Using An Expert System For Earthmoving Equipment Selection And Estimation Of Low Coasting

Nitesh Gupta[1] , Rakesh Gupta[2] , Mukesh Pandey[3]
[1] PG scholar, Civil Engineering Department ITM University, Gwalior, India
[2]Assistant Professor Civil Engineering Department ITM University, Gwalior, India
[3] Head Civil Engineering Department ITM University, Gwalior, India

---

***Abstract* - Earthmoving is often one of the most important operations in many construction projects in terms of its great effect on costs and productivity. In planning earthmoving operations, the selection of appropriate machines and the estimation of earthmoving costs are particularly important the process of selecting and estimating earthmoving equipment relies heavily on human experience and knowledge due to numerous factors influencing selection. Because of the nature of earthmoving equipment planning, it is desirable and possible. This thesis addresses the important aspects of earthmoving equipment selection and estimation. Realistic knowledge and experience in the earthmoving process was acquired by sending questionnaires to contractors in Delhi, India and Bhopal Stated and by interviewing experts. By investigating the problems existing in reality, a mathematical model for earthmoving equipment production and cost estimation is proposed and implemented in the expert system developed in this research. Into which the knowledge obtained from experts in the industry and from other sources was stored, and three data bases. It has the capability of selecting appropriate fleets of machines, from sixty machines considered in the system, and estimates their outputs and costs based on the given working conditions. Through a relatively easy question-answer routine of consultation, recommendations with relevant results can be quickly made and presented by the system.**

I. INTRODUCTION

Construction is an important industry in India in terms of the annual capital invested in construction work and its high employment. The importance of the industry can also be measured by its contribution to the gross national product However, the construction industry in India is in a difficult position due to the decline in construction productivity which started in the mid The current stringent financial situation aggravates these difficulties.

Facing these challenging problems, the construction industry became aware of the importance of productivity improvement and cost reduction, and is striving for such improvements. Historically, productivity improvement was often focused on labour effort; this also applied to the construction industry. As projects became larger and more complicated, no single cause could be accounted for the decline in construction productivity. Productivity has been widely acknowledged to be a management function and there are complex issues relating to productivity improvement.

To achieve improvements in construction productivity, concentration should be primarily placed on planning, scheduling, site supervision, engineering design, and the marketing practices of a construction organization along with the labour efforts.

In the construction industry, large amounts of construction companies' capital are invested in equipment, and a variety of construction equipment has been used in construction. The utilization of equipment reduces the reliance of the construction industry on intensive labour to a certain extent, and generally increases construction productivity. With this advancement, however, additional stresses have also been imposed on contractors who employ equipment to complete construction projects. This is because the contractors may face the potential risk of high equipment cost, without being compensated due to inefficient equipment utilization. Improper equipment planning and management often result in cost overruns, and consequently, lead to a decline in productivity.

The development of the infrastructure is vital for the healthy economic growth and prosperity of a country. To build the infrastructure such as roads, highways, railroads, airports, canals, dams, irrigation systems, and power or industrial plants, it is often inevitable to move earth to alter the surface configuration or conditions so that project requirements can be met.

Earthmoving is characterized by the intensive utilization of machines. It is therefore often one of the most important operations in many construction project in terms of its effect on costs and productivity. Hence, earthmoving planning is a potential area for further productivity improvement.

II. HISTORY

Applications of simulation techniques to earthmoving operations were made in the 1960s A model was developed using a computer simulation language,GPSS (General Purpose Simulation System), to estimate costs for earthworks.

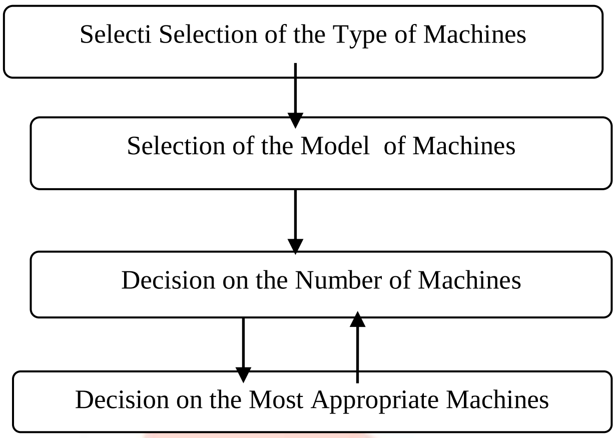
A recent application of simulation is the system developed researchers (1987), using the INSIGHT (Interactive Simulation using Graphical Techniques) simulation package. Using this system with the aid of a microcomputer, users can build a specific operation simulation model. The model can duplicate the real-time operations, extract and analyze data recorded at previous field operations, and give the estimates of cost and production, information on resources needed, and other activity performance data.

The rapid development of computer technology not only contributes effective ways to reach solutions, which are sometimes difficult to obtain manually, for the conventional mathematical methods, but also provides a useful means for earthmoving equipment planning. A computer wrote programed assist in the selection of earthmoving equipment.

III. SELECTION OF EARTH MOVING EQUIPMENT

In planning equipment for an earthmovjng operation, a decision should be made on what machines could be employed in the operation. In making such a decision, many interactions between engineering and economic considerations must be taken into account The process of selecting appropriate machines, however, can generally follow a decision-^ making path as the one shown in Figure 3.1.

Selection of the Type of Machines



IV. METHODOLOGY

SPECIFIC RESEARCH

The factors that affect the selection of earthmoving equipment and summarized these factors into four categories.

1. Spatial Relationships. In this category, the major factors were identified to be the elevation of the working platform, the face and level of excavation; obstructions in excavation; side, bottom and overhead clearances; the configuration of excavation, required reach, and maneuverability; and the proximity of on-site disposal area or location of hauling units.
2. Soil Characteristics. This category covers the soil's ability to support excavators and hauling units, and other soil characteristics such as traction, rolling resistance and gradcability; changes in soil characteristics while being processed or exposed to the environment; break-out force required to loosen; character of in-situ and loosened material; the need for ripping, pushing the excavators, and other assistance.
3. Contract Provisions. The factors in this category include the quantities of excavation, moving, and fill; the allowable time and length of construction season; provisions for payment and subsequent cash flow; the legal limitations on weight and size of equipment; work restriction such as hours, dust, noise and traffic.
4. Logistical Considerations. The factors included in this category involve the availability of equipment and operators with applicable experience; the time and cost to mobilize and demobilize crews; the use of equipment in preceding and in subsequent operations (resource leveling); the time parked or idle; rental costs, ownership costs, operating costs, and production rates; support facilities, standby units, and other required backup.

In a particular earthmoving operation, there may be different machines that can be selected after all the factors influencing the operation are considered. In finding the machine that is the most appropriate one among the alternatives, a machine selection model was also provided by Gates and Scarpa (1980). In this model, the costs of an operation were considered to be (1) costs due to nonproductive time of equipment, and (2) costs of production.

The nonproductive costs are the costs for mobilization and demobilization and costs for stoppages between successive operations. They may also include costs for prolonged shutdowns on account of weather, labour disputes, or other analogous factors. These costs are generally independent of the quantity of work, and thus are fairly fixed. The productive costs are the total costs of completing all of the work. They include the ownership or rental costs of machines, and the costs of fuel, oil, grease and maintenance, associated labour, and so forth. The total productive cost varies directly with the quantity of work and is the product of the unit cost of production and the quantity. The costs of two alternative kinds of machines and the relationships of the productive and nonproductive costs are show in Figure 2.1. The intersection of the two total cost lines is the point of equal total cost and the associated quantity, and is a point of indifference, Q . Through cost analysis, machines can be selected by comparing the actual quantity of material needed to be handled with the quantity at the point of indifference.

The point of indifference can be found from the following equations:

$$c_l Q + n_l = c_2 Q + n_2 F_2 \qquad (2.1)$$

and

$$Q^* = \frac{n_l = F_2 - n_l F_l}{\mathbf{C_1 - C2}} \qquad (2.2)$$

where c_1 and c_2 are the unit costs of productivity for two alternative kinds of machines, in Rupees per unit volume,

n_1 and n_2 are the numbers of the two alternative kinds of machines,
F_1 and F_2 are the fixed costs for the two alternative kinds of machine, in Rupees
Q is the quantity of material, in units of volume, and
Q* is the quantity of material at the point of indifference, in units of volume.

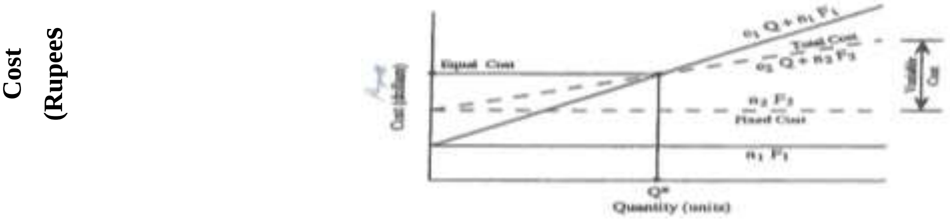


Figure 2.1 Point of Indifference, Q*, and Point of Equal Total Cost

The developed a graphical model, shown in Figure 2.2, for solving the machine matching problem by analyzing machine output. In developing this model, it was found that the load of a scraper increases rapidly, but the loading rate decreases as the scraper capacity is approached as shown by line BDO.

In Figure 2.2, the vertical axis indicates the amount of material loaded, and the horizontal axis represents certain parts of the cycle time. Line BDO is a typical load-growth curve for a bottom-loading scraper pushed by a track type tractor. AO (2.7 minutes) is the cycle time less the loading time for this particular scraper and soil, CO (0.3 minutes) is the cycle time less the loading time of the pusher. The slopes of lines connected from points A and C to the load-growth curve BDO indicate the output per unit time of the scraper and loader respectively, and the two lines would have their steepest slopes (maximum output per unit time) if they were drawn tangential to the load-growth curve. In each case, the optimum loads are determined to be about 31 and 23 cubic meters with pushing time being 0.8 and 0.35 minutes respectively. If the pusher works with two or more scrapers, this model can determine the most optimum production of the fleet when the costs of the pusher and scrapers are considered.

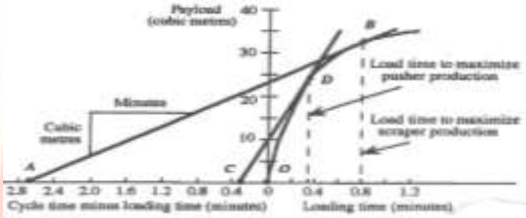


Figure 2.2 A Graphical Model Tor Maximizing Production of a Pushed Scraper

A mathematical model, called Revenue Requirements Method, was developed) for calculating the hourly cost of equipment to covenr.

1. direct operating costs,
2. repair, maintenance and insurance costs,
3. invested capital,
4. the repayment of borrowed capital,
5. income taxes,
6. the payment of interest on borrowed capital;

and to provide a return on investment (profit).

In the model, annual costs (C) are calculated by considering the costs directly related to the actual hours of operation such as fuel, oil, grease, etc., and the costs related to time such as insurance. Repairs, overhauls, and general maintenance, although hourly dependent, are treated as a yearly estimate. Thus,

C = estimated operating hours x hourly costs + estimated yearly costs (2.3),

The annual amount to recover the invested sum, interest, and profit is calculated by subtracting the product of the salvage value (SV) and the sinking fund factor (SFF) from the product of the purchase amount (P) and the capital recovery factor (CRF),

$$CRF = \frac{i_a(1+i_a)^N}{(1+i_a)^N-1} \qquad (2.4)$$

$$SFF = \frac{ia}{(1+ia)^N-1} \qquad (2.5)$$

$$ia = r(i_d - i_d t) + (l-r)i_e \qquad (2.6)$$

where i_a is the maximum acceptable rate of return
i_d is the interest rate on debt capital
i_e is the desired rate of return on equity capital,
N is the useful life of a machine, in years,

r is the debt ratio of the firm, and
t is the tax rate.

Income tax calculations account for annual revenue (R), annual costs (C), and annual depreciation (D). Thus,

$$\text{taxable income} = R-C-D \tag{2.7}$$

$$\text{income tax payable} = t» (R-C-D) \tag{2.8}$$

.Therefore, the annual revenue requirements (R) for a particular machine are the sum of the estimated annual operating costs, recovery, repayment, and return plus income taxes. The equations for calculating the annual revenue requirements (R) are as follows:

$$R = C+P.(CRF)-SV.(SFF)+t.(R-C-D) \tag{2.9}$$

$$R = C + \frac{P.(CRF)-SV.(SFF)-t.D}{(1-t)} \tag{2.10}$$

and thus:

$$\text{Hourly Rate} = \frac{R}{\text{Estimated operating hours per year}} \tag{2.11}$$

In addition to equipment ownership and operating costs, research has been conducted on the subject of equipment downtime costs. The downtime costs result from idle equipment and the time the equipment is unavailable. Direct downtime costs are those accrued as a result of a particular machine being idle, the machine operators' wages, and the loss of production by the machine. Indirect downtime costs, or consequential downtime costs, may include costs accrued due to the loss of production of other machines which are working together in a fleet with the machine considered, overhead costs over the extended period needed to accomplish the job, and so forth.

The consequential equipment costs caused by breakdown time and unavailability into four components:

1. associated resource impact costs (ARJ) that arise when failure in one machine impacts on the productivity and cost-effectiveness of other machines working in close association with it,
2. lack-of-readiness costs (LOR) that may be incurred when a machine is idle, resulting from a failure,
3. service level impact costs (SLJ) that arise when one machine in a fleet fails to the extent that other machines in the fleet must work in an uneconomical manner to maintain a required service level, and
4. alternative method impact costs (AMI) that arise when failure causes a change in the method of operations.

A developed conceptual model to deal with these four components. The cost-accumulation method is used to generate cumulative-cost profiles of the LOR, SL1, and AMI costs which grow over impact time. Particularly, the LOR and AMI costs can be calculated on a monthly basis using the following forms:

$$LOR= P. [\ D-(v.L_1) \tag{2.12}$$

$$AMI= S. [D-(V.L_2)] + V.M_p. (M_z+D_z) \tag{2.13}$$

where LOR is the lack-of- readiness costs for a machine in a month, in Rupees,

P	is the lack of readiness penalty cost, in dollars per hour,
D	is the number of hours the machine is broken down and unable to respond to operational demands in the month, in hours,
V	is the number of times the machine breaks down and disrupts planned operations in the month,
L_1	is the period of time from a failure to the start of penalty, in hours,
AMI	is the alternative method impact costs for the machine in the month, in Rupees,
S	is the cost surcharge caused by the alternative method, in/dollars per quantity unit,
Q	is the quantity produced by the alternative method, in units per hour,
L_2	is the period of time from a failure to the start of the alternative method, in hours,
M_p	is the mobilization time as a percentage of the time a machine breaks down and disrupts planned operations in the month, in hours, .
M_z	is the cost of mobilization, in dollars per hour, and
D_2	is the cost of demobilization, in dollars per hour.

To deal with the SLI costs, a Monte Carlo simulation model was developed to perform the following functions:

1. calculating the down ratio (breakdown hours divided by worked hours plus breakdown hours in a month) for each machine (machines X = A, B, C,... N).
2. producing two results: the probability P(q) of having q = 1, 2,3,... m machine units broken down in any one day; and the frequency of unit (X = A, B, C,... N) broken down on the day,
3. calculating the joint probability P(X, q) that q units are broken down in a given day and that unit X will be among the down units, and
4. calculating the SLI costs by multiplying the joint probabilities by the monthly charge calculated from a series of user inputs. The SLI costs reflect the additional expenditure needed to maintain the service level if q units are broken down on a particular day.

An expert system (ESEMPS) for earthmoving equipment in road construction, using the SAVOIR shell program. In order to identify the job task, the system first requires the user to input pre-determined cut and fill sections along the road, and the amount of soil that needs to be cut or can be filled in each section. Following the task-identification, more information relating to job conditions is required. This information includes the time needed for the job, road gradients, elevation, the soil type and its properties such as swell and compaction factors, weather, the loading and dumping area, accessibility, length of working day, shift work, etc. According to the information obtained, the system evaluates job conditions in terms cf being favorable or unfavorable. When job conditions are favorable, wheel type machines are considered; while unfavorable, track type machines are selected.

Depending on the job conditions and other factors, such as the haul and return distances, the equipment conditions, operator efficiency, delays, and cost data, particular machine models are recommended. The final selection is based on the lowest cost per volume. However, if there is a time requirement for completing the operation, the system suggests a fleet of machines with the lowest unit cost among those that meet the time requirement.

The mode of consultation is a question-answer routine. In most cases, the user responds to the questions with YES, NO or DO NOT KNOW. In the event of uncertainty, questions can be answered by indicating a number within a given range from -5 to +5.

An expert system (SIMEX) using the EXSYS Professional shell program. The system integrates with the INSIGHT simulation software to incorporate qualitative decision-making ideas with quantitative simulation modeling. In the system, four modules were developed. Based on the user's input of haul distance, type of material, rock size, and haul road conditions, the first module chooses the appropriate equipment from three alternative material-handling systems: bulldozer, scraper or pusher-scraper, and truck-shovel or truck-loader. The second module accesses a data file containing equipment specification (load, maneuver and spread time, capacity, and hourly cost) and assists the user in selecting a specific equipment model based on several parameters, such as underfoot conditions, adverse grades, and soil moisture content. The third module generates a set of simulation codes written into an ASCII file for the specific operation after receiving the input of project duration, number of earthmoving units, etc., along with the information received earlier from the user's input and data file. Finally, the system executes the INSIGHT program using the simulation codes in the ASCII file to suut a simulation process. After the simulation analysis is completed and the control is returned to the expert system shell, the system presents the final results of the analysis. The final results include equipment choices, hourly rates, waiting times, cost performance, and duration times. .Another expert system for earthmoving equipment (Earthmoving E.S.P.) was using the VP-Expert shell program. The main difference of this system, compared with the two systems discussed above, is that this system takes into consideration the size of the projects, since the equipment requirements would be different for different sizes of projects. The system consists of a main knowledge base and four sub-knowledge bases.

The main knowledge base determines the soil properties, the job conditions, and (he estimated scope of an earthmoving project The four sub-knowledge bases arc individually chained to the main knowledge base according to the size of projects classified as small projects (7,500 -38,000 bcm), medium projects (38,000 - 380,000 bcm), large projects (380,000 -1,500,000 bcm), and extra-large projects (1,500,000 - 3,000,000 bcm). At the end of the consultation process, the system generates the results by using the knowledge stored in the chained sub-knowledge bases.

V. LITERATURE REVIEW

The literature review in this chapter contains three parts. The first **part** is an overview of the research development in the area of earthmoving and the methods and techniques used in previous work. The second part presents several models more closely associated with earthmoving equipment. The third pan briefly describes the endeavors made in this research from previous research work.

VI. CONCLUSION

This thesis develops a simulator system for modeling earthmoving operation and conducting productivity estimations on a microscopic level. The case study given in Paper shows that the system can represent the earthmoving operations on a detailed level and is a suitable tool for the project managers to estimate productivity and compare alternative operating methods on the operational level.

VII. REFERENCES

[I] Adrian, J.J. "Construction Productivity Improvement^{11}, Elsevier Science Publishing Co., Inc., New York, N.Y., USA. 1987.

[2] AGCA. "Contractors' Equipment Manual", ed. 7th, The Associated General Contractors of America, Washington, D.C., USA, 1974.

[3] Alkass, S., and Harris, F. "Expert System for Earthmoving Equipment Selection in Road Construction", ASCE, Journal of Construction Engineering and Management, Vol. 114, No. 3, New York, N.Y., USA, 1988, pp. 426-440.

[4] Alkass, S., and Harris, F. "Computerized Earthwork Planning and Equipment Selection", CIB. Poster Book, Tome 2, Montreal, Que., Canada, 1992, pp. 574-575.

[5] Allwood, R.J. "Techniques and Applications of Expert Systems in the Construction Industry", Ellis Horwood Ltd., Chichester, West Sussex, U.K., 1989, pp. 13-25,46-57.