only be done by the site level supervisors, who must therefore possess the necessary skills and authority for this purpose.

Health/Nutrition Considerations

Sufficient evidence has been collected in the study to indicate a significant effect of health and nutrition status of workers on productivity. Several of these deficiencies can be corrected at relatively modest cost and yield high benefits. Studies of adult male plantation workers in Indonesia indicated a significant correlation between iron deficiency anemia and the output of rubber plantation workers. [8] A simple iron supplementation program at a cost of US$0.50 per worker resulted in increased productivity by up to 25 percent. The benefit/cost ratio of such a program is obviously large. A similar study in India of road construction workers (Technical Memorandum No. 4) and an independent study in Jamaica [9] of sugar plantation workers indicated correlation between output and body weight and dimensions. This would suggest a possible relationship between work output and caloric consumption which can be augmented by locally available food supplements. Present work underway in Kenya is attempting to study the benefits and costs of caloric supplementation. Various public health measures can also be used to reduce the incidence of certain health deficiencies which may limit worker productivity and/or availability. However, there is inadequate knowledge of the delivery mechanisms which may be used for nutritional/health interventions on a scale larger than the experimental level, and further work needs to be done in this area.

Organizational Framework

The unique requirements of labor recruitment, payment, supervision and motivation, combined with the geographical dispersion of sites and the major influence of site variables on labor productivity, suggests three main organizational requirements for labor-intensive public works programs:

a. as much of the decisionmaking as feasible must be delegated to the site level supervisor in order to enable him to respond quickly to changes in site conditions;

b. sufficient flexibility must be given to site supervisors to revise wage rates and an incentive built in for the site manager to ensure that labor is employed productively; and

c. the organization must be responsive to the relative prices of labor and equipment, to ensure that labor-intensive methods are adopted in low wage situations where such methods may be more economical than equipment.

The first two considerations would tend to favor the use of private contractors, while the last consideration may necessitate the use of force account construction particularly in countries where labor-intensive methods have not been traditionally used in spite of the prevalence of low wage rates. However, both of these systems have certain weaknesses which limit their application to labor-intensive projects.

Private contractors have the necessary flexibility and incentives for carrying out construction projects efficiently. However, established contractors show little inclination in using labor-intensive methods, even in countries like Indonesia where such methods may be more profitable on certain projects. The larger contractors have generally developed specialized expertise in the use of equipment and perceive the use of labor-intensive methods as being management-intensive, time consuming and generally inefficient; the element of risk is large in dealing with unfamiliar methods. In countries where these contractors can find sufficiently large and specialized jobs (e.g., major bridge contracts in India and large civil works contracts in Indonesia), the smaller jobs are regarded by them to be marginal and therefore they prefer to leave them to the smaller contractors. Moreover, many construction authorities consider access to equipment as a major criterion to judge the contractors' ability to execute works. These and similar regulations inhibit the contractors from adopting labor-intensive methods. In the circumstances it seems unlikely that large contractors will opt for labor-intensive methods even if they are free to choose their technology.

The system of "petty" contracting which is widely used in India is oriented specifically to the use of labor-intensive methods. Under this system works are sliced into a large number of small contracts varying in value form $10,000 to $100,000 per year. The contractors by virtue of their small size and fragmented works, have virtually no access to capital and therefore own little or no equipment. Their principal characteristic is the ability to perform labor-intensive works, as the only capital outlays these works require are the funds for the payment of small labor advances and for their current payroll expenditures.

While the petty contractor method is effective in ensuring that the contractors will choose labor-intensive methods without the construction authority having to specify this administratively, this system suffers from some drawbacks which limits the efficient use of labor. Because of their small size, the petty contractors generally possess little or no formal skills in contracting or construction management. Their financial status is so limited that they cannot afford to experiment with unfamiliar technologies. Essential items of equipment, e.g., rollers, must normally be provided by the construction authority. The individual slices of works which are given to the petty contractors tend to be not only small but also limited in scope, as they commonly specialize in particular tasks, e.g., earthworks, stone production, or transport of materials. But fragmentation of this type imposes a major responsibility on the construction authority to schedule and sequence the various contractors' works. In practice this often proves to be a difficult undertaking and numerous instances are observed in the field where the inability of just a single contractor to complete his part of the job prevents other contractors from completing their works.

By using force account construction, it is possible to specify the appropriate technology to be used. However, force account construction normally implies a centralized, hierarchical management structure and experience indicates that it is difficult to provide the flexibility required for site staff to respond to varying conditions and to the needs for labor recruitment and payment. Force account construction also generally suffers from a lack of financial discipline and control. With dispersion of sites and fragmentation of resources, financial control of labor intensive projects becomes even more difficult. However, despite the potential difficulties, force account may provide the only feasible avenue for introduction of labor-intensive methods in those countries where modern equipment has become the established technology. In these circumstances force account programs may be used to test the efficiency of alternative labor-intensive methods, evaluate different management schemes and develop a reservoir of skilled manpower familiar with the use of labor-intensive methods. By demonstrating through such programs that labor-intensive methods can be cost effective, the element of risk will be reduced and the adoption of similar methods by the contracting industry encouraged. The Kenya Rural Access Roads program, which is discussed in the section 'Future Work' below, is one example of this approach.

PROJECT DESIGN

The issue of the choice of technology is closely linked with the question of appropriate design of the project. Treating the project design as "fixed" may in many instances preclude the use of labor-intensive methods. Under certain circumstances, it may be possible to alter the design to facilitate adoption of manual methods and build a facility with essentially the same performance characteristics or with only a limited loss of benefits. This is indeed a common practice in countries where labor-intensive construction methods are commonly used.

There are three ways in which the design of a civil works project can be altered to make the project amenable to construction by labor-intensive methods. These are:

a. Selection of a basic design concept or type or project which has a high labor component, e.g., in the irrigation sector a choice may sometimes be possible between surface water schemes, which can largely be carried out by labor-intensive methods, and ground water schemes which are generally capital-intensive.

b. Variation in project scale and timing to conform to the availability of labor, e.g., a large irrigation channel can sometimes be subdivided into two smaller channels, a road can be constructed to low standards initially and upgraded in subsequent stages as labor is available.

c. Variation in engineering design and specifications, e.g., earthworks in irrigation channels may be reduced by lining the channels, and the use of masonry rather than concrete lining materials creates further employment; similarly relaxation of aggregate gradation standards and specification of larger size stone in pavement construction will enhance the feasibility of labor-intensive methods.

Where a labor-intensive design solution which yields the same or similar performance standards cannot be found, labor-intensive methods may be more competitive for lower design standards or slower implementation schedules. In these cases the reduced or deferred benefits must be explicitly recognized and a comparison of benefit and cost streams made for alternative designs. Further research is being undertaken to determine the performance of alternative designs and specifications in roadworks and to explore various avenues in the adaption of engineering design to facilitate labor-intensive methods of construction.

FUTURE WORK

Measures to Promote Labor-Intensive Technologies

The results of the Bank study to date have highlighted the conditions necessary for the successful (economical) implementation of labor-intensive technologies. Availability of labor for civil construction at low wage (or opportunity cost) is, of course, a prerequisite, and the extent to which labor-intensive methods can be adopted would depend upon the elasticity of labor supply. But whether labor-intensive methods could be implemented on a large scale is determined by the organization and management capabilities of the construction authorities. Development of such capabilities must be undertaken simultaneously with the adoption of labor-intensive technologies, particularly in countries where such methods have not been traditionally employed. This is likely to be a slow and difficult process and the effort required for it should not be underestimated. It would be necessary initially to provide major inputs of technical assistance for training of staff from the foreman to the supervisory engineers and project planners on pilot construction programs. These programs, while providing training for staff, could also serve as "demonstration programs" for labor-intensive technologies and expanded in their coverage as the organizational capability is developed. Ultimately, the programs should aim at the development of a local contracting industry which would be geared towards the use of labor-intensive methods. As the research findings of the Bank have been generally established, future work is now primarily focussed on such demonstration/training programs. Kenya and Honduras have been selected as two countries for the implementation of the study recommendations.

Demonstration/training programs being undertaken in both Kenya and Honduras have been designed with the following considerations:

a. The works involved (feeder road construction) are relatively small which do not require large numbers of labor at one site. This permits an evaluation of the labor market potential for such works below the maximum break-even wages.

b. The program horizon is medium to long-term (5-10 years) which permits a gradual expansion of the program. In Kenya the program employed 1,000 laborers in the first year, and this is to be expanded to 20,000 laborers in about 10 years.

c. A training program for site supervisory staff has been initiated to produce the requisite supervisory staff as the program expands.

d. A detailed monptoring and evaluation program is concurrently undertaken to evaluate and improve the technologies used.

The initial phase of the program in Kenya, which has been underway since early 1975, has required a considerable amount of management input. A team of three engineers and an organization and management specialist provided from the study funds is assisting the Ministry of Works in implementing the program. A labor economist will investigate the local labor market conditions in the areas of the construction sites. Since many of the tools normally required for labor-intensive methods are not locally produced in Kenya or are of poor quality and design, a small scale industry specialist will explore possible ways of developing local manufacturing capability in this area. In addition, the senior management positions are presently occupied by expatriate staff. Thus, in the initial stages, while the direct costs of the program have been very competitive indeed because of the prevalent wage rates (about $0.75 per day), management costs have been quite substantial. At present, the program is carried out entirely by force account, but consideration is now being given to the development of local contractors. Ultimately, the success would depend on whether the program can sustain itself without the need for an inordinate amount of management input.

The work in Honduras is currently in the planning stages and actual constructions is expected to get underway by late 1976. More recently, assistance has also been provided to initiate similar programs in Lesotho and Chad as a part of Bank financed projects. The results of all these efforts would be monitored closely in the study to evaluate their effectiveness. It is likely to be a long and tedious process, and if the experience from the study so far is a guide, it is unlikely that any quick solutions can be developed.

Research

WHile the main thrust of future work will be on implementation of efficient labor-intensive technologies, certain gaps in knowledge remain which require further research, as listed below. As most of these issues are pertinent to the Kenya and Honduras programs, many facets of the research will be encompassed within those programs; in addition, separate efforts will be undertaken through research institutions in other countries which by virtue of their established capacity have an advantage in executing more complex, long term research.

(i) *Labor supply.* The seemingly paradoxical problems of labor shortages in labor abundant economies has been discussed above. Regional and seasonal conflicts in demand with agriculture and other sectors constitute one of the most important constraints in the use of labor-intensive methods. A good understanding of the exact nature of the available labor supply is essential in planning any labor-intensive works programs. Through continuing investigation of labor supply conditions in India and Kenya, an attempt will be made to develop simple predictive models which can be applied at the project or micro district level to forecast available labor, both local and migrant, on a seasonal basis.

(ii) *Adaption of Engineering Designs.* Research should be pursued of the performance characteristics of alternative road designs which may extend the feasible range for labor-intensive technologies. Possible areas for investigation include: compaction standards, aggregate gradation standards, use of larger aggregates in pavements, and surface tolerance specifications for premix surfaces.

(iii) *Equipment Research and Development.* While the introduction of suitable tools and equipment selected from existing technologies has resulted in significant productivity improvements compared to traditional manual methods, the limited research that has been undertaken to develop and test more innovative concepts has not been encouraging, as discussed in the third section. At this stage it is not clear to what extent further research can lead to useful investigations, particularly with respect to scaling down of equipment. Attention is being given to identifying specific areas where the scope for development of new or modified equipment would appear most promising. Subsequent research would then be subcontracted to institutions with established capacities in design engineering.

FOOTNOTES

1. The World Bank study is being supported by the Governments of Canada, Denmark, Finland, Germany, Japan, Norway, Sweden, United Kingdom and United States, and by the World Bank. The Governments of India and Indonesia have collaborated with the Bank in the study. The International Labour Organization has also been examining similar issues within the broad framework of the World Employment Programme.

2. The term 'wage rate' as used in this paper may be interpreted either as the market wage (including any allowances for housing, transport, etc.) if these reflect the real economic cost of employing labor, or as the opportunity cost of labor if distortions exist in the labor market. However, in cases where the market wage is above the break-even wages for labor-intensive methods but the opportunity cost of labor is lower there are special problems associated with implementation of labor-intensive methods which are not treated in the present paper.

3. Prices of equipment have increased substantially (about 75 percent) since 1973, thus improving the competitiveness of labor methods.

4. Cost comparisons for earthworks are treated in greater detail in Technical Memoranda No. 3.7.12.13.17.18.19 and 20.

5. See World Bank Staff Working Paper No. 224, "Public Works Programs in Developing Countries" (February 1976) for a comparative review of 24 labor-intensive works programs in 14 countries.

6. See World Bank Staff Working Paper No. 223, "Some Aspects of Unskilled Labor Markets for Civil Construction in India: Observations Based on Field Investigation" (November 1975). Follow-up work is continuing.

7. The migratory labor are provided with either extremely modest or no accomodation at all on site. Low-cost huts are built by the labor for accommodation.

8. See "Iron Deficiency Anemia and the Productivity of Adult Males in Indonesia", **IBRD Staff Working Paper No. 175** (April 1974)

9. Heywood, Peter F., "Malnutrition and Productivity in Jamaican Suger Cane Cutters", Ph. D. Dissertation (unpublished), Cornell University, Ithaca, Cornell, 1974

APPENDIX

WORLD BANK STUDY OF THE SUBSTITUTION OF LABOR & EQUIPMENT IN CIVIL CONSTRUCTION

Reports and Technical Memoranda

A. Study Reports

Study of the Substitution of Labor and Equipment in Road Construction, Phase I: Final Report (IBRD, October 1971)

Study of the Substitution of Labor and Equipment in Civil Construction, Phase II: Final Report (IRBD, Staff Working Paper No. 172, January 1974).

Iron Deficiency Anemia and the Productivity of Adult Males in Indonesia (IBRD, Staff Working Paper No. 175, April 1974)

Some Aspects of Unskilled Labor Markets for Civil Construction in India: Observations Based on Field Investigations (IBRD, Staff Working Paper No. 223, November 1975).

B. Technical Memoranda Available as at June 30, 1976

Technical Memorandum No. 1

Comparison of Alternative Design Wheelbarrows for Haulage in Civil Construction Tasks, January 1975

A comparison is made of productivity in haulage of different design of wheelbarrows. Two-wheel and one-wheel barrows, solid tired v.s. pneumatic rubber tired barrows, and ball-bearing vs. bushed bearing wheels for barrows are investigated. On the basis of 6 weeks of trials, it is concluded that a light-weight, single-wheel barrow with a scooter-tire and ball-bearing wheels, is the most economicial type of wheelbarrow of earth haulage. (See also Technical Memorandum No. 13 (October 1975)).

Technical Memorandum No. 2

Increasing Output of Manual Excavation By Work Reorganization: An Example of Passing Place Construction on a Mountain Road

January 1975

The Paper demonstrates the need for proper organization of labor-intensive tasks of civil construction. It is shown that for excavation and hauling activities, labor productivity can be increased two to three fold with

(i) proper work organization,

(ii) incentive payment methods, and

(iii) proper selection and maintenance of hand tools.

Work was carried out on a passing place construction on a mountain road in northern India. Using the improved organization and work procedures, output per man-hour for excavation and haulage of earth was increased from 0.11 cubic meters to 0.28 cubic meters.

Technical Memorandum No. 3
Comparison of Different Modes of Haulage in Earthworks
June 1975

A comparison is made of the economics of earthmoving using different combinations of labor and capital. The range of alternatives varies from entirely labor-intensive methods to fully equipment-intensive methods. Intermediate technologies are introduced based on the usage of better modes of manual haulage and with the use of animals. The intermediate technologies are found to be generally economical for unskilled labor wage rates of $0.75 per day or less. Equipment-intensive methods are found to be optimal for wage rates of over $1.00 per day. The traditional labor-intensive methods are not found to be efficient under any assumptions of wage rates.

Technical Memorandum No. 4
Effect of Health and Nutrition Status of Road Construction Workers in Northern India on Productivity
January 1975

A pilot study was conducted to assess the health and nutrition status of a population of road construction workers in the mountainous region of Northern India. Clinical, dietary and biochemical analyses were carried out for a sample of 198 workers belonging to two distinct groups. In addition, the output of workers in haulage was measured over a period of six weeks. A number of health and nutritional deficiencies were observed. Among these were vitamins A and B complex, calories, fats, serum folic acid and red cell folate. Significant variations in work output were observed. Output of one population labor was positively correlated with homatocritic levels, but no such correlation existed for the other population. For both groups, output was strongly correlated with height, weight and arm circumference. However, because of several limitations of data, it was not possible to relate work output to any of the other health and nutrition variables. It is believed that these effects would be discernible in an intervention study in which intervention is undertaken to correct one or more deficiencies. Future work is planned in this direction.

Technical Memorandum No. 5
Comparison of Hand-Laid and Machine-Laid Road Surfaces
February 1975

A comparison is made of the quality of hand-laid with machine-laid road surfaces on a surfacing project in India. The machine-laid surface was found to be markedly superior with a rideability ratio of 2.5. Densities of asphaltic concrete for the two methods were similar. However, the cost of hand-laid surface was considerably lower than that of the paver-laid surface under Indian conditions. It should be noted that the surfacing by hand was carried out using labor who had no training in the operation and who did not employ even elementary tools. It is felt that the quality of hand-laid surface could be significantly improved by making a few simple changes. Future work is planned in this area.

Technical Memorandum No. 6
Haulage with Lift of Materials: Lifting Sand by Ropeway
February 1975

In labor-intensive haulage activities, labor productivity is reduced substantially if the materials have to be lifted over more than a certain height. This paper describes an experiment in which sand was to be hauled over a distance of 100 meters and a lift of 18 meters. Manual productivity was increased three-fold by the introduction of a ropeway arrangement which was manually operated. Applications of such an arrangement are possible in construction of embankments and in haulage of excavated materials from canal beds.

Technical Memorandum No. 7
Productivity Rates of Earthmoving Machines
May 1975

This paper attempts to arrive at some agreement as to what could be considered as "average" productivity of machines used for earth haulage. It studies the productivities of four basic machines -- bull-dozers, motorized scrapers, towed scrapers, and front-end loaders -- from various sources and under varying conditions. By comparing the various sources of productivity and the way machine productivity is affected by both the mechanical and the job condition characteristics, the paper recommends some adjustment factors that could be used to calculate machine productivities of Caterpillar equipment.

A "Supplement to Technical Memorandum No. 7" was published in August 1975.

Technical Memorandum No. 8
A Field Manual for the Collection of Productivity Data from Civil Construction Projects
July 1975

The collection of productivity data is the first (and last) step in any systematic procedure for choosing the "appropriate" technology to carry out a particular civil construction project. This manual describes a system for productivity data collection that is simple and concise enough for field use. It is specifically designed for application to labor-intensive construction projects.

Technical Memorandum No. 9
Report of First Road Demonstration Project
August 1975

A summary is given of observations and measurements taken during one construction season (1974) for a mountain road project in northwest India. In addition to recording overall productivities for the season's work, experiments and/or studies were made of the main operations, including earthworks (formation cutting), aggregate production, the transportation of materials, the laying of sub-base and base layers, and surfacing work. It was concluded that measurable improvements in productivity of labor-intensive tasks was achieved by the re-organization of work procedures and/or the use of modified or new equipment.

Technical Memorandum No. 10
A System of Deriving Rental Charges for Construction Equipment
August 1975

This paper investigates the requirements and aims of costing procedures for plant and equipment on civil engineering projects with particular reference to developing countries. Various existing systems of equipment rental charges are examined and a particular system is recommended for use by public works authorities in developing countries. Methods for derivation of the various elements of the charging system are described in detail.

Technical Memorandum No. 11
A Literature Review of the Ergonomics of Labor-Intensive Civil Construction
August 1975

This is a summary report of a literature study of the ergonomics of labor-intensive civil construction tasks. Some examples of potential uses of the subject are included in the appendices. The conclusion is reached that further work is necessary to make full use of this science.

Technical Memorandum No. 12
Haulage by Headbaskets, Shoulder Yokes and Other Manual Load-Carrying Methods
October 1975

This memorandum describes the use of headbaskets, shoulder yokes and other manual load-carrying methods traditionally used in civil construction. In addition, relationships for estimating productivity using headbasekets are presented, based on a simple theoretical work cycle "calibrated" by using the results of production studies currently available. An illustrative example is also given showing how the cost of headbasket haulage can be calculated by using the productivity data presented.

Technical Memorandum No. 13
The Use of Wheel barrows in Civil Construction
October 1975

This memorandum describes the characteristics of wheelbarrows, the mechanics of their use, various aspects of their design and features of wheelbarrow working, all with particular reference to the task of haulage in civil construction. In addition, relationships for estimating productivity using wheelbarrows are presented, based on a simple work cycle that has been calibrated by using the results of productivity studies currently available.

An earlier memorandum (No. 1) dealt with some limited experiments with wheelbarrows. This memorandum describes new work which is complementary to those experiments.

Technical Memorandum No. 14
Hardware Research Summary
October 1975

This memorandum outlines the investigations into the field of hardware made in the Study to date. A summary is given of the scope of future work planned, or needed, in construction hardware research for labor-intensive and intermediate technologies, primarily in connection with tasks related to earthworks.

Technical Memorandum No. 15
The Planning and Control of Production, Productivity and Costs in Civil Construction Project
October 1975

The planning and efficient control of production, productivity and costs in a civil construction project is the major task of site management. This memorandum briefly discusses planning and describes a control system which should assist site managers to make sound decisions based on measurements and should assist planners to have more reliable data for future projects. The system described is complementary to and compatible with the Manual for Productivity Data Collection, already issued as Technical Memorandum No. 8 of this series. It is specifically designed for use in labor-intensive construction projects.

Technical Memorandum No. 16
Lever Cranes
October 1975

This memorandum describes the testing of two types of manually-powered lever cranes on a canal excavation site in Indonesia. Traditionally soil is moved by headbaskets on such sites and this involves the haulers lifting their own bodyweight as well as their payload when working over a rising grade. It was felt that by lifting the load alone some improvement in productivity could be obtained. The report shows that if lever cranes are used for this haulage activity several factors combine to reduce the productivity markedly below that for headbasket haulage and concludes that manually-powered lever cranes appear to have little application in civil construction, except for a very few special circumstances.

Technical Memorandum No. 17
Compaction
December 1975

This paper reviews the techniques applicable to compaction on labor-intensive projects. It does not purport to be a treatise on compaction, but discusses the on-going processes as noted by observers in various countries and examines the results of an intervention study carried out on a canal construction project in Indonesia where the productivity of various types of simple equipment, powered by animals or humans, was measured.

Technical Memorandum No. 18
Spreading Activities in Civil Construction
December 1975

Spreading is a common but frequently minor activity in civil construction. During the study observations have been made of on-going methods in earthworks and pavement construction, including surfacing. This memorandum summarises the results of these observations and concludes that for non-bituminous materials there is a relationship between the productivity (expressed as output per man-hour, etc.) and the layer thickness. It also appears that spreading bituminous materials requires less effort than that needed for non-bituminous materials of similar thickness.

Technical Memorandum No. 19
Excavation
February 1976

The activity of excavation is basic to all civil engineering projects to a greater or lesser extent. This paper presents excavation data from sites in India and Indonesia largely from observations of on-going work, but in some instances intervention techniques, such as pre-ripping by plough, were applied. It is found that in many cases the excavation activity is inextricably connected with the loading activity and that in general labor-intensive methods are very similar in cost to, and often somewhat cheaper than, equipment-intensive methods. The use of tracked or wheeled machines for excavation alone is substantially more expensive than manual excavation.

Technical Memorandum No. 20
Loading and Unloading Activities
February 1976

The loading and unloading of materials into or from vehicles and other equipment are activities which occur on all civil construction projects. During the study observations have been made of manual loading and unloading of a variety of equipment using hard tools. This memorandum summarizes the results of these observations. A full statistical analysis of the data shows that productivity is significantly affected by the payment method being used and the level of supervision.

Technical Memorandum No. 21
A Literature Review of the Work Output of Animals with Particular Reference to their Use in Civil Construction
February 1976

This is a summary report of a literature study of the work output of animals and the factors which affect animal productivity. It is intended as a complementary memorandum to Technical Memorandum No. 11 on human ergonomics, and should be read in conjunction with it. The conclusion is reached that further work is necessary and that special attention should be paid to the work of animals when used on civil construction tasks and to particular problems this work may cause.

Technical Memorandum No. 22
Haulage Using Aerial Ropeways
June 1976

This paper discusses the results of experimental field studies with ropeways, and outlines the scope for using aerial ropeways in labor-intensive construction work. It is shown that in appropriate circumstances a simple ropeway installation can give significant reduction in unit cost of haulage compared with manual load carrying.

(Note: Part of the technical material in this paper formed the subject of a previous memorandum in this series (No. 6) entitled 'Haulage with Lift of Materials, Lifting Sand by Ropeway'.)

Technical Memorandum No. 23
The Use of Rail Systems in Civil Construction
June 1976

This memorandum describes the methods of assessing the suitability of rail systems for haulage work in civil construction and describes various types of systems used experimentally for such work in India.

Technical Memorandum No. 24
The Use of Agricultural Tractor/Trailer Combinations
June 1976

This memorandum describes the use of agricultural tractors to haul construction materials in trailers, it explains the problems in their use and ways of overcoming these problems. Various options are discussed, such as the choice between two- and four-wheeled trailers, tipping trailers and ballasting of the tractor. A large portion of the memorandum is devoted to the question of load transfer from trailer to tractor and to the manner in which this affects the traction available to the tractor. The paper gives a numerical guide to the selection of appropriate combinations of tractor and trailer size for a given haul route surface and gradient, followed by an explanation of how to calculate the numbers of laborers and trailers required. Detailed instructions for calculating productivity and unit costs are given, and the relative merits, in cost terms, of truck and tractor/trailer haulage are discussed. The memorandum ends with a review of other implements available for use in conjunction with tractors, such as rippers, graders and rollers.

Technical Memorandum No. 25
Aggregate Production
June 1976

Aggregates are extensively used in civil construction and the cost of their production is often a significant part of the total project cost. If suitable aggregates can be gathered (with or without screening) from sources close to the site, then this will probably be the cheapest method of production. However, it is usually necessary to crush or break quarried rock and/or collected boulders to produce aggregate of an acceptable size, shape and strength. These tasks are carried out by equipment-intensive crushers or by labor-intensive methods using hammers. Although a crushing plant can be highly automated, a significant number of laborers can be employed with small-scale equipment for such activities as loading and hauling to stockpiles.

This memorandum discusses aggregate production with particular reference to labor-intensive and semi-labor-intensive methods, and given the results of field observations of productivity. As a result of these observations it is concluded that for hand-breaking of stone the size, shape and construction of the hammer is important, and more attention needs to be given to the steel used for the hammer head. In addition, there appears to be a relationship between manpower required for manual breaking and the size of product, reduction factor, and hardness of the rock being processed.

Cost comparisons at a daily wage rate of U.S. $0.5 suggest that there is a break-even aggregate size between 15 and 25 mm above which manual breaking is generally cheaper than using crushers. At that wage rate and for 1975 costs, the cost of producing aggregates are, typically, about U.S. $0.1 per tonne for 150 mm output size, U.S. $0.8 per tonne for 50 mm size and U.S. $2.0 per tonne for 15 mm size.