The Use of Wheelbarrows in Civil Construction
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WORLD BANK STUDY OF THE SUBSTITUTION OF LABOR AND EQUIPMENT IN CIVIL CONSTRUCTION

Technical Memorandum No. 13

The Use of Wheelbarrows 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 theoretical work cycle 'calibrated' using the results of production studies currently available.

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

Transport Research Division
Transportation and Urban Projects Department

Preface

This is one of a series of papers prepared in the course of the Study of the Substitution of Labor and Equipment in Civil Construction. The paper is prepared with the objective of generating discussion on the results of the study as and when they are available. The conclusions of this paper, therefore, must be considered tentative and subject to revision in the light of further field work and analysis. It is hoped that engineers will find these results useful in planning and executing labor-intensive civil construction projects. Comments are solicited from all interested persons.

The paper is based on the field work in India and Indonesia undertaken by Scott Wilson Kirkpatrick & Partners (Consultants) in collaboration with the Governments of India and Indonesia; M J Sharrock carried out the analysis under the overall direction of P A Green. All the work in the study is supervised by Inder K. Sud of the World Bank. Financial support for the study is being provided by the World Bank and the Governments of Canada, Denmark, Federal Republic of Germany, Finland, Japan, Norway, Sweden, United Kingdom and the United States.

Contents

I. INTRODUCTION

1. In earlier times in western countries wheelbarrows were a common mode of mass haulage in labor-intensive civil construction. Indeed, the so called 'navvy' barrow for general light haulage purposes is still very much in evidence on small construction contracts. In China, where the wheelbarrow probably originated, it has long been widely used for earthworks haulage, although in a form and method of use distinctly different from the European pattern. By contrast, in India and Indonesia (and probably other parts of the world also) the wheelbarrow does not appear ever to have come into common use. Hence it has often been suggested that productivity of labor in India and elsewhere could be improved by the introduction of wheelbarrows because, while they are less versatile than traditional load carrying haulage methods such as the headbasket, they enable a worker to move a load many times as great as a typical basket load, given a good level surface.

2. During the present study, experimental investigations have been made of wheelbarrow haulage in earthworks. Construction of road and canal embankments has also been carried out using either specially designed or locally available wheelbarrows of western style. This program of work is continuing, using both western and chinese wheelbarrows, but on the evidence available at present it is possible to give some indications about the usefulness of wheelbarrows for haulage in civil construction and about the productivity that can be expected using western-style wheelbarrows. In addition, the appropriate circumstances and methods of working can be suggested and some of the limitations of using wheelbarrows can be described.

II. WHEELBARROW CHARACTERISTICS

3. Traditionally, wheelbarrows have been provided with a single wheel. Two-wheel barrows and small carts are not uncommon, but these are generally most suitable for handling materials in an industrial or similar environment where smooth paved surfaces are common. The single-wheel layout is to be preferred for the rough surfaces encountered in earthworks owing to its better manoeuvrability and greater ease of avoiding or overcoming obstacles. Furthermore, where a barrow run (1) has to be provided, the need to provide only a single narrow track is a considerable advantage in favor of the single-wheel layout. Although a two-wheel barrow has better lateral stability for a given load, the balance of advantages definitely seems to lie with the single wheel, which also can be unloaded more quickly and easily than the two-wheel variety.

4. Western-style barrows have a struck capacity in the region 0.06 to 0.08m^3, and this has usually been found during the study to allow a satisfactory payload of loose soil. A strongly made barrow of this size can weigh 40 to 50 kg. For earthworks containing rocks or boulders, this weight may be necessary, but for ordinary soil a lighter type of barrow construction weighing 20 to 30 kg is usually adequate. Extra light-weight barrows of 10 to 15 kg have been found to be rather short-lived, but could be used in special circumstances and on the basis of regular renewal of a replaceable body. The largest wheel which can be usefully accommodated is 40 cm diameter and a pneumatic tire and sealed ball bearings are probably economically justifiable despite the high initial cost. Handle width and height must be tailored to the stature of the workforce, so as to give a fairly upright stance, with straightened arms and back.

5. The modern Chinese earthmoving wheelbarrow has a large-diameter pneumatic-tired wheel of spoked construction. The capacity is around double that of the western type, and the load is carried on a flat platform placed above the wheel. On other than slight gradients, assistance is provided by pulling on ropes attached to the barrow. The increased weight on the handles and greater balancing problems, compared with the western barrow, are countered by the use of a strap fixed to the handles and passing over the hauler's shoulders.

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(1) A barrow run is a specially smooth strip on which the wheel of the barrow can run; often it is a line of timber planks laid end to end (see Fig. 1).

6. Various wheelbarrows in use for earthmoving are shown in Figs. 1 - 4. Other wheelbarrows have been illustrated in Technical Memorandum No. 1 of this series.

III. WHEELBARROW MECHANICS

7. The following considerations investigate in a general way some of the physical constraints on wheelbarrow performance and design. In the absence of special studies to determine exact values of parameters, quantities derived must be regarded as approximate. However, the results are confirmed in part at least by experimental observations made in the course of the present study.

Rolling Resistance

8. When a body rolls on a surface the force resisting the motion is termed rolling friction. This has a different value from that of ordinary sliding friction. A simple expression[2] used in mechanical engineering for rolling friction, applicable to fairly hard elastic materials, is:

$$\text{Rolling Resistance Force} = \frac{\text{Weight of Body x Rolling Friction Coefficient}}{\text{Radius of Wheel}}$$

This expression indicates that, other factors remaining constant, the rolling resistance is inversely proportional to the diameter of the wheel. Therefore, in seeking to minimise rolling resistance the aim should be to use as large a wheel diameter as possible. The coefficient in the above expression has dimensions of length, it varies with the conditions, but is mainly controlled by the nature of the materials in contact. For examples, with an iron wheel on an iron rail the value of the coefficient may be assumed to be 0.5 mm, with an iron wheel on asphalt 4 mm, and with an iron wheel on a wooden plank 6 mm. These figures are approximations, since various investigators are not in close agreement on the 'true' values for rolling friction coefficients.

9. Considering next pneumatic tires, the situation is more complex, as rolling resistance can arise from two different sources. When operating over hard surfaces, resistance is mainly due to energy absorbed in the flexing of the tire as it rolls; whilst on soft ground a large amount of work may be done in the deformation of the soil by the wheel. In the former case high inflation pressure reduces resistance, in the latter case, low inflation pressure can minimise the energy losses due to soil disturbance and hence reduce rolling resistance. It is evident that wheel diameter, tire pressure and soil characteristics all influence

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(2) See Machinery's Handbook 1974

the rolling resistance, and as yet no simple theory has been developed to predict rolling resistance of pneumatic tires on soil. In civil engineering calculations for earthmoving, an all-embracing assessment of rolling resistance is used. This is sometimes referred to as the Rolling Resistance Factor, and may be expressed as kg per tonne or as a decimal fraction of total load. Not surprisingly, various texts of reference list markedly differing values for this factor, so that it is usually difficult to select representative values. However, together with the data on iron wheels quoted above, the values of rolling resistance factor given in Table 1 are probably appropriate in the context of wheelbarrows and similar light haulage.

Table 1: Typical values for rolling resistance factor.

Wheel Description	Running Surface	Rolling Resistance Factor (as decimal fraction of total load)
30 cm diam. iron wheel	iron rail	.003
40 cm diam. pneumatic wheel	asphalt	.015
40 cm diam. iron wheel	asphalt	.02
30 cm diam. iron wheel	wood plank	.04
40 cm diam. pneumatic wheel	smooth hard earth	.05

Relation between Load and Gradient

10. The continuous force which can be exerted manually to push a wheelbarrow is about 15 kg. To obtain a precise knowledge of this force would require sophisticated experiments and study of a range of individual workers under various conditions. However, a precise knowledge is not necessary in the following reasoning, and the figure of 15 kg (obtained in simple tests using a spring balance attached to an empty barrow) is sufficiently accurate to give some useful indication of the relation between load and gradient for wheelbarrow haulage.

11. Assuming that the wheelbarrow is running on a good surface and with a factor of rolling resistance equal to 0.05 (see Table 1), the maximum gradient which can be negotiated with various all-up weights (W) is shown in Table 2.

Table 2: Typical maximum gradients which can be negotiated by wheelbarrows having different all-up weight. (Assumes pushing force of 15 kg and rolling resistance factor of 0.05).

All-up Weight of Barrow plus Load (W) (kg)	Rolling Resistance (0.05W) (kg)	Gradient Force Available (15-0.05W) (kg)	Maximum Gradient $\frac{(15-0.05W)\times 100}{W}$ (%)
130	6.5	8.5	6.5
170	8.5	6.5	4
200	10	5	2.5
250	12.5	2.5	1

Further calculations are shown graphically in Fig. 5 for three different running surfaces, viz. a hard smooth surface, poorly maintained earth, and loose sand and gravel.

12. These calculations are necessarily of an illustrative nature only, but experimental work previously reported(3) does provide a 'spot' confirmation. In these experiments a gross load of 170 kg at 4% gradient was found to be too great a load on a hard earth running surface, whilst [illegible]kg gross load could be handled continuously, albeit at a somewhat reduced speed. This is seen on Fig. 5 to agree quite well with the theoretical prediction developed above. In passing, it may be noted that this calculation indicates that at about 10% grade and on the best surface considered only about two headbasket loads (i.e. 60-70 kg) can be moved.

Optimum Wheelbarrow Load

13. The argument above can be a basis for determining the optimum wheelbarrow load under various conditions. The most important of the operating conditions is clearly the running surface. It is suggested that it will normally prove economic to provide a good haul route condition, since the load which may be moved is seriously limited by a poor working surface (unlike human or animal load-carrying modes of haulage).

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(3) See Technical Memorandum No. 1 of this series.

14. To date in the study, wheelbarrow haulage has been employed on work where individual haulers have moved their own loads without any external assistance. This is the most obviously suitable mode of working on linear sites. However, on compact sites, it is thought that assistance on steep slopes might be an economical solution, when winching, towing, or other means might be provided to help the movement of the wheelbarrow and effectively increase the load which could be handled. This could involve a semi-permanent installation at points where haul routes traversed inclines. In these circumstances the primary factor governing maximum load would be the rolling resistance on level ground, and it is suggested that 200 to 250 kg would probably be about the correct all-up weight to aim for, on the basis of Fig. 5. This would correspond to a pay load of say 150 to 200 kg. For the case of fully independent haulers, a much lower load will normally be appropriate, since the great majority of earthworks involves at least some haulage on rising grades. Taking for example low embankment construction as a typical case, a rise of 2-3 meters often occurs in a haul length of say 50 to 60 meters; as an overall gradient this is equivalent to 3 to 6%. In practice a combination of level haul and short ramps would occur in this task, but assuming that the overall grade is of relevance, an all-up weight of 120 to 170 kg would be the predicted maximum. This would allow a payload of 90 to 120 kg.

IV. WHEELBARROW DESIGN

15. In seeking an efficient wheelbarrow design it must be recognised that no single solution can be put forward as an ideal, since the circumstances of particular wheelbarrow applications lead to conflicting requirements. Most wheelbarrows will in practice be used under a variety of conditions and therefore a compromise must be achieved which will best meet the most frequently prevailing conditions (4). The factors which have been noted affecting size, geometry, construction, etc., as they apply to the main compounds of the barrow, are discussed below.

Wheels and Tires

16. The primary factor influencing the choice of wheel and tire is the running surface on which the barrow is used. On rough uneven surfaces a large diameter wheel overcomes small obstacles more easily than a small wheel and encounters less resistance. The same can be said of pneumatic tires in comparison with solid tires. On a smooth paved surface by contrast the advantage of a large wheel is no longer really significant, and any hard tire will give a relatively low rolling resistance. Pneumatic tires are more costly than solid tires, but can have an equal or higher resistance to wear, and are lighter, thus increasing the possible payload.

One or Two Wheels, Western or Chinese Pattern

17. In the case of one-wheel western style barrows, the wheel diameter cannot be much greater than 40 cm without causing the axle to become too far from the center of gravity of the load, thus transferring an undesirable proportion of the load to the handles. At the same time, the height of the center of gravity rises as the wheel diameter is increased, and this produces an increasingly unstable situation as the balance of the barrow worsens making any tendency to topple difficult to control. On the large wheel, Chinese-pattern wheelbarrow the high load center and resulting balance problem are offset by the use of a shoulder strap, but this will tend to lengthen the processes of taking up the load and of unloading. This factor, together with greater load capacity, would probably increase the optimum haul length for use of the Chinese barrow in comparison with the western pattern. More difficulty is also experienced in unloading two-wheel barrows compared

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(4) However, details have been given in Technical Memorandum No. 1 of a robust, single-wheel, western-style barrow (Type G) which appears to be well suited to haulage in civil construction; although it must be stressed that its proportions may not be ideal for all types of physique.

with the single-wheel western pattern, and two wheels give very poor manoeuvrability, except on smooth even surfaces. This effectively rules it out for use on rough terrain; however, for use on paved areas the two-wheel layout is very suitable for carrying heavy loads of concrete, aggregate or asphalt over longer distances.

Bearings

18. A good plain bearing when new, and with lubrication, is not much inferior to a ball bearing as far as friction is concerned, and makes only a small contribution to rolling resistance compared with the contribution due to the tire. However, one of the principle causes of the short life of barrows frequently observed in practice is excessive wear of plain bearings, and for this reason sealed ball bearings appear to have a definite advantage despite their relatively high cost. They are generally maintenance free and subject to practically no wear.

Body

19. Ideally the size of the body should be a function of the load to be carried and the nature and density of the material being transported. For a typical payload of 100 kg (see para. 14) and when carrying loose dry soil, a capacity of approximately $0.1m^3$ is required, whilst with wet concrete a capacity of $0.05m^3$ would suffice. Some compromise is possible, as a body of intermediate size can be heaped up with soil or partially filled to avoid spillage when carrying concrete. The body shape should be shallow to give a low center of gravity, with sloping sides for ease of emptying in the case of single-wheel barrows, when too it should be deeper at the front to place the load close to the wheel. Bodies should be replaceable, since this part of the wheelbarrow is subject to the most wear and if made of metal sufficiently thick to resist all normal damage would be uneconomically heavy and expensive. The connection to the frame should be with bolts rather than by welding for the same reason.

Frame

20. With the concept of the replaceable body proposed above, the purpose of the frame is to provide a strong supporting member which maintains the axle, body and handles in the correct relative positions. Steel tubing is probably the most suitable material for this purpose, although a structurally sound arrangement can also be achieved with angle iron. Some critical dimensions of the frame are the overall length as this affects manoeuvrability, loaded weight at the handles and ease of emptying; the width and height of the handles, which must be tailored to the requirements of the operative; and the attitude of the body when standing and when travelling, which must be close to the horizontal in both conditions with sufficient

ground clearance when lifted. In proportioning the frame the overall distribution of weight between the axle and the handles is an important consideration. It is not desirable to carry 100% of the load on the axle, and this is not feasible with the single-wheel barrow layout in any case. A comfortable weight at the handles aids the hauler in applying the necessary tractive effort to move and control the barrow; however, an excessive weight at the handles is counterproductive in these respects. In practice this means that for a western, single-wheel barrow the wheel should be placed as close to the body as a minimum working clearance will allow, whilst a two-wheel barrow should require an effort of about 10-15 kg to lift the handles when loaded. If insufficient weight is carried at the handles, the momentum of the load will tend to tip the barrow forward out of control when the wheel meets a slight obstacle.

V. WHEELBARROW WORKING

Western-Style Wheelbarrows

21. In considering possible ways of organising earthmoving by wheelbarrow, it is useful to draw some parallels with traditional operations such as haulage by headbasket. In these traditional methods of working, a variety of gang organisations have been observed. At the simplest level, a single worker excavates and loads his own basket, and then hauls, unloads and returns, to repeat this cycle independently of other workers. In practice this method of working does not occur frequently, as it has the particular disadvantage that the amount of load which can be transferred to the head unaided is much less than that which can be comfortably carried once the load is in position; output is therefore limited and the method is restricted to those small-scale works having only one or two workers where assistance at the pick-up-load stage would not give sufficient increase in output to justify additional labor. However, the same consideration does not necessarily apply to wheelbarrow working and it is quite feasible for an individual worker to carry out the complete excavate/load/haul/unload cycle, with good results, provided the conditions of the work are not unduly arduous in any way. Thus medium-heavy work can be performed with about 15% of the working day as rest[5] and given (say) no more than medium hard soil and a mainly level haul, quite acceptable unit costs can be achieved. If however the work is very heavy (say difficult excavation and up-grade haulage) more than 50% rest could be required with resulting low utilisation of tools and equipment. In these circumstances alternative methods of working could probably give better equipment utilisation whilst providing acceptable rest periods for the workers.

22. The above description of individual working raises additional questions. If a group of labour is accustomed to headbasket patterns of working, they may as a consequence show considerable initial resistance to working one man per barrow, this arrangement being contrary to their normal experience. Again, female workers often do not by custom carry out excavation, and in India for example it is unlikely that pushing of wheelbarrows would

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(5) This 15% excludes normal meal breaks, but it would include essential rest defined as non-working time in Technical Memorandum No. 8 of this series. In addition, the question of rest is discussed in more detail in Technical Memorandum No. 11 entitled "A Literature Review of the Ergonomics of Labour-Intensive Civil Construction".

be acceptable to women in many areas. A further factor to the problem is the possibility of increased skill to be gained by specialisation in an activity, particularly excavation or loading, or alternatively the possible benefits of each worker undertaking a range of activities in what might otherwise be a monotonous work setting (6).

23. Turning therefore to alternatives for the simple, one-man-per-barrow organisation, examples are found in the methods observed during the study. What could be described as the second level of organisation involves two categories of worker, viz. the excavator/loader at the borrow pit digging the soil and loading the barrow, and the hauler who is hauling, unloading and returning. Under most conditions using this arrangement it is found that loading takes longer than the necessary rest period required by the hauler, thus he waits longer for his barrow to be refilled than he needs and unproductive time will result unless spare barrows are used. The best productivity recorded to date was obtained from work organised in this second-level manner and using spare wheelbarrows.

24. Quite rapid loading car be obtained at the next level of organisation involving three categories of worker, viz. excavators loading into headbaskets, loaders transferring the soil from the headbaskets to barrows and the barrow haulers themselves. Spare baskets are an alternative to spare barrows in this situation. This type of organisation has been observed on canal construction in Indonesia where it was particularly suitable because of mixed rock and soil causing difficult excavation and loading conditions; however, the possible drawback in this instance was seen to be the difficulty of achieving good gang balance(7) with such a diversity of individual activities comprising the task. In general, for any method more complicated than one-man-per-barrow, gang balance is a critical factor.

25. It is hoped that the brief discussion above on organisation of wheelbarrow working indicates that it is not possible to give rigid rules, each situation must be studied on its merit. In introducing an unfamiliar piece of equipment, attention to details of the method of working in the paricular circumstances of the site will generally prove to be very rewarding in terms of productivity, but it is suggested that improvements to performance will take place

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(6) It should be noted that in the industrialised countries the whole question of work organisation, over-specialisation and worker monotony is currently an urgent research topic by behavior scientists and work-study engineers, and there is now a general movement towards <u>decreased</u> specialisation.

(7) The question of gang balance is discussed in Technical Memorandum No. 8 of this series (see particularly para. 15).

over a fairly lengthy period if there is a significant departure from the equipment and/or organisation traditionally used.

26. Finally in this context a point which can easily be overlooked is the importance of regular and careful maintenance of wheelbarrows and barrow runs. A small but definite input here will undoubtedly make all the difference between good and only moderate results. Thus, for example, on a barrow run even a small step or discontinuity can completely destroy the momentum of the barrow. The principle advantage of using barrows for haulage is their ability to move a quite heavy load with ease, and it is starting and stopping the barrow which consumes the most energy in the hauler's cycle. Unnecessary interruptions to smooth running are therefore most disadvantageous and should be treated as such, emphasis on this being given in explaining the method to the work-force. In addition, under-inflated tires or stiff bearings can significantly increase rolling resistance.

Chinese Wheelbarrows

27. Experience has not yet been gained during the study of methods of working with Chinese wheelbarrows. The higher load capacity and use of more than one hauler per barrow, or towing by winch, animal power, etc. (whichever may be appropriate) will require consideration in examining suitable organisation of the work. It is hoped to report on this subject in a revision or supplement to this memorandum, in due course.

VI. PRODUCTIVITY OF WHEELBARROWS

28. The productivity data available and analysed at the date of this memorandum comes from two sites in India and one site in Indonesia, where barrows were introduced for experimental or demonstration purposes. In India, wheelbarrows were used on a paved surface to haul earth and rock to spoil [(8)], and for haulage in low embankment construction on a new road project. In the low embankment work a 70 to 80 m haul on a wood-plank barrow run was involved (see Fig. 1). Both the Indian tasks were on essentially level hauls. In Indonesia the wheelbarrows were used in irrigation canal construction on sidelong ground. Haul length was mainly in the region of 20 to 30 m, predominantly on down gradients, but also including some up-grade haulage. Wood-plank barrow runs were employed here also. In total, the data represents some 50 days work, with gang strengths of typically 4 to 10 men. In addition to this data of actual construction work, the experience gained from experimental studies with wheelbarrows in India and Indonesia has been used in formulating the technical relationships given in the following paragraphs.

29. Fig. 6 shows the present interpretation of wheelbarrow productivity. This analysis of wheelbarrow haulage data has been carried out in terms of working time [(9)], with data specially abstracted from the field observations. This has been necessary, partly because of modified data abstraction and processing methods developed during the study, but more importantly, to exclude as far as possible the effects of poor gang balance and method-of-working differences between sites. In this way the underlying characteristics of the haulage mode are brought out more clearly. However, the productivity figures thus derived represent 'good practice' on site, and must be viewed accordingly when compared with average productivities from data covering the wide range of conditions and levels of efficient and inefficient working found in practice. Nevertheless, a wide scatter of input coefficients [(10)] was obtained from the analysis - typically showing 100% variation for any

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(8) For details of this work see Technical Memorandum No. 2 of this series entitled, 'Increasing Output of Manual Excavation by Work Reorganisation: An Example of Passing Place Construction on a Mountain Road'.

(9) This working time (WT) is similar to that defined in Technical Memorandum No. 8 of this series. Basically, it does not include an allowance of necessary rest or enforced waiting time.

(10) The input coefficient is the quantity of resource input (e.g. man-hours) per unit of work output (e.g. cubic-meter).

given haul distance as represented by the difference between Line A and Line B in Fig. 6. It is believed that this range is mainly the result of differences that can occur between high-incentive piecework payment at the more productive level and daily-paid work at the less productive level. Other, unidentifiable site-dependent factors also contribute to the range of values found however, and a statistical basis for the effect of payment method has not yet been fully established.

30. The method of analysis used to produce Fig. 6 approached the determination of productivity by a twofold path. Firstly, extensive records of the work-element values measured in the field were used to establish theoretical cycle times. The cycles being calculated for the case where no wait-while-loading occurs, as would be obtained with correct gang balancing and sufficient spare wheelbarrows. Upper and lower bounds of the work-element values were selected, to reflect the differences observed between sites. A simple mathematical model of the work cycle was then used to generate a technical relationship between input coefficient and haul length. The basic elements of this model are given below in Table 3 and in the formula for Line A and Line B.

Table 3 : Upper and lower cycle elements for wheelbarrow haulage (see also Fig. 6).

Cycle Element in Working Time	Site Management Conditions	
	Line A: Good Organisation High Incentive	Line B : Fair Organisation Non-Incentive
Payload	100 kg	70 kg
Speed Full	80 m/min.	50 m/min.
Speed Empty[11]	75 m/min.	40 m/min.
Pick-up Load Time	0.1 min.	0.2 min.
Unload Time	0.25 min.	0.3 min.
Rest[11]	0.5 min.	1.1 min.

The hauler input coefficient is therefore given as:

LINE A Man-hour (WT)/m^3 = 0.25 + 0.0076H
LINE B Man-hour (WT)/m^3 = 0.67 + 0.019H
where H = Haul length in meters.

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[11] It is interesting to note that the speed empty is usually less than the speed full and undoubtedly the hauler gets some essential rest while walking back to the loading point. However, rest will be taken at other points in the cycle and it is not necessarily obvious when this rest occurs; the commonest point is usually at the borrow area immediately prior to taking up a refilled barrow.

31. Secondly, an analytical approach was used to abstract from the field data the observed resource inputs and total outputs for each available group of observations. In doing this, the time spent by haulers waiting-while-loading was excluded, unless it was very small. Necessary rest and all other essential working time was included.

32. In using Fig. 6 it should be noted that Line A and Line B give haulage productivity on the basis of the simple cyclical load-haul-unload-return model. The resource input considered is the hauler's working time, and therefore includes the time elements for taking up the loaded barrow, hauling loaded, unloading, returning empty, and necessary rest (irrespective of where it occurs in the cycle). Also, the haul distance in meters assumes a more-or-less level haul route as no accurate relationship has yet been determined to enable the equivalent haul length to be calculated[12]. However, initial consideration of this subject suggests that each meter rise will effectively add 10 - 20 meters to the haul length; thus a haul of 80m with a total rise of 4m would have an equivalent haul length of about 140m (i.e. 80 + 4 x 15).

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[12] The method of calculating equivalent haul length for headbasket haulage is discussed in Chapter V of Technical Memorandum No. 12 of this series; the approach for wheelbarrows will be similar, but it is not to be expected (necessarily) that the same equivalence factor will be appropriate.

VI. COST OF WHEELBARROW HAULAGE

33. If it is first verified by observation that for a particular site the results given in Fig. 6 are applicable to that site, then it is possible to derive unit costs for wheelbarrow haulage. An illustrative example is given below.

34. Firstly, as the results have been expressed in terms of WORKING TIME an estimator concerned with daily or weekly production must first decide what the actual average daily working time and daily wage of labor will be. In this matter it is suggested that the values given in Table 4 might represent 'typical' values for Line A and Line B situations.

Table 4 : Suggested (and illustrative) values of available time[13], working time and daily wage.

	Site Management Condition	
	Line A : Good Organisation High Incentive	Line B : Fair Organisation Non-Incentive
Available time per day	10 hours	8 hours
Ratio WT/AT	90%	75%
Working time per day	9 hours	6 hours
Daily wage for labor *	U.S.$ 1.2	U.S.$ 0.5

* The term 'daily wage rates' for the incentive method of payment is merely a notional concept as the actual wages paid are based on the output. For incentive method of payment, it in reality reflects the daily earning of a worker.

35. Secondly, the mean haul length for the work must be assessed - let us assume three values of 25,50 and 100m (Note: The calculation should be in terms of equivalent haul length to allow for the effect of rise, but this cannot be done until an accurate equivalency factor has been determined, as discussed in para. 32). The likely range of outputs and costs can now be calculated as given in Table 5 and plotted in Fig. 7.

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(13) For definition of Available Time (AT) see Technical Memorandum No. 8 of this series.

Table 5 : Range of output and costs for wheelbarrow haulage.

	Unit	Haul Length (m)	Site Management Condition	
			Line A	Line B
Input coefficient (From Fig. 6)	man-hr (WT) per m^3	25 50 100	0.44 0.63 1.01	1.15 1.62 2.57
Output per man-day (= Working time per day / Input coefficient)	m^3	25 50 100	20.5 14.3 8.9	5.2 3.7 2.3
Cost per unit of output (Daily wage plus equipment cost / Output per man-day)	U.S.$ per m^3	25 50 100	0.08 0.11 0.18	0.15 0.22 0.35

36. As indicated in Table 5, in calculating the unit cost of output it is necessary to add to the wage of the hauler his portion of the cost of equipment, including the cost of any barrow runs. This equipment cost will not be a constant and generally has to be averaged over a working season. It also depends on a number of factors such as the size of gang, the number of spare barrows and the haul length. However, typically for a Line A situation the equipment will cost between U.S. $ 0.2 - 0.6 per day per hauler, with an average value of U.S. $ 0.4. This average value has been used in Table 5. Similarly, for a Line B situation equipment cost is likely to be between U.S. $ 0.15 - 0.45 per day per hauler, with an average of U.S. $ 0.3. In terms of wage rates this means that on average for Line A situations the equipment is 33% of the hauler's wage or 25% of the total cost of haulage. The corresponding values for Line B situations are 60% and 37½%.

37. It must be stressed that the unit costs given in Table 5 refer to the haulage only and they do not include:-

(a) costs of other activities in the task (e.g. excavation and loading);
(b) supervision and overhead costs; and
(c) profits (if appropriate).

VII. DISCUSSION

38. Various traditional labor-intensive haulage modes such as the double yoke, the head basket, different beasts of burden, and animal-drawn carts are found on earthworks projects in India and Indonesia. In addition the diesel truck, loaded and unloaded manually, is a common mode of haulage. At their best and with the current wage rates in those countries (i.e. U.S. $ 0.5 per day for daily paid labor), such operations yield costs believed to be on a par with, or lower than, equipment-intensive costs in similar circumstances. When operated efficiently, as is often the case where small contractors are working, these existing modes show a quite definite pattern of application. In this pattern, a principal factor is haul length. Thus, manual load carrying is the most competitive method on short hauls, for short to medium distances the beast of burden is used, for medium hauls the animal cart, and finally on long hauls the truck gives the lowest unit cost. On examination of this pattern it is seen that the size of the load carried in each mode of haulage correlates well with the appropriate haulage distance, as shown in Table 6.

Table 6 : Correlation between haulage method, typical load carried and preferred haul distance.

Haulage Method	Typical Load (kg)	Preferred Haul Distance (m)
Headbasket, yoked basket	35	0 - 100
Donkey	150	50 - 250
Camel	350	200 - 400
Mule Cart, Ox Cart	500	200 - 600
Truck	4000	500 and upwards

39. It is not proposed to discuss in this memorandum the explanation of this pattern, rather to say that the wheelbarrow, or any other introduced method, is basically in competition with certain particular modes, and will be of use under particular conditions, given that a range of alternative modes is available. It is considered that in the Indian and Indonesian context, the wheelbarrow appears to be an appropriate mode for haulage distances of about 30 to 150 m, and is a viable alternative to headbasket and donkey haulage. Indeed, the productivity data analysed so far suggests that at an optimum haul distance approaching 100m, where steep gradients are not involved, the western-style barrow can give results superior to either headbaskets, donkey haulage, or equipment-intensive methods.

40. However, it must be stressed that in an environment different from that of India the applications for wheelbarrows could well be different. It seems for example that in some regions of China the wheelbarrow is used very extensively in earthmoving work, over haul lengths up to nearly 1 km. It is possible to speculate that the occurrence of one predominant mode of labor -intensive haulage may be due to a very different relative cost and availability of human and animal labor in the different conditions there. Similarly it may be suggested that in some African countries, where perhaps pack animals are scarce and no tradition of construction work is found, introduction of wheelbarrows would be more acceptable than the headbasket or yoke, whilst to introduce a suitable beast of burden may not be feasible.

41. Some of the data upon which the analysis presented in this memorandum is based has been obtained from work conducted on an experimental basis. It thus occurs that factors not present when on-going traditional works are observed can influence the results obtained. The two main effects are those of an insufficient learning period available when workers are introduced to new techniques and of the rather higher supervision level, which is difficult to avoid. Possibly however, these factors may tend to compensate rather than being additive in effect. Amongst the objects of the program of studies still continuing is to gather data where greater familiarity with new methods and a more normal supervision input exist by virtue of a longer period of work in a given experimental area. Greater confidence will thus be obtained in making comparisons with traditional methods.

42. Future revisions of this memorandum will, it is hoped, benefit from the additional data and expand the coverage of the topic by considering more fully alternative methods of working and wheelbarrows based on the Chinese pattern. The results of institutionalised research on fundamentals such as the soil-wheel interaction should also be available.

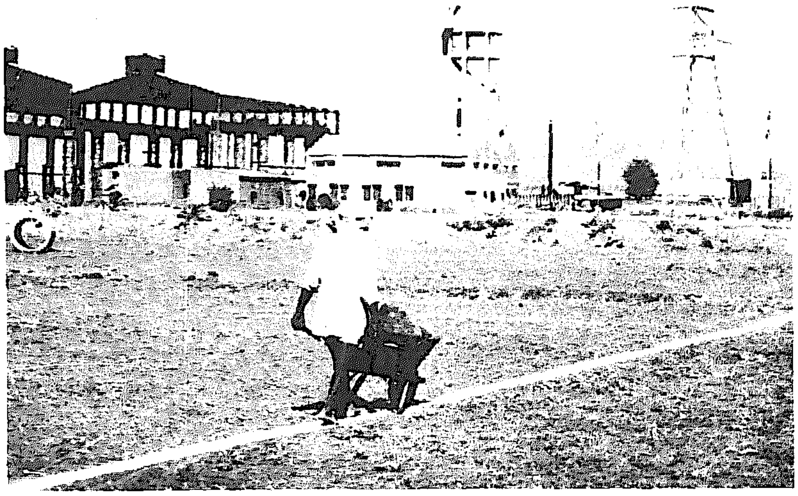


Figure 1. WESTERN-STYLE BARROW DEVELOPED FOR STUDIES OF LOW EMBANKMENT CONSTRUCTION IN INDIA
(Weight 26kg Payload 100kg)

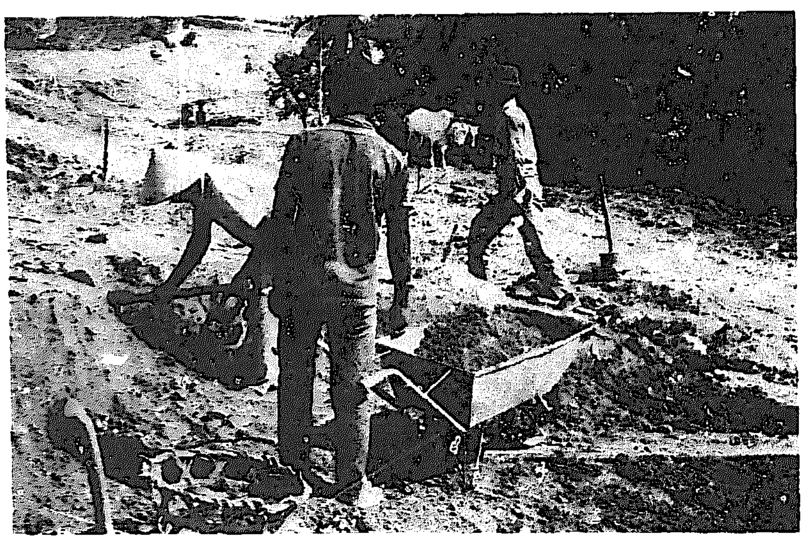


Figure 2. WESTERN-STYLE BARROW, LOCALLY AVAILABLE IN INDONESIA, USED IN CANAL CONSTRUCTION STUDIES
(Weight 16kg Payload 75kg)

Figure 3. HAULAGE ON UP-GRADE USING WESTERN-STYLE WHEELBARROW AND TIMBER BARROW RUN
(Weight 16kg Payload 75kg)

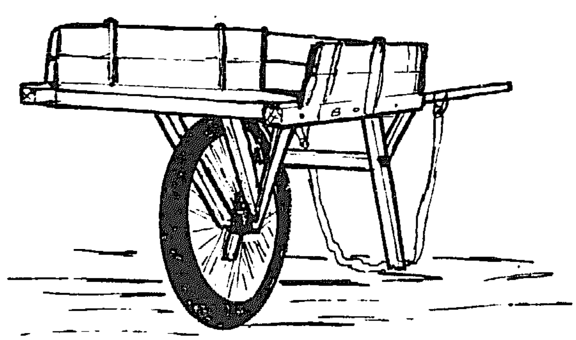


Figure 4. CHINESE WHEELBARROW IN USE ON FLOOD PREVENTION WORKS IN NORTHERN CHINA
(Weight Approx 50kg Payload Approx 200kg)

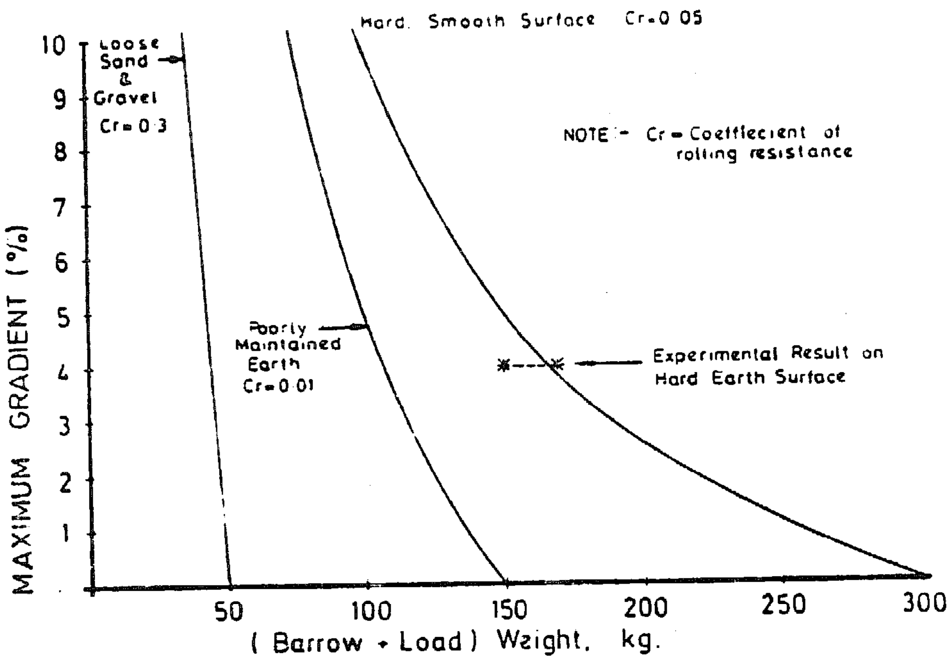


Figure 5. CALCULATED RELATION BETWEEN MAXIMUM WHEELBARROW WEIGHT AND GRADIENT.

Wheelbarrow haulage activity consists of :

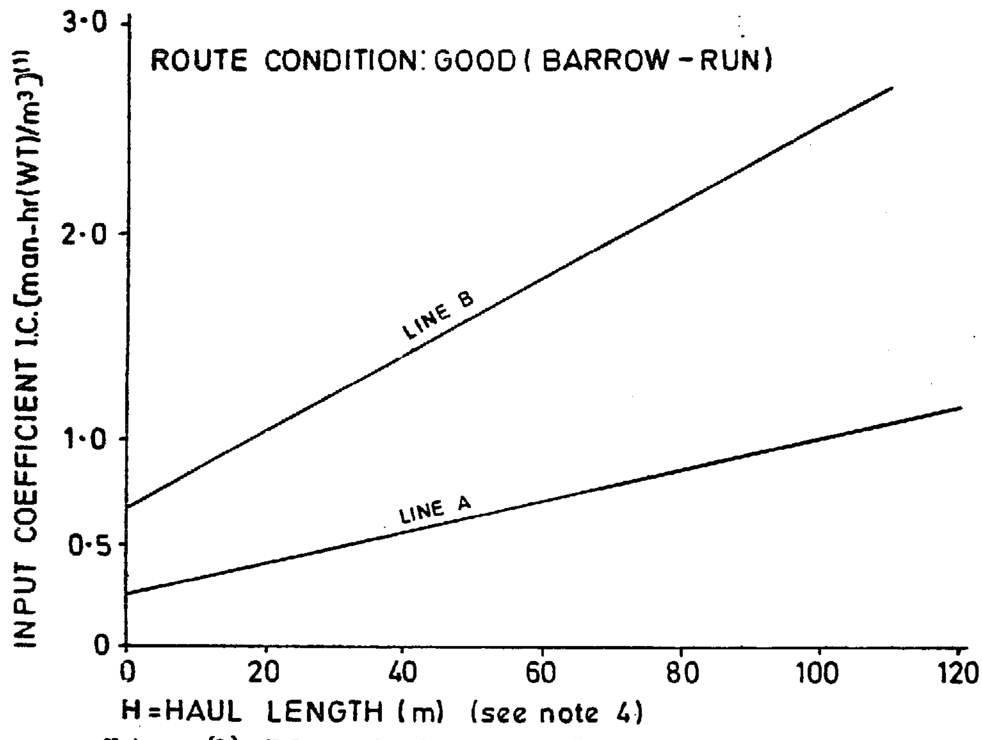
Pick-up Load - Haul Full - Unload - Haul Empty.

The figures given below assume good gang balance and include NO waiting-while-loading time, other than essential rest.

	Site Management	Barrow Load (kg)	Speed Full (m/min)	Speed Empty (m/min)	Pick-up Load time (min)	Unload time (min)	Rest time (min)
LINE A	Good Organisation High Incentives	100	80	75	0·1	0·25	0·5
LINE B	Fair Organisation Non-Incentives	70	50	40	0·2	0·3	1·1

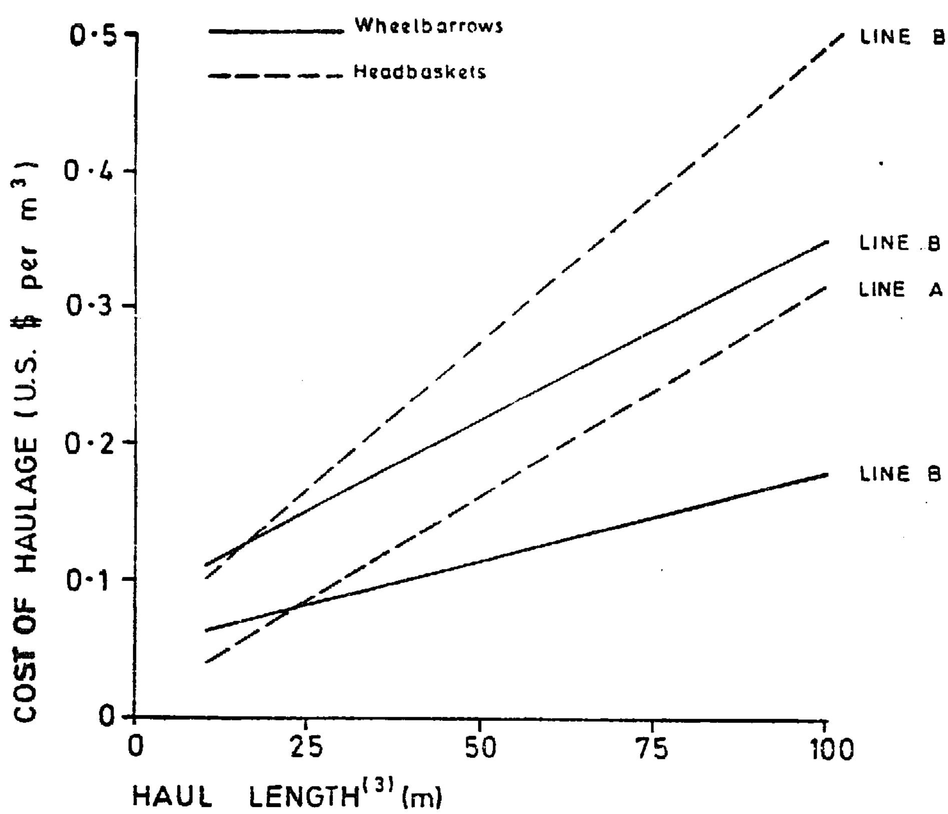
Equations
LINE A $I.C. = 0{\cdot}25 + 0{\cdot}0076\,H$
LINE B $I.C. = 0{\cdot}67 + 0{\cdot}0186\,H$
H in meters

Cycle Times
LINE A $0{\cdot}85 + 0{\cdot}0267\,H$ minutes
LINE B $1{\cdot}60 + 0{\cdot}0444\,H$ minutes
H in meters



Notes:
(1) Volume of output measured in-situ at borrow area.
(2) Calculations assume in-situ soil density of 1.75 tonne/m^3.
(3) Outputs applicable to hauler with average body weight of 55 kg.
(4) Applicable for more-or-less level haulage (see para. 32), haul length is distance from the pick-up point to the unloading point.

Figure 6. WHEELBARROW HAULAGE : PRODUCTIVITY/HAUL LENGTH RELATIONSHIP



Notes:

(1) Graphs for wheelbarrows prepared on basis of Table 5.
(2) Graph for headbaskets taken from Technical Memorandum No. 12 of this series, with minor corrections for soil density differences.
(3) This should be regarded as the equivalent haul length (see para. 32).
(4) See notes (1) & (3) of Fig. 6.

Figure 7. UNIT COST OF WHEELBARROW HAULAGE FOR DIFFERENT HAUL LENGTHS COMPARED WITH SIMILAR HEADBASKET HAULAGE.

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3	Comparison of Different Modes of Haulage in Earthworks	Jan'75	Completely revised and re-issued June 1975
4	Effect of Health and Nutrition Status of Road Construction Workers in Northern India on Productivity	Jan'75	
5	Comparison of Hand Laid and Machine Laid Road Surface	Feb'75	
6	Haulage with lift of Materials Lifting Sand by Ropeway	Feb'75	
7	Productivity Rates of Earthmoving Machines	May'75	Supplement issued August '75
8	Collection of Productivity Data from Civil Construction Projects	July'75	
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11	A Literature Review of the Ergonomics of Labor-Intensive Civil Construction	August '75	

Number	Title	Dated	Revisions
12	Haulage by Headbaskets, Shoulder Yokes and other Manual Load Carrying Methods	October '75	
13	The Use of Wheelbarrows in Civil Construction	October '75	
14	Hardware Research Summary	October '75	