MACHINE COST CALCULATION - AN EXAMPLE IN A ROAD BUILDING PROJECT IN SIRAN PROJECT DIVISION, NWFP.

Gerhard Stoehr*

Abstract

For the calculation of cost of machine operations different costs like capital costs, personal costs and overhead costs are taken into consideration. Capital costs are the actual costs of the machine and are further divided into fixed, semi-variable and variable costs. Hourly cost of machine operation is calculated by summing up different costs (capital costs + personal costs + administration costs + overhead costs) divided by the useful life of the machine in hours. Hourly cost of machine when divided by the hourly productivity of the machine gives the machine cost/unit of production. Based on this scheme, cost of road construction with an angledozer in Siran Forest Division was calculated as Rs. 10.30/m^3 (US $ 0.56/m^3) of loose earth and Rs. 12.83/m^3 (US $ 0.69/m^3) of unexcavated earth. These figures of cost of angledozer provide useful information for cost estimation of road construction projects, with the use of angledozer, in mountainous regions of Pakistan.

Intoduction

For planning purposes and for controlling the use of machines, it is strictly necessary to have a quite exact knowledge about the running costs of machines. Any comparative study for the selection of better alternative of machines and equipment use in forest road building, requires reliable data about costs perhour and technical productivity in order to find out the cost per running meter of road.

FAO/ECE/KWF developed a scheme for the calculation of time costs. For more reliable time cost the required data can be taken from the catalogues or from similar experiences of "a priory" cost estimations, or collected during the operation. Normally the first type of estimation is useful, if own data is not available and a rough cost estimation for previous analysis is required. The definite costs per running meter of road can be calculated after having recorded and processed all the data.

Time costs vary mainly due to 2 factors:

- intensity of use of the machine
- roughness of the conditions under which machines have to work

The first factor is related with the number of productive hours per year. It is obvious that less the hours that machine works the higher will be the costs per hour due to higher depreciation, interest, etc. (Fig. 1a and 1b).

*Chief Technical Adviser, Pak-German Project at Pakistan Forest Institute, Peshawar/Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) Eschborn, F.R. Germany.

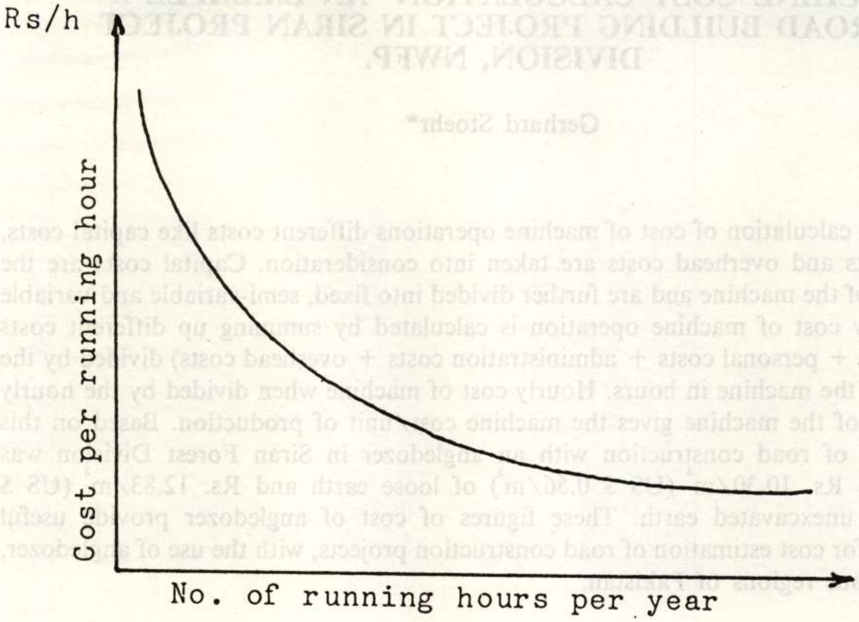

Fig 1a : Cost per running hour dependant on the intensity of use of a machine

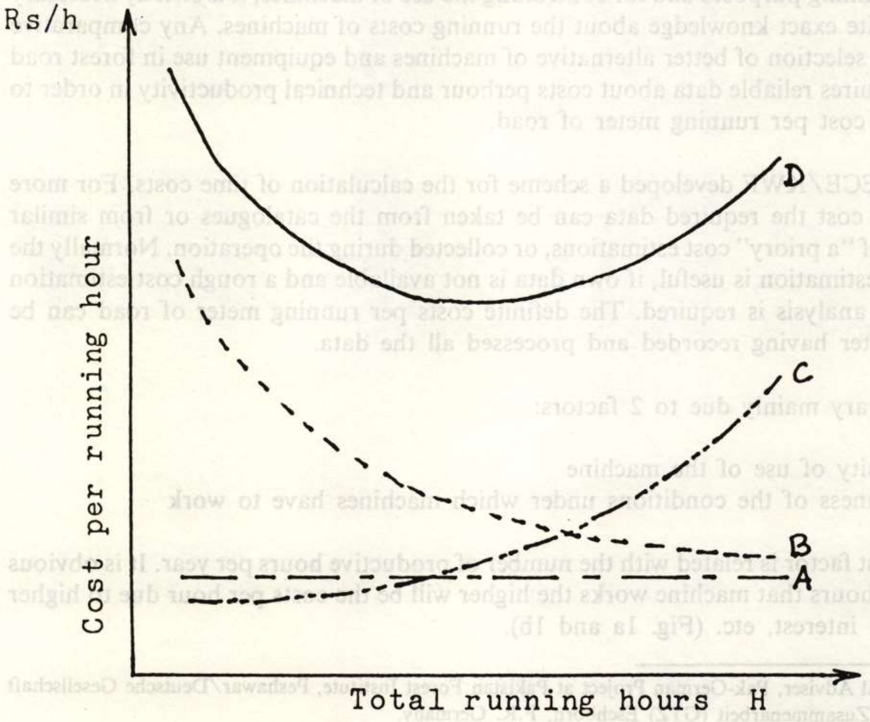

Fig 1b : Development of fixed and semi variable costs dependant on the total time of use of a machine

The second factor has a strong effect on the maintenance costs, because under more difficult conditions the wear and tear of machine will be quite heavy with higher expenditure on repair and maintenance.

Methodology of Time Costs Calculation

The proposed scheme considers 3 types of cost components:

- costs of the machine
- costs of the personnel
- costs of the administration

The costs of the machine can be sub-divided into:
fixed costs (interest, taxes, insurance)
semi-variable costs (depreciation, maintenance)
variable costs (P.O.L., repairs and spares)

Figure 1a and 1b show that how the different components of the time costs vary during the life time of a machine:

- Curve A (interest, taxes, insurance) is constant during life time because interest, taxes, insurance are paid annually independent how old the machine is.
- Curve B (depreciation) is degressive, this means that the older the machine gets, the smaller becomes the value of depreciation.
- Curve C (repair and maintenance) follow a progressive line. In other words, the older the machine gets, the more repairs have to be done.
- Curve D (total machine costs) represents the addition of the aforementioned partial costs.

Costs of the Machine:

Capital Costs

All costs which accrue due to acquisition, keeping and operating the machine.

– Fixed Costs

The components are interest, insurance, taxes and garaging. These costs are normally paid annually and divided by the productive work hours per year in order to get the fixed cost per hour. The interest is calculated on average investment or tied-up capital at the interest rate for which money could be borrowed from a bank.

$$I = A \times i \times f$$

A = Acquisition value of the machine
i = rate of interest
f = correction factor for compound interest (0.6)

Insurance and taxes are calculated on the basis of a rate expressed as percent per year of the acquisition cost, independent of annual depreciation.

– Semi-variable Costs

The components of semi-variable costs are depreciation and repairs/maintenance. Depreciation is the reduction in pay back amount per year or per hour of machine use. This value depends on the useful life time of the equipment, which in term is set by wear (deterioration) and technical/economical development (which causes obsolescence). There is no clear way to determine this span of time before hand. The proposed appropriate time periods are as follows (Bendz, 1974):

Equipment	Nomal conditions	Severe conditions
Power saws	1500 h or 2 years	1000 h or 1 year
Tractors	10,000 h or 4 years	8000 h or 4 years
Trucks	400,000 Km or 4 years	300,000 or 4 years

Depreciation (hours or years) however, depends upon the climatic and use conditions, degree of maintenance and skill and experience of the operators and drivers.

(a) $D = \frac{A-R}{H}$ when mu h

A : acquisition cost (Rs)
R : residual price (Rs)
H : life time (hours)
mu : minimum use per year (hours)
h : productive hours per year

(b) $D = \frac{A-R}{Nxh}$ when mu h

N = years when obsolescence occurs

Maintenance and Repairs:

Since only certain part of this cost is more or less unaffected by the degree of utilization, the formula for the estimation of these costs must consider whether the machine is depreciated within its obsolescence period or not.

(a) M = Dxc, when mu h

(b) $M = Dxcx\frac{Nxh}{4}$, when mu h

For this purpose 2 coefficients are used

(c) = coefficient of repairs for the whole depreciation period

$\frac{Nxh}{H}$ = coefficient to be applied when machine is depreciated without reaching the life time expressed in working hours (H)

– *Variable costs*

These costs mainly depend on the use of machine and are incurred on fuel, oil and lubricants (P.O.L.). The average consumption of each component is mostly given in the catalogues and manuals accompanying the machines.

Fuel: Fuel consumption vary heavily according to the type of work to be done. If no data is available, the estimation can be done on the basis of 0.1 liters of Diesel per hour and per HP.

Lubricants: Consumption of lubricants are strongly related with the fuel consumption of a certain machine. Therefore, a coefficient is normally used for the estimation (25—30%). If Diesel price is subsidized and lubricants do not, then a higher coefficient must be used.

– *Costs of personnel*

These costs include the salaries, allowances and social contributions etc. of the operators and helpers. The monthly costs will be divided by the running hours of the machine during 1 month. For the purpose of maintenance and repair, an increase of 15% of the personnel costs per hour of the operator is usually added to the regular personnel costs. A higher factor is required if maintenance work is more labour demanding e.g., greasing of cables on cable crane yarder.

– *Overhead costs*

Every activity besides the workers themselves, also requires the participation of technicians, engineers and administrative staff in order to allow an operation to run smoothly. Some of them will be responsible for the planning of the work, supervision, acquisition of spare parts, accounting, salaries and book-keeping etc. It has been suggested that 10—15% of the direct costs should be added to the total direct cost in order to cover the cost of supervision and administration.

In some cases additional costs have to be charged if the machine is run by a contractor, due to risks, profit and taxes:

= 5—10 % for risks
= 5—10 % for profit
= 10 % for taxes

TABLE 1

Scheme for calculation of time costs (STOEHR, 1977)

		Rs/year	Rs/h
1.	Cost of the machine		
	1.1 Fixed costs (FC)		
	– Interest (A x f x i/100)	. . . .	
	– Insurance (2.2%)	. . . .	
	– Taxes	. . . .	
	– Garage		
		F C:	
	F C: h = S_1		S_1: ....
	1.2 Semi-variable costs (SVC)		
	– Depreciation		
	(a) $D = \frac{A-R}{H}$, mu < h		....
	(b) $D = \frac{A-R}{NxH}$, mu > h		....
	– Maintenance and Repairs		
	(a) M = Dxc, mu < h		....
	(b) $M = Dxcx \frac{NxH}{H}$, mu > h		S_2: ....
	1.3 Variable costs (VC)		
	– fuel (1/h x Rs/1)		....
	– lubricants & oil		....
	(x: 25% of fuel cost)		S_3: ....
	1.4 Machine costs		
	($S_1 + S_2 + S_3$)		S_4: ....
2.	Costs of personnel		
	2.1 Operator (s) (N° x Rs/h)		....
	2.2 Helper (s) (N° x Rs/h)		....
	2.3 Maintenance (X: 15% of operator)		....
	2.4 Costs of personnel		S_5: ....
3.	Direct cost		
	($S_4 + S_5$)		S_6: ....
4.	Overhead cost (10—15%)		S_7: ....
5.	Total cost		
	($S_6 + S_7$)		S_8: ....

6. Costs of entrepreneur
   6.1 Risk 5—10% ....
   6.2 Profit 5—10% ....
   6.3 Taxes 10% ....
   6.4 Costs of entrepreneur S_9: ....

7. Total operational time cost
   ($S_8 + S_9$) S_{10}: ....

Symbols

A : acquisition value
B : residual value
f : correction factor for using simple rate of interest (0.6)
i : percent of rate of interest
D : depreciation
H : life time in hours
N : years to become obsolete
mu : minimum productive hours per year $= \frac{H}{N}$
h : productive hours per year
M : maintenance and repairs
c : coefficient of maintenance & repairs

Methodology of calculation of machine production

The first step when estimating machine costs is to calculate a theoretical value as explained below. This theoretical value is then adjusted according to actual figures obtained from past experience in similar operations. On the basis of these figures (particularly those for job efficiency), it will be possible to determine values suitable for the project which will be neither over-optimistic nor wasteful.

It is therefore, first necessary to fully understand the theoretical cost calculations and to be able to obtain a figure for working efficiency which is feasible on that job site. From this it is possible to obtain a realistic figure for the work volume that can be attained (Anon).

Formula for calculation of earth work volume

It is usual to express the operating capacity of construction machines in terms of production per hour (m^3/h or cu.yd./h). This is basically calculated from the volume of work per cycle, and the number of work cycles.

$$Q = q \times N \times E = q \times \frac{60}{Cm} \times E$$

where Q : Hourly production (m^3/h; cu. yd/h)

q : Production (m^3; cu.yd) per cycle, of loose excavated soil (This is determined by the machine capacity.)

N : Number of cycles per hour $N = \frac{60}{Cm}$

E : Job efficiency

Cm : Cycle time (in minutes)

Earth volume conversion factor (f)

The volume of earth work depends on the natural ground condition (undisturbed, loose or compacted). The conversion factor depends on the type of soil and the operating state. Machine productivity is expressed in terms of loose earth. However, when planning actual projects, work volume is calculated in terms of undisturbed or compacted earth, so care must be taken to convert these figures.

Example:

1,000 m^3 of undisturbed earth has to be worked

(a) What will be its volume when it has been excavated ready for hauling?

(b) What will be its volume if it is then compacted?

	Unexcavated volume	Loose volume	Compacted volume
Ordinary soil:	1,000 m^3 x 1.25 =	1.250 m^3 1.250 x 0.72 =	900 m^3
Gravel:	1,000 m^3 x 1.13 =	1.130 m^3 1.130 x 0.91 =	1.030 m^3
Soft rock:	1,000 m^3 x 1.65 =	1.650 m^3 1.650 x 0.74 =	1.220 m^3

Job efficiency (E)

When planning a project, the prescribed hourly productivity of the machines employed is the standard productivity under ideal conditions multiplied by a certain factor. This factor is called job efficiency.

Job efficiency depends on many factors such as topography, operator's skill, proper selection and employment of machines and the standard of maintenance. In order that the value for job efficiency can anticipate change in productivity, each combination of factors has it own value. However, it is very difficult to give a value for job efficiency from a combination of many factors, as it requires a lot of skill, therefore, efficiency given here is a rough guide.

TABLE 2

Job efficiency

Operating conditions	Maintenance of machine				
	Excellent	Good	Normal	Rather poor	Poor
Excellent	0.83	0.81	0.76	0.70	0.63
Good	0.78	0.75	0.71	0.65	0.60
Normal	0.72	0.69	0.65	0.60	0.54
Rather poor	0.63	0.61	0.57	0.52	0.45
Poor	0.52	0.50	0.47	0.42	0.32

Operating conditions refers to the following points and an overall judgement should be made to decide the level:

(a) Suitability of the machine in regard to topography.
(b) Arrangement and combination of machines.
(c) Job site environment and conditions, such as terrain, weather and lighning conditions.
(d) Operating method and preparatory planning.
(e) Skill and experience of operator and supervisor in regard to the operation.

The following points should be considered when selecting the level for maintenance of machine:

(a) Regularity of periodical maintenance which must be suitable for job condition, e.g. environmental condition.
(b) Condition of consumable parts, e.g. cutting edge for bulldozer.

Machine production calculation for angledozer

The hourly production of an angledozer (bulldozer) when excavation and dozing is as follows:

$$Q \ (m^3/h;\ cu.yd/h) = \frac{q \times 60 \times E}{Cm}$$

where: q : Production per cycle (m^3 ; cu.yd)
Cm : Cycle time (in minutes)
E : Job efficiency (see table 3)

Production per cycle (q)

For dozing operations, production per cycle is calculated as follows:

$$q = L \times H^2 \times a$$

where L : Blade width (m; yd)
H : Blade height (m; yd)
a : Blade factor

When calculating the standard productivity of an angledozer (bulldozer), the figure used for the volume of .earth hauled in each cycle.

Cost of angledozer in forest road construction

A Komatsu angledozer (bulldozer) was taken as an example of cost and productivity calculation. This machine was employed in the construction/improvement of forest road linking the town of Shinkiari and Kund as a joint venture between N.W.F.P. Forest Development Corporation, Pak-German Project, PFI and the Pakistan Forest Institute, (PFI), Peshawar, for the improvement of accessibility of forest of PFI Field station in Siran Forest Division.

On the basis of a calculated production capacity of 49 m^3 of unexcavated earth and 61 m^3 of loose earth on one hand and costs per running hour of Rs. 628.44 (for a state owned enterprise) the costs of earthwork would be:

for loose earth:	Rs. 10.30/m^3	(US \$ 0.56/m^3)
for unexcavated earth:	Rs. 12.83/m^3	(US \$ 0.69/m^3)

SEDLAK (1979) calculated for a secondary forest road in Austria for different terrain conditions a cost of US \$ 0.7/m^3 of earthwork, based on a machine cost per productive hour of USD 30/h (Rs. 560/h). These figures are quite similar to those calculated under Pakistani conditions. A reliable comparison is not possible because Austrian data are already 10 years old and the costs have definitely increased since then.

On the assumption that under difficult terrain conditions upto 6 m^3 per running meter have to be removed, one can assume that the furtherance of and angledozer as described before would be able to make 8 meters of road in one hour of productive work, provided that blasting has been done already. The costs of angledozer would be then Rs. 78.56/running meter (US \$ 4.25/m). This result is also similar to that calculated by SEDLAK (1979) for forest road construction under difficult terrain conditions in Austria. Under the assumption that due to difficult organization of work on the road on one hand and the need to retreat the angledozer during blasting the increase in cost may vary between 20% and 50%, but not necessarily.

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