A COMPUTER MODEL FOR SELECTING EQUIPMENT FOR EARTHMOVING OPERATIONS USING QUEUING THEORY

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SUMMARY

This paper presents a computer model "*FLSELECTOR*" for equipment fleet selection for earthmoving operations. The methodology based on the queuing theory is incorporated in a computer module to account for the uncertainties in that are normally associated with the equipment selection process. *FLSELECTOR* is capable of assisting the users in making decisions required for earthmoving operations, such as determining the size and number of trucks and excavators, haul road lengths and surface conditions, etc…These decisions are based on the calculated output for all feasible fleets.

An actual case study is presented in order to illustrate the effectiveness and performance of the *FLSELECTOR* in comparison with the simulation method.

INTRODUCTION

Careful selection of a fleet of equipment for earthmoving operations can result in substantial savings in both time and cost of a construction project. Equipment selection for earth-moving operations is usually based on the amount of material need to be moved and the available equipment production rates. This deterministic method is simple and can provide satisfactory results for small projects requiring a single loader and several trucks. For large projects requiring multi-loader-truck fleets, however, the selection process can be more complicated, and cost can fluctuate widely (Farid and Koning, 1994).

Many methods for selecting equipment for earth-moving operations are reported in the literature including: *Knowledge-based expert systems (KBES)* (Amirkhanian and Baker, 1992; Alkass and Harris, 1988), *Linear Programming (LP)* (Mayer and Stark 1981, Easa1987, Easa 1988, Jayawardane and Harris 1990). *Simulation* can be generally grouped into two main categories; General-purpose simulation (Halpin and Woodhead 1976, McCahill and Bernold 1993) amd special-purpose simulation (Clemmens and Willenbrock 1978, Marzouk and Moselhi 2001, AbouRizk and Mather 2000), and *Queuing method* (O'Shea et al, 1964; and Carmichael, 1987; Karshenas and Farid, 1988)

Of the above-mentioned methods, only simulation and queuing theory consider the uncertainty that is associated with the cycle time of the equipment involved in earthmoving operations making them more suitable for modeling these operations. However, (FLEET, Karshenas and Farid, 1988), this can be attributed to assumptions underlying the queuing theory that are unrealistic in construction. Specifically, the exponential distribution does not accurately model load and travel-time duration, and the transient effects of the process start-up and shutdown must be included to more closely model real-world construction processes (Farid and Koning 1994).

This paper emphasis the usefulness of the queuing theory after being slightly modified, in modeling earthmoving operations including equipment fleet selection.

Proposed model (FLSELECTOR)

The *FLSELECTOR* is a prototype computer model designed as a stand-alone module to assist engineers and contactors to select the best fleet combination of loaders and haulers that can complete an earthmoving operation with optimum output (least cost, maximum production, or minimum project duration). *FLSELECTOR* provides the user with a list of the best ten fleet alternatives. In addition to the fleet selection, *FLSELECTOR* allows the user to compare between the outputs of the different hauling routes from the loading to the dumping area. *FLSELECTOR* is implemented using Visual Basic for Application (VBA) and Microsoft Excel 2000, and it consists of one main module, with multi-page tab controls. Figure 1 illustrates the module's flow chart.

Based on the user's input data regarding the project characteristics (Altitude, hauling road grade and rolling resistance and type of soil) and the selected type of loader the system calculates equipment performance and performs the selection process. The module matches between the selected type of loader and the different available types of haulers in order to select the most appropriate haulers that can work with the selected loader. Different fleet configurations are listed, and using queuing method the production, duration, and cost/unit are calculated for each fleet, and the best ten fleets can be listed according to a selected criterion. The user can select the suitable fleet from the list and then repeat the process again for the different hauling routes.

As shown in Figure (1), the process starts with entering the project information, weather condition, haul road conditions, and the type of material to be hauled in addition to its quantity. Loader selection with its components should be completed before launching the matching process to select the appropriate haulers to work with the loader, in this selection process dimensional, capacity, and safety criteria should be satisfied.

Time components for all equipment are calculated, and different fleet configurations are listed. Using queuing method the production, duration, and cost unit are calculated for each fleet, and the best ten fleets can be listed according to a selected criterion. The user can select the suitable fleet from the list and then repeat the process again for the different hauling routes.

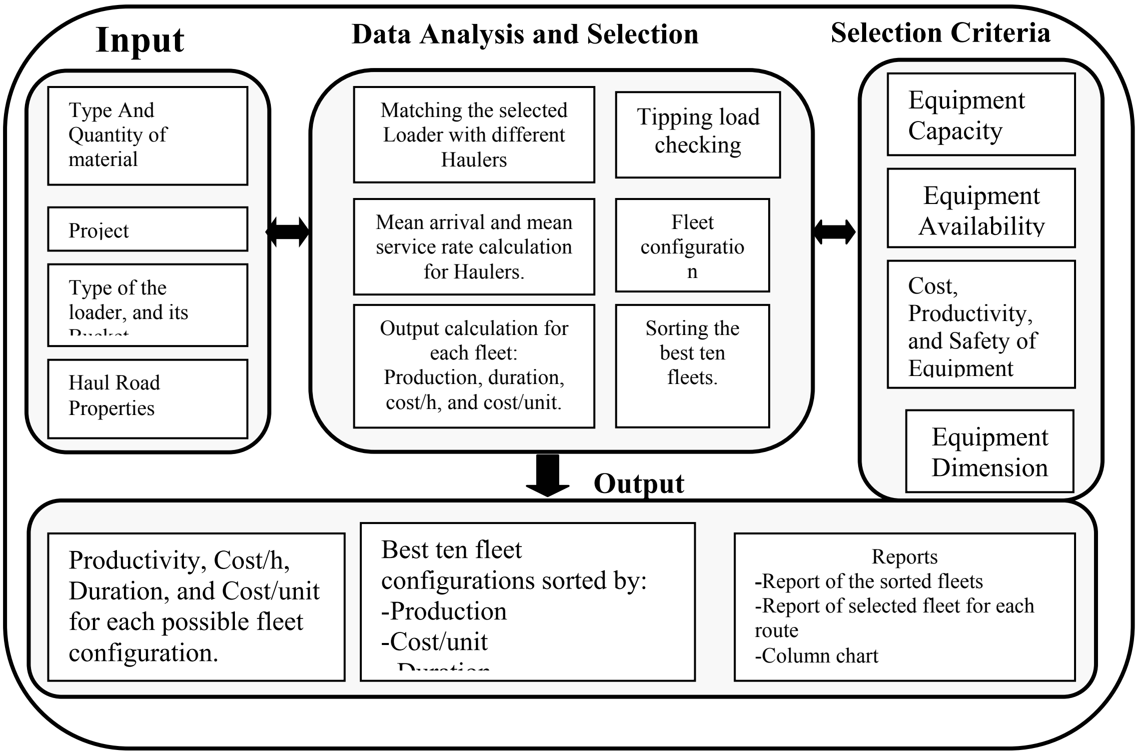


Figure 1 Fleet selection process and Data analysis

Equipment Selection

IFLSELECTOR is capable of automatically select a fleet of equipment. After choosing the loader and specifying its bucket type, a set of selected matching haulers is automatically listed. Two criteria are taken in consideration when matching between loaders and haulers: 1) the ratio of the capacity of haulers to the capacity of loaders (3 to 6 Bucketfuls / Hauler); 2) the difference between the dumping height of loaders (The distance from the lowest point of the bucket to the ground at 45 degree discharging) and the loading height of haulers (The distance from the highest point of the sideboard of the hauler to the ground). Figure (2) shows the flow chart of the matching process.

Haul-unit Speed Calculation

The mathematical formula proposed by Hicks, (1993), has been adopted to calculate the hauler's speed for different road segments for both haul and return trips. This equation uses coefficients that are extracted from the performance chart of each hauler, the weight of the hauler, and the effective resistance (grade plus rolling) of the road segment.

The speed (velocity) of a hauler can be calculated using the following mathematical formula (Hicks, 1993):

$$V_h = K_o\,[0.01\, C_f\,(W_e + U_w B)\, G_o]^{n'}$$

Four factors that affect the hauler performance (speed) are taken in consideration in *FLSELECTOR*: 1) the Traction force between the hauler's wheels and the road surface, 2) Effective resistance of the road segment (grade plus rolling), 3) speed correction that depends on the hauler's wheel diameter and 4) altitude effect.

Production Loss

The potential production of loading and hauling equipment is generally much higher than the achieved on a long-term basis. In the proposed model the loss in production is considered to be due to:

- Weather condition
- Operator efficiency
- Equipment availability

Haul-unit performance

Instead of using performance charts for determining haul-unit performance, an equation presented by (Hicks, 1996) is adopted. The advantages for using the equation are: (1) It is suitable and very easy to program for computer applications; (2) it is much faster than using the alignment charts when computing speeds; (3) it is not prone to alignment-chart measurement errors; and (4) it does not require continuous access to specifications.

The performance equation used to calculate the speed of the hauler is:

$$V = K_o\,[0.01\, C_f\,(W_e + U_w B)\, G]^{n}$$

Where V = haul-unit speed (km/hr); K_o = a coefficient determined by regression analysis; C_f = units conversion factor; W_e = empty weight of haul unit (t or kip[mass]); U_w = bank unit weight of material (t/m^3 or yd^3); B = bank carrying capacity of haul unit (m^3 or yd^3); G = effective resistance (grade plus rolling) (%); n = an exponent determined by regression analysis; F = haul unit manufacturer's rated rim pull (KN); and RP = rim pull (KN).

Output calculation

Equipment matching is achieved based on their operating cost, so as to produce an operation of minimum total cost per unit output or production.

For an operation involving c loader and K trucks, the total operating cost is

$cC_1 + C_2K$

Where C1 is the cost per hour of the loader and C_2 is the cost per hour of a truck. Both costs include those of the operators, maintenance, ownership cost and other charges.
For an operation output of μη, the production per hour is μ η C in units of

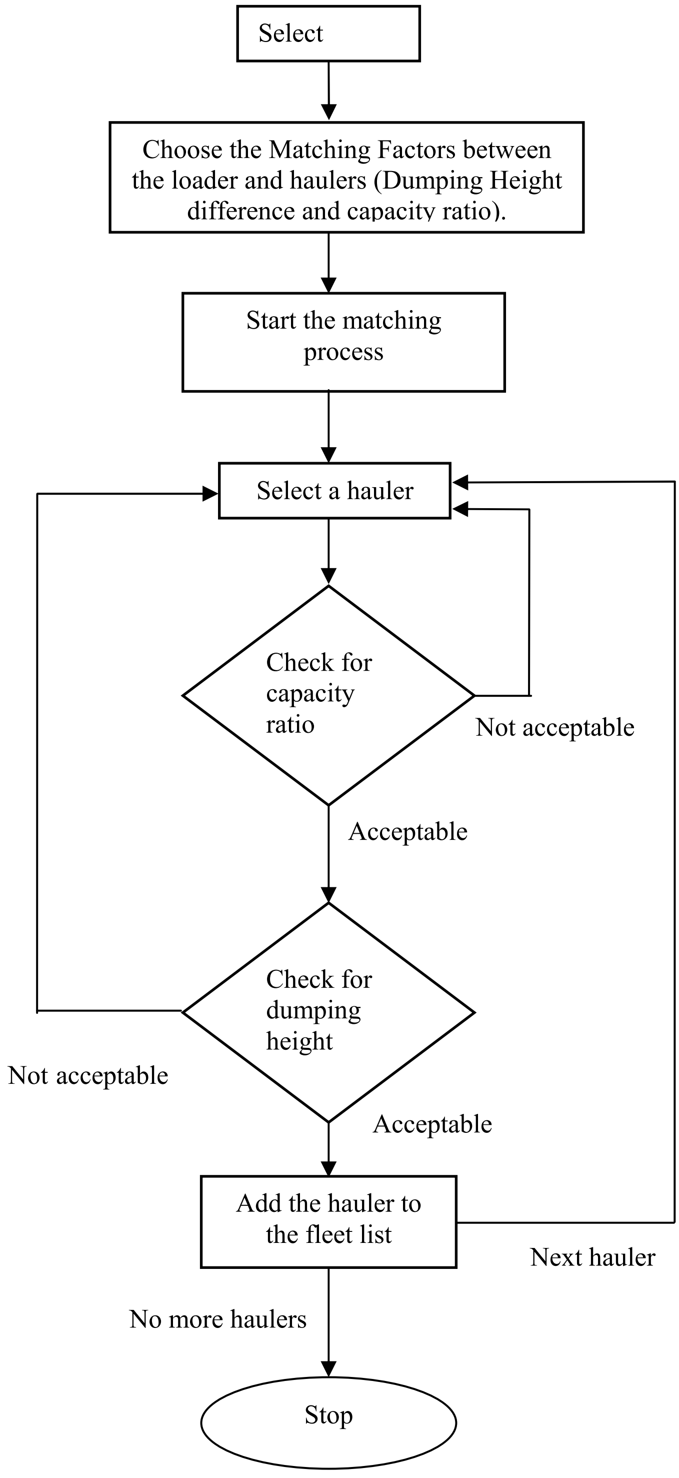


Figure 2 Flow chart of the equipment matching

cubic meters (or tones) per hour. Here the μ is in units of trucks per hour and C, the capacity of a truck is in units of cubic meters (or tones) per truck.

The total cost per cubic meter of earth moved is then

$$C_t = \frac{cC_1 + C_2K}{\mu\eta\, C}$$

FLSELECTOR considers all the possible alternatives of hauler distribution. It is noticeable that the number of fleets can be very huge (for 3-type haulers it may exceed 2500 different fleets). These fleets will be listed in order, so that they start with all the one-server fleets and their possible configuration and end with the three server ones.

To limit the number of alternative loader-truck configurations, the optimal number of trucks will be close to the case where the production or cycle times of the loader matches the production or cycle times of the trucks. For the deterministic case, the service time is $1 / \mu$ and the back cycle time is $1 / \lambda$. For K\` trucks traveling and 1 in service (that is the total number of trucks, K= K\`+1), then the production is matched when

$1 / \lambda = K` (1 / \mu)$ or $K` = \mu / \lambda$

and the total number or trucks, $K= K`+ 1 = \mu / \lambda + 1$. that is, $K= \mu / \lambda + 1$ and the optimum number of trucks should be in range of K - 1 to K + 1.

Heterogeneity:

In practice not all the trucks that are used in the same operation have identical characteristics and that is the case for the servers too. Construction and mining equipment organizations are usually forced to use whatever equipment is available.
Such operations where the servers have different characteristics are referred to as having heterogeneous servers, and where the customers have different characteristics they are referred to as having heterogeneous population of customers.
In our methodology the heterogeneity will be limited to the customers only.

Case example

In order to demonstrate FLSELECTOR capabilities, a case example of a project was performed using a particular project's conditions. The results are compared with those of the conventional (deterministic) method solution.

The project requires moving 1,000,00 bcy (bank cubic yards) of earth. The material is dry, loose sand, weighting 2700 lb per bcy. The available borrow pit requires an average haul of 5500 ft where:

1350ft with average grade of 3%, average rolling resistance of 10%, coefficient of traction of 0.45 and maximum allowable speed of 45 mph.

3100 ft with average grade of 2%, average rolling resistance of 3%, coefficient of traction of 0.55 and maximum allowable speed of 50 mph.

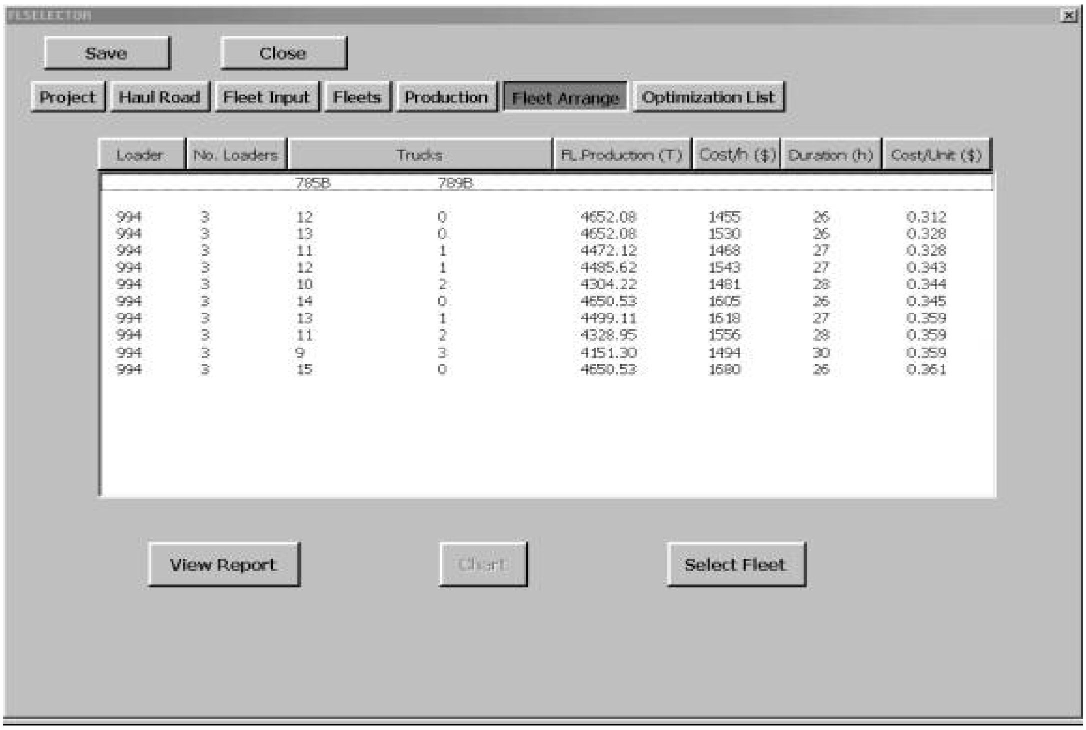
1050ft with average grade of 4%, average rolling resistance of 10%, coefficient of traction of 0.36 and maximum allowable speed of 40 mph.

The earth will be excavated with a wheel loader 994. The average elevation of the project is 6300 ft above sea level. Weather condition is of Temperature equal to +5°F, Wind speed equal to 20 miles/hour, and no precipitation.

Operator efficiency will be equal to 85%. Loader availability is 78% and cost /h is $185

As shown in the screen printout (table 1) the best fleet combination is 3 (994) loaders with 12 (985B) trucks, the sorting is according to the cost/unit.
The outputs of the best fleets are:

Production = 4652.08 t/h, Cost = $1455/h, Duration = 26hrs, Cost/unit = 0.312



Loader	No. Loaders	Trucks		FL Production (T)	Cost/h ($)	Duration (h)	Cost/Unit ($)
		785B	789B				
994	3	12	0	4652.08	1455	26	0.312
994	3	13	0	4652.08	1530	26	0.328
994	3	11	1	4472.12	1468	27	0.328
994	3	12	1	4485.62	1543	27	0.343
994	3	10	2	4304.22	1481	28	0.344
994	3	14	0	4650.53	1605	26	0.345
994	3	13	1	4499.11	1618	27	0.359
994	3	11	2	4328.95	1556	28	0.359
994	3	9	3	4151.30	1494	30	0.359
994	3	15	0	4650.53	1680	26	0.361

Table 1 A Screen printout of the system

CONCLUSIONS

This paper presented a computer model "*FLSELECTOR*" for equipment fleet selection for earthmoving operations using queuing theory models of the form $(M/E_i/c)/K$. The developed system is designed to assist engineers, owners, and contractors for earthmoving projects in selecting the best equipment fleet that can complete the task in minimum time, total cost, or cost per unit. It also provides fleet production rates, project duration, and cost/unit for each fleet. In addition an output report for this list with the option of column charts is available. Users can compare between the productions of different routes. Data on stored equipment can be extended in order to use customized equipment in the fleet selection.

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