

AUTOMATED SYSTEM FOR COST ESTIMATING OF EARTHMOVING OPERATIONS

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Abstract: This paper presents an automated system, designed to assist contractors in estimating time and cost of earthmoving operations utilizing object oriented simulation. The proposed system consists of two main modules (simulation/optimization, and reporting), equipment database, and equipment cost application (ECA). The system is developed in Microsoft environment and its components are integrated through a user-friendly interface. The paper provides an overview of the proposed system and describes briefly its main components. It also provides a detail description of the developed application ECA that is dedicated for estimating equipment owning and operating costs. A numerical example is presented to demonstrate the use of the developed application and illustrate its essential features.

Keywords: earthmoving operations, object-oriented simulation, equipment hourly cost, optimization, equipment database.

1. INTRODUCTION

Construction operations are frequently performed under different job conditions, which may give rise to uncertainty. This includes equipment breakdown and inclement of weather. Simulation is one of the modeling techniques that has been used to model such uncertainty [1]. Considerable efforts have been made to model construction operations using simulation after the development of the CYCLONE [2] simulation language. These efforts include INSIGHT [3], UM-CYCLONE [4], MODSIM [5], DISCO [6], CIPROS [7], STROBOSCOPE [8], and HSM [9].

Earthmoving operations represent a major task in heavy civil engineering projects such as dams, highways, airports, and mining projects. Providing earthmoving contractors with a system that models uncertainties using simulation can ease their task during bid preparation. Most cost estimators and schedulers are not familiar with simulation languages, which require specialized training. This paper presents an automated system, designed to assist contractors in estimating time and cost of earthmoving operations utilizing object oriented simulation. The user of the system is not required to

be familiar with any simulation language. The paper also presents the development of a software application for estimating equipment owning and operation costs. The developed application provides, in a highly interactive environment, the user with cost data and a set of functions, designed to facilitate the cost estimating process. It is compatible with the current industry practice, with respect to the cost break down structure and software systems developed by major equipment suppliers. A numerical example is presented to demonstrate the use of the developed application and illustrate its practical use.

2. SYSTEM COMONENTS

The proposed system consists of two main modules (simulation/optimization and reporting), equipment database, and equipment cost application (ECA), which will be described in Section 3 below. The simulation/optimization module controls the dynamic behavior of earthmoving operations and recommends the optimum case scenario(s) according to the contractor's stated objectives. Whereas, the reporting

module provides the contractor with a facility to generate a number of reports pertaining to project cost and schedule, characteristics of the selected equipment, and owning and operating costs for any given piece of equipment. The user interacts with the system through a user-friendly interface, which is connected to the system components as shown in Figure 1.

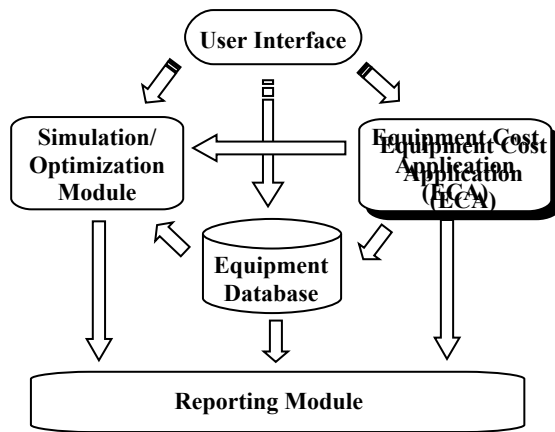


Figure 1. The Main Components of the Proposed System

2.1 Simulation/Optimization Module

Simulation process represents the main component of the system. It is designed to control and link the rest of the system components. It has been designed utilizing discrete event simulation (DEVS) technique, employing object-oriented concepts. The three-phase simulation approach was employed to control the system dynamics which is considered an efficient approach for object oriented simulation (OOS). The system activities are classified into two main categories: primary and secondary. Primary activities are those, which must exist in any earthmoving operation such as load, haul, dump and return. Whereas secondary activities may or may not exist such as pile, compact, and spread.

With respect to optimization, it provides the user with the most suitable fleet scenario according to his stated objectives. The user is required to 1) define different fleet scenarios, which constitute an input to the simulation process by specifying the number and/or the type of feasible equipment for the job being considered, and then 2) his/her objective(s) whether to minimize the total project cost, minimize the overall project duration, or minimize the idle time for a specific piece of equipment. The system performs statistical analysis on the simulation results and provides the user with the scenario that meets his objectives.

2.2 Reporting Module

This module tracks all information and processed data from the rest of the system components. It provides the user with necessary information required for bid preparation. The reporting module consists of two main sub-modules: dynamic and static sub-modules. The dynamic reporting sub-module extracts its data only from the simulation outputs. Whereas, the static sub-module extracts its data from all of the system components. It should be noted that the data processed through simulation/optimization module go to static sub-module only if it pertains optimization and to the two sub-modules if it relates to the simulation process. Figure 2 shows the reporting sub-modules and their data flow.

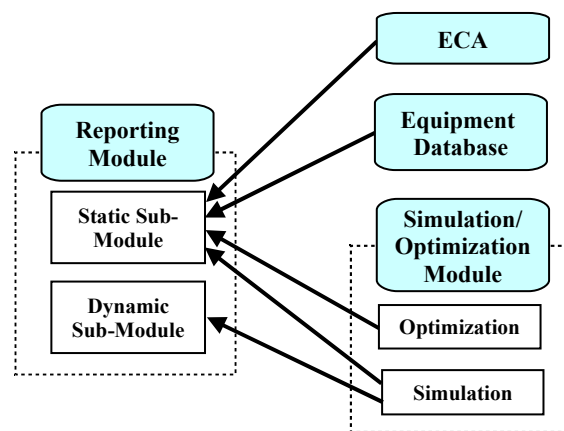


Figure 2. Reporting Sub-Modules and their Data Flow

Table 1. Description of the Static Reports

Report	Description
Simulation Results	Queues Statistics (Average Wait Time, Queue Length , etc.) Activities Statistics (Distributions, Average activity Dur., etc.)
Selected Equipment	Fleet equipment characteristics, attachments, range dimensions ... etc for all selected scenarios
Equipment Cost	The cost breakdown structure for owning and operating cost of all the fleet equipment in the different scenarios.
Project Schedule	The expected project duration with different degrees of probabilities. The schedule time of each piece of equipment.
Project Cost	The expected total cost with different degrees of probabilities. The project direct cost (equipment, Labor), and the project indirect cost.

The static sub-module provides output reports in a paper format containing pertinent information on the selected fleet, equipment owning and operating cost

details, simulation results, project total duration, and project total cost. Table 1 summarizes the different static reports and their descriptions. Whereas, the dynamic sub-module provides, in a 3-D animation format, the overall system dynamics, the interaction between the customer and server resources, the bottlenecks of the system, and the delay associated with the resources.

2.3 Equipment Database

This database feeds the system with all equipment related information including their own characteristics and possible attachments. The database is essentially a relational database, designed using MS Access. Equipment information were extracted from Caterpillar performance handbook [10] and used to build the database. Earthmoving equipment were classified into three major categories, according to the type of the process they perform. These categories are load, haul, and support equipment. One piece of equipment may perform more than one process in different earthmoving operations. For example, an excavator can be used as a loader equipment to load and as a support equipment to pile excavated soil.

3. EQUIPMENT COST APPLICATION

This application has been developed for estimating equipment cost, accounting for the three main categories of cost outlined in Figure 3, i.e. owning costs, operating costs, and wages of equipment operators. The equipment cost application (ECA) is essentially a spreadsheet application, designed to provide the user with the total hourly owning and operating costs along with their respective breakdown. In order to estimate owning costs, the calculations are carried out in a highly interactive user friendly environment supported with a set of functions as per Caterpillar performance handbook [10]. For example, in calculating the interest cost item 4 of Figure 5, the following equation has been used:

$$\frac{\frac{N+1}{N} \times \text{Delivered Price} \times \% \text{Simple Interest Rate}}{\text{Estimated Usage (Hours/year)}} \quad (1)$$

Where N is the estimated ownership period (in years) of the equipment under consideration. The same equation has also been used to calculate cost items 5 and 6 (insurance and tax costs) of Figure 5. ECA provides further assistance to the user via a set of input values compatible with the type of equipment being considered. A total of nine main types of earthmoving equipment are included in the application along with their respective models as

shown in Figure 4. Similar developments have been made for calculating operating costs and their respective breakdown (see Figure 6). A set of supporting data tables can easily be retrieved to support interim calculations by triggering the *GetValue* button shown in Figure 6. Upon calculating the owning and operating cost items and entering operator hourly wage, ECA provides, by activating the *Preview Report* button, the user with a report that contains hourly cost breakdown for the equipment under consideration (see Figure 7).

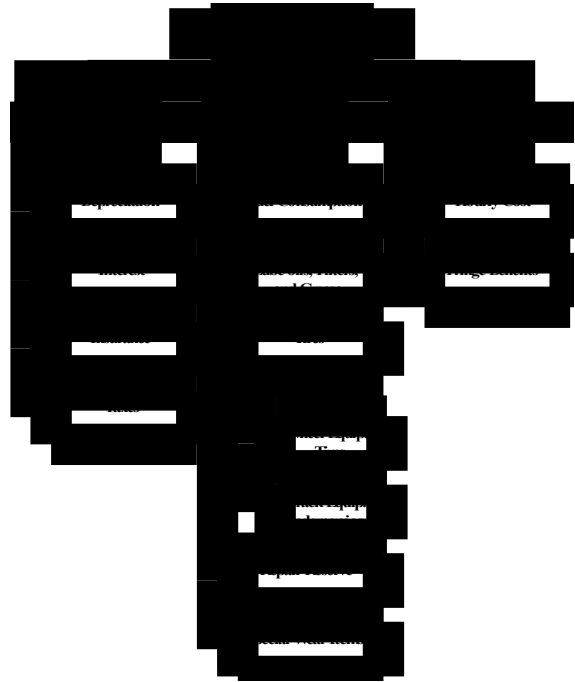


Figure 3. Equipment Cost Components

ECA has a number of interesting features: 1) it provides an easy to use and understand user interface, 2) it allows data import and export to support the integration with other modules of the system, 3) it is compatible with the current industry practice, with respect to the cost break down structure and software systems developed by major equipment suppliers. The application was developed in Microsoft Excel and coded using Microsoft Visual Basic Micros.

4. NUMERICAL EXAMPLE

In order to demonstrate the practical features of the developed ECA and illustrate its capabilities, a numerical example is presented. In this example, an earthmoving contractor is required to estimate the hourly owning and operating cost of a front shovel, which has the following characteristics:

- Purchasing (delivered) price with attachments is \$2,520,000.
- The shovel will be used for three years with approximately 10,000 hrs ownership period.
- Salvage value at the end of use period represents 30% of the delivered price.
- Interest Rate = 10%
- Insurance Rate = 1%
- Tax Rate = 1%
- Fuel unit price = \$0.45/Litre (Load factor is high)
- The condition multiplier is moderate for the I, A, and Z factors (Caterpillar performance handbook [10]).
- The operating condition is Zone C (Caterpillar performance handbook [10]).
- Special wear items estimated to cost \$5,000 for an estimated life of 200 hrs (see Figure 7).

Step 1: The user selects, in an interactive manner, the machine type from a menu list as shown in Figure 4. Then, he/she enters its ownership period in years and ownership usage (the total operating hours during its ownership period). The user can also obtain ownership usage periods utilizing those incorporated in the system by activating the *GetValue* button (see Figure 4) as specified by equipment manufactures.

Step 2: The user is required to enter owning costs data, i.e. the delivered price, salvage value percentage, interest rate, insurance rate, and tax rate. Finally he/she ends up with the hourly owning cost. Figure 5 depicts the user interface screen for owning costs.

Step 3: The user is required to enter operating costs data, i.e. the fuel unit price, consumption rate, and the hourly cost of the lube oils, filters, and grease. The machine in the given example is track type, should the user try to enter data related to tires he will receive a warning message. Then, he enters the cost of undercarriage, repair, and special wear items. Figure 6 shows the user interface screen for operating costs.

Step 4: The user enters the operator hourly wage including the fringe benefits. Finally, ECA calculates the total owning and operating costs for the specified equipment (see Figure 7).

5. CONCLUSIONS

This paper presented an automated system, designed for estimating time and cost of earthmoving operations. The system consists of two main modules

(simulation/optimization, reporting modules), equipment database, and equipment cost application (ECA). The system's components have been developed in MS environment to facilitate its use. Each component of the system has been briefly described and its respective functions outlined. The paper also presented a detail description of the developed equipment cost application (ECA) which has been designed to assist earthmoving contractors in estimating the hourly owning and operating costs for each piece of equipment in their fleet. A numerical example was presented to demonstrate the essential features of ECA.

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Hourly Owning & Operation Costs for Construction Equipment

	ID	Machine Designation
	3	<div style="border: 1px solid black; padding: 2px;"> (All) (Top 10...) (Custom...) BACKHOE LOADERS CONSTRUCTION & M EXCAVATORS FRONT SHOVELS TRACK LOADERS TRACK-TYPE TRAC WHEEL LOADERS WHEEL TRACTORS & WHEEL TRACTOR-SI </div>
Machine ID	3	
Model	5130B	
Estimated Ownership Period (Years)	3	
Estimated Usage (Hours/Year)	3330	
Ownership Usage (Total Hours)	10000	<input type="button" value="GetValue"/>

Figure 4. Machine Characteristic User Interface

OWING COSTS

1.a. Delivered Price (including attachment) (\$)		2520000
b. Less Tire Replacement Cost if desired		
c. Delivered Price Less Tires		2520000
2.a. Residual Value at Replacement		
Percent of Delivered Price	30 %	756000
3.a. Value to be recovered through work		1764000
b. Cost Per Hour (Value/Hours)		176.40
4. Interest Cost		
Simple Interest Rate	10 %	50.45
5. Insurance		
Insurance Percent	1 %	5.05
6. Taxes		
Taxes Percent	1 %	5.05
7. TOTAL HOURLY OWNING COST		236.94

Figure 5. Owning Costs User Interface

OPERATING COSTS

liter	U.S. gal
62 - 74	18 - 20
129 - 132	34 - 35
208 - 227	55 - 60

Approx. Cost Per Hour	
Material	Labor
6.16	0.57
8.83	0.60

8. Fuel:

Unit Price (\$) 0.45

Consumption (Units/Hour) 132

Fuel

59.40

9. Lube Oils, Filters, Grease:

6.73

GetValue

10.a. Tires:

Replacement Cost (\$)

Life in Hours (Units/Hour)

Tires

0.00

b. Undercarriage:

Impact 0.2

Abrasiveness 0.2

Z Factor 0.5

Total 0.9

Basic Factor 13.75

Condition Multipliers

	Impact	Abrasiveness	"Z"
High	0.3	0.4	1.0
Moderate	0.2	0.2	0.5
Low	0.1	0.1	0.2

Basic Factor

19.0
17.0
13.75

Warning Message

Your Equipment is Track Type

OK

11. Repair Reserve :

Extended Use Multiplier 0.4

Basic Repair Factor 52.5

GetValues

21.00

12. Special Wear Items:

(cutting edges, ground engaging tools, bucket teeth, excavator stick repair, etc.)

	Cost	Life	Cost/Hour
1	5000	200	25.00
2			0.00
3			0.00
4			0.00
5			0.00

25.00

Hours

Multiplier

0 - 10,000	0.4
0 - 20,000	0.8
0 - 30,000	1.0

Zone

	A	B	C
5130B	25 - 32	32 - 35	35 - 52.5
5230	36 - 50	50 - 53	53 - 70

13. TOTAL OPERATING COSTS **124.51**

Figure 6. Operating Costs User Interface

14. MACHINE OWING PLUS OPERATING **361.45**

15. OPERATOR'S HOURLY WAGE (include fringes) **37.5**

16. TOTAL OWNING AND OPERATING COST **398.95**

Preview Report

Print Report

Figure 7. Total Owning and Operating Costs