Multiloader-Truck Fleet Selection for Earth Moving

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Loaders and trucks are often used in earthwork projects. In major earth-moving operations, careful selection of the number of machines used and the size of the equipment can produce substantial savings in both time and cost. Currently, the only method available for determining the optimum size-number combination for loaders is comparison of all possible alternatives. This is a tedious and time-consuming task, especially if a large volume of soil must be hauled, requiring several loading units. In this study, optimal multiloader-truck fleets are investigated, and sensitivity of the production cost to the key variables is analyzed. The cost-capacity and capacity-horsepower relationships for trucks and loaders are investigated by using published equipment specifications and cost data.

In planning an earthwork operation, the number and size of the loading units are usually determined on the basis of the productivity required and the equipment already on hand. Use of equipment on hand can give satisfactory results for small projects. However, careful selection of an equipment fleet for a major earth-moving operation can produce substantial savings in both time and cost.

For a given loader, the optimal number of trucks may be obtained by using queuing theory (*1, 2*). However, the questions of what size of loader and how many loaders must be used to minimize the total production cost remains unresolved. To answer these questions, a mathematical model representing multiloader-truck system production will be presented, and solutions of the model for various project conditions are given as examples.

FORMULATION OF MULTILOADER-TRUCK FLEET PRODUCTION

The steady state expected production per hour, Q, of an earth-moving fleet consisting of a number of loading units and trucks is

$$Q = T \cdot Q_l \tag{1}$$

T is the production factor, which takes into consideration the fact that loaders and trucks may not be busy all the time. Q_l is average productivity of a loading unit if there is always a truck available to be loaded.

Q_l and T in Equation 1 can be calculated as follows:

$$Q_l = \frac{f \cdot q_l \cdot b_f}{t_c} \tag{2}$$

$$T = \sum_{n=1}^{N_l} n \cdot P_n + \sum_{n=N_l+1}^{N_t} N_l \cdot P_n \tag{3}$$

where

f = operating efficiency of loading unit,
q_l = rated bucket capacity of loading unit,
b_f = bucket fill factor of loading unit,
t_c = average cycle time of loading unit (hr),
N = total number of loading units,
N_t = total number of trucks, and
P_n = the steady state probability of exactly n trucks being loaded or waiting to be loaded.

Substitutions for Q_l and T in Equation 1 from Equations 2 and 3 yield

$$Q = \left(\sum_{n=1}^{N_l} nP_n + N_l \sum_{n=N_l+1}^{N_t} P_n\right) \frac{f \cdot q_l}{t_c} \tag{4}$$

By using the assumptions of exponential interarrival and loading time distributions, Taha (*3,* p. 616–617) developed the following equations for calculating P_n:

$$P_n = \binom{N_t}{n} r^n \cdot P_0 \qquad 0 \le n \le N_l \tag{5a}$$

$$P_n = \binom{N_t}{n} \frac{n! \cdot r^n}{N_l! \cdot N_l^{n-N_l}} \cdot P_0 \qquad N_l \le n \le N_t \tag{5b}$$

where r is the ratio of average loading time to average interarrival time (i.e., time between two consecutive arrivals of the same truck, excluding loading and queue time) of a given truck. The probability of an empty system, P_0, is calculated as follows (*3,* p. 616):

$$P_0 = \left[\sum_{n=0}^{N_l} \binom{N_t}{n} r^n + \sum_{n=N_l+1}^{N_t} \binom{N_t}{n} \frac{n! r^n}{N_l! \cdot N_l^{n-N_l}}\right]^{-1} \tag{6}$$

Thus the estimation of production, Q, from Equation 4 requires the calculation of r first, then calculation of P_0 (using Equation 6), and then P_n (Equation 5). By using N_l = 1 in

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these equations, the loader-truck production equations developed by O'Shea et al. (4) can be obtained.

The average loading time of a truck with a volume capacity equal to q_t is

$$t_l = \frac{q_t \cdot t_c}{q_l \cdot b_f} \qquad (7)$$

The average truck travel time (excluding loading and queue time) is the sum of the haul, dump, and return times. It can be calculated as

$$t_t = \frac{L}{\overline{V}_h} + \frac{L}{\overline{V}_r} + t_d \qquad (8)$$

where

L = length of the haul and return roads,
$\overline{V}_h$ = average haul speed,
$\overline{V}_r$ = average return speed, and
t_d = dump time.

According to the principles of engineering mechanics, the power required to move an object with a constant speed of V while overcoming a constant resisting force of F is

$$\text{power} = F \cdot V \qquad (9)$$

For a truck, in terms of engine horsepower, Equation 9 would be

$$\text{hp} \cdot \alpha \cdot k = F \cdot V \qquad (10)$$

in which hp is the rated engine horsepower and α is the mechanical efficiency of a truck. The mechanical efficiency of most trucks ranges from 80 to 85 percent (2). The unit conversion factor, k, is 16.5 ft-ton/min when V is expressed in feet per minute and F is in tons; in metric units, k = 746 N-m/sec when V is in meters per second and F is in Newtons.

The total resistance against the movement of a piece of equipment on a road consists of rolling and grade resistances. The rolling resistance may be expressed in terms of equipment weight as

$$F_r = W \cdot R \qquad (11)$$

where

F_r = rolling resistance,
W = equipment weight, and
R = rolling resistance factor, expressed as a fraction of equipment weight.

For small grades, it can be demonstrated (1, 2) that grade resistance is equal to the product of equipment weight and grade:

$$F_s = W \cdot S \qquad (12)$$

where

F_s = grade resistance,
W = equipment weight, and
S = absolute value of the haul road grade.

Grade resistance may be zero, positive, or negative, depending on the haul road grade. If $F = F_r + F_s$ in Equation 10, the maximum haul and return speeds may be calculated as follows:

$$V_h = \frac{\text{hp} \cdot \alpha \cdot k}{(W_t + W_w)(R \pm S)} \leq V_l \qquad R \pm S > 0 \qquad (13)$$

$$V_r = \frac{\text{hp} \cdot \alpha \cdot k}{W_t\,(R \mp S)} \leq V_l \qquad R \mp S > 0 \qquad (14)$$

where

V_h = maximum haul speed,
V_r = maximum haul return speed,
V = truck speed limit,
W_t = net truck weight,
W_w = truck weight capacity, and

$R \pm S$ is the total road resistance (effective grade).

Equations 13 and 14 can be used to calculate the maximum speed of trucks as long as the truck's retarder is not applied, that is, the total road resistance is positive. When the total road resistance is positive, the maximum speed of off-highway trucks is limited by the engine's governor to about V_l = 40 mph (64.4 km/hr). To ensure that the maximum speeds calculated from Equation 13 do not exceed the truck's speed limit, $R \pm S \geq 2$ percent must be used in Equation 13. In other words, when the total resistance of a portion of a haul load is between 0 and 2 percent, $R \pm S = 0.02$ must be used to calculate the maximum truck speed for that portion of the road from Equation 13. For calculating return speeds from Equation 14, a minimum resistance of 5 percent must be used. Therefore, if the total resistance of a portion of return road is between 0 and 5 percent, $R \pm S = 0.05$ must be used in Equation 14. Speeds calculated from Equations 13 and 14 in this way are close to those that can be determined from the charts provided by truck manufacturers.

If the average truck speeds are represented as percentages of the maximum speeds, the average truck travel time can be calculated from Equation 8 after substituting for travel and return speeds from Equations 13 and 14:

$$t_t = \frac{L(W_t + W_w)(R \pm S)}{\text{hp} \cdot \alpha \cdot k \cdot \beta} + \frac{L \cdot W_t \cdot (R \mp S)}{\text{hp} \cdot \alpha \cdot k \cdot \beta'} + t_d \qquad (15)$$

where β and β' are speed factors for converting the maximum haul and return speeds to average speeds. Estimates of β and β' are given elsewhere (5). For a haul road consisting of m sections with different grades and rolling resistance factors, Equation 15 can be modified as

$$t_t = \sum_{i=1}^{m} \left[\frac{W_t + W_w}{\text{hp}} \cdot \frac{L_i(R_i \pm S_i)}{\alpha \cdot k \cdot \beta_i} + \frac{W_t}{\text{hp}} \cdot \frac{L_i(R_i \mp S_i)}{\alpha \cdot k \cdot \beta_i'} \right] + t_d \qquad (16)$$

The scatter diagram of $W_t + W_w$ versus horsepower for the trucks listed in Table 1 is presented in Figure 1. As this figure

TABLE 1 PRIMARY SPECIFICATIONS AND HOURLY OWNING AND OPERATING COSTS OF TRUCKS (6)[a]

Model[b]	Flywheel Horsepower hp (k watt)	Capacity, $yd^3(m^3)$ Heaped (SAE)	Net weight lb. (kg)	Cost[c] Dollars/hr
Caterpillar				
769C	450 (336)	30.8 (23)	69,100 (31344)	88
773B	-650 (485)	44.6 (34)	86,630 (39295)	114
777	870 (649)	67. (51)	127,100 (57653)	156
DJB				
D25B	260 (194)	18.3 (14)	40,800 (18507)	60
D445	450 (336)	31.1 (24)	61,600 (27942)	102
Cline				
A22-R	235 (175)	20 (15)	35,000 (15876)	55
235R	400 (298)	25.5 (19)	52,260 (23705)	78
Euclid				
R25	220 (164)	19.5 (15)	39,200 (17781)	55
R35	450 (336)	29 (22)	58,300 (26445)	89
R50	608 (429)	41.4 (31)	77,100 (34963)	109
R75	755 (563)	60 (45.6)	101,000 (45814)	140
R85	818 (563)	66.5 (50.5)	117,100 (35117)	149
International-Hough				
350B	607 (453)	41.8 (32)	71,800 (32568)	111
WABCO				
35D	441 (313)	29 (22)	61,140 (27733)	93
50B	577 (429)	40 (30)	77,240 (35036)	119
60B	651 (474)	48 (36.5)	85,000 (38556)	129
75C	694 (506)	57 (43)	91,500 (41504)	144
85D	818 (610)	67 (51)	120,100 (54114)	165
TEREX				
33-03B	215 (160)	18.3 (14)	38,000 (17237)	52.5
33-05B	321 (239)	24.6 (19)	49,500 (22453)	74
33-07	493 (367)	31.9 (24)	71,600 (32478)	93
33-09	624 (465)	47.5 (36)	93,200 (42275)	115
33-11C	840 (626)	63.7 (48)	124,900 (52481)	158

[a] Adapted from "Contractor's Equipment Cost Guide" (6)
[b] All trucks are off highway, diesel powered
[c] Operator cost is not included

shows, $(W_t + W_w)$/hp is roughly constant for the various makes and sizes of trucks listed in Table 1. The average value of $(W_t + W_w)$/hp is 0.163 ton/hp (0.146 metric ton/hp), with a coefficient of variation (COV) of 0.076. Figure 1 also shows the curve $(W_t + W_w)/\text{hp} = 0.163$ for comparison with the data. A plot of truck weight, W_t, versus horsepower revealed that W_t/hp is roughly constant, with an average value of 0.071 ton/hp (0.063 metric ton/hp) and a COV of 0.087.

If 16.5 ft-ton/min were substituted for K, 0.163 ton/hp for $(W_t + W_w)$/hp, and 0.071 ton/hp for W_t/hp in Equation 16, the average truck travel time would be

$$t_t = \left\{ \sum_{i=1}^{m} \left[0.011 \frac{L_i(R_i + S_i)}{\alpha \cdot \beta_i} + 0.004 \frac{L_i(R_i + S_i)}{\alpha \cdot \beta_i'} \right] \right\} + t_d \qquad (17)$$

In this equation, when L_i is in feet, the calculated t_t is in minutes. Equation 17 expresses the truck travel time independent of the truck's horsepower or size. This simplifies loader-truck fleet analysis considerably.

If $\lambda = b_f \cdot t_t$, λ would be a function of the characteristics of the haul road, the material to be hauled, and the trucks

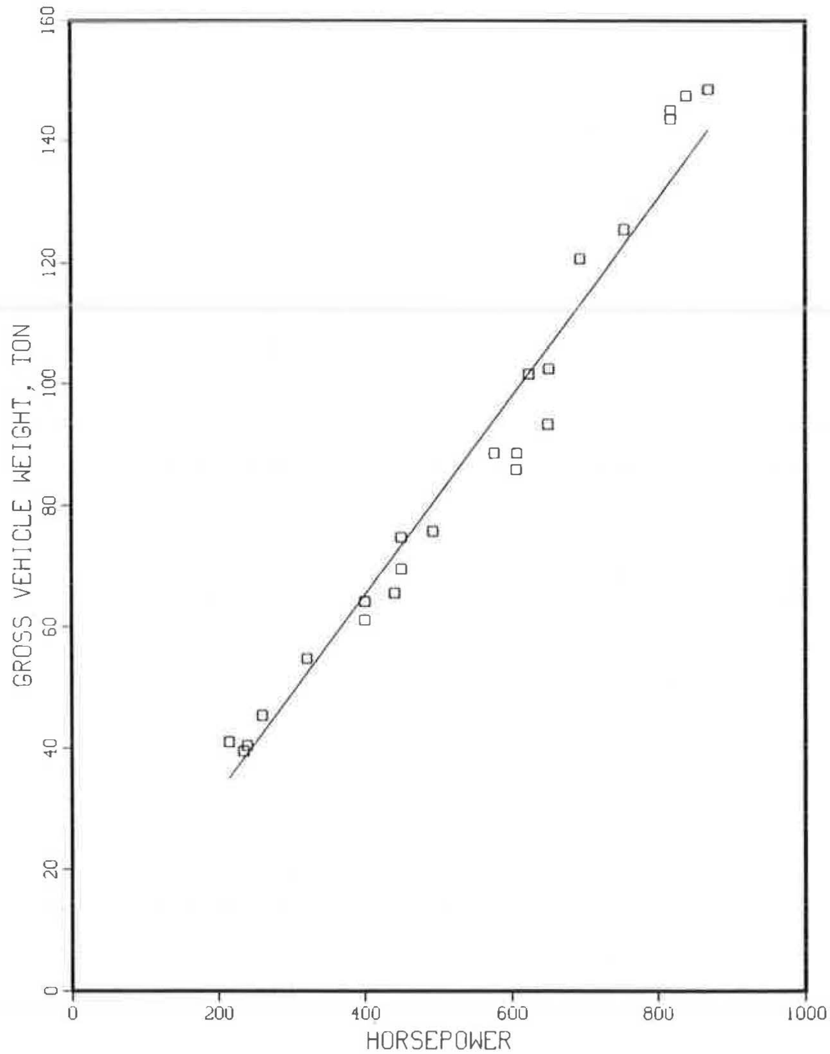

FIGURE 1 Scattergram of gross weight versus power for trucks.

used. Hereafter, λ will be referred to as the project factor. By using Equations 7 and 17, the ratio of loading to travel time, r, can be calculated as follows:

$$r = \frac{q_t \cdot t_c}{q_l \cdot \lambda} \tag{18}$$

MULTILOADER-TRUCK FLEET PRODUCTION COST

The cost per unit volume of production, C, for a fleet consisting of N_l loading units and N_t trucks is

$$C = \frac{N_t \cdot C_t \cdot N_l \cdot C_l}{Q} \tag{19}$$

where C_t and C_l are average truck and loader owning and operating costs, respectively, per hour (the rest of the variables in Equation 19 were defined previously). To reduce the number of variables in Equation 19, the equipment costs can be expressed in terms of equipment capacities. This procedure requires an estimate of the owning and operating costs of various sizes of trucks and front-end loaders. The equipment owning and operating costs from the 1986 edition of the *Contractor's Equipment Cost Guide* (*6*) are used here. Costs published in this manual are based on average working conditions. These include depreciation, insurance, facilities capital, storage, license fee, record keeping, overhaul, field repair, lubrication, and fuel ($0.96 per gallon for diesel fuel) costs. Costs published in this guide are not the actual equipment costs but are approximate national averages. For a comparative study of equipment production costs, such as the current study, these figures are sufficient.

The monthly equipment cost provided by the *Contractor's Equipment Cost Guide* is calculated by multiplying the hourly owning and operating cost of the equipment by 176. Therefore, to determine the hourly costs presented in Table 1, the published monthly equipment costs were divided by 176.

The cost data used to investigate the truck cost-capacity relationship are presented in Table 1. The owning and operating costs given in Table 1 do not include any sales or property taxes, freight costs, main office overhead, or profit. These costs, however, are usually expressed as percentages of equip-

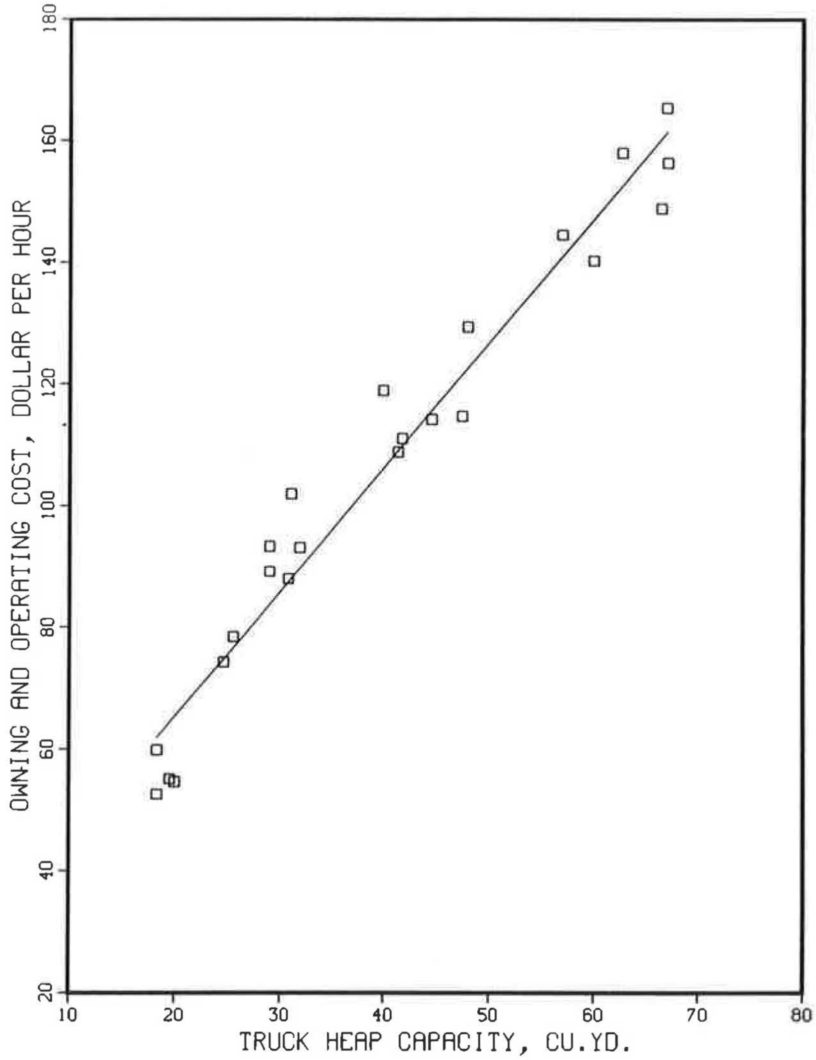

FIGURE 2 Cost-capacity scattergram for trucks.

ment direct costs, so such costs do not influence the optimal equipment fleet design.

Figure 2 shows a scattergram of the heaped capacities (SAE) versus the hourly owning and operating costs of trucks listed in Table 1. The method of least squares was used to obtain the following relationship between the cost and heaped capacity of various trucks:

$$C_t = 2.04\, q_t + 24.6 \tag{20}$$

This equation is plotted in Figure 2. Because the published equipment costs do not include operator cost, \$20 per hour should be added to account for the hourly cost of an equipment operator. Thus the total truck owning and operating cost would be

$$C_t = 2.04\, q_t + 44.6 \tag{21}$$

By applying the same methodology, the cost capacity relationship of front-end wheel-loaders was also investigated. The data used for this investigation are given in Table 2. All loaders were assumed to be equipped with their standard bucket sizes. The owning and operating costs of loaders listed in Table 2 are also from the 1986 cost guide (*6*). The cost equation obtained by the least squares method for front-end loaders is

$$C_l = 11.19\, q_l - 6.82 \tag{22}$$

After adding \$20 per hour for the loader operator cost,

$$C_l = 11.19\, q_l + 13.18 \tag{23}$$

By substitution for C_t, C_l, and Q in Equation 19, the unit production cost can be expressed in terms of loader and truck bucket sizes, number of loaders and trucks in the fleet, loader cycle time, and haul road characteristics:

$$C = \frac{(2.04\, q_t + 44.6)N_t + (11.19\, q_l + 13.18)N_l}{\left[\sum_{n=1}^{N_l} nP_n + N_l \sum_{n=N_l+1}^{N_t} P_n\right] \cdot f \cdot q_l \cdot b_f/t_c} \tag{24}$$

TABLE 2 PARTIAL SPECIFICATIONS AND HOURLY OWNING AND OPERATING COSTS OF FRONT-END LOADERS (*6*)[a]

Model[b]	Rated Bucket Capacity (heaped, SAE) yd^3 (m^3)	Cost[c] Dollars/hr
Case		
W24C	2.5 (1.9)	24.5
W26B	3 (2.29)	23
W36	3.5 (2.67)	31
Caterpillar		
936	2.5 (1.9)	23
950B	3 (2.29)	27.8
966D	4 (3.0)	41
980C Hi-Lift	5 (3.8)	56.5
980C	5.25 (4)	54
988B	7 (5.3)	76
988B Hi-Lift	6.5 (5)	78
992C Hi-Lift	12 (9.2)	154
Clark		
55C	2.5 (1.9)	21
75C	3 (2.29)	27.5
125C	4 (3.0)	40
175C	5 (3.82)	51
275C	7 (5.35)	72
475C	12 (9.2)	131
475C Turbo	12 (9.2)	140
Dresser		
550	5.25 (4.)	53
560B	7.5 (5.7)	76
570	12 (9.2)	131
644D	3 (2.29)	24
844	4.5 (3.4)	68.35
Fiat-Allis		
605B	2.5 (1.9)	18.5
645B	3 (2.29)	24
FR20	4.5 (3.4)	41
International-Hough		
H80B	3.5 (2.67)	27
H100C	4.5 (3.4)	46
560	6.5 (5)	65
H400C	11 (8.5)	108.5
TEREX		
72-31B	3 (2.29)	26.5
72-61	5.5 (4.2)	53
90B	8 (6.1)	75
72-71B	8 (6.1)	73
72-81	9 (6.88)	95
Trojan		
5500	6 (4.6)	52
7500	7.5 (5.8)	69

[a]Adapted from "Contractor's Equipment Cost Guide" (6)
[b]Diesel powered, wheel loaders
[c]Operator cost is not included

Thus an estimation of the unit production cost, C, from Equation 24 will first require calculation of r from Equation 18, then determination of P_0 by using Equation 6, followed by P_n from Equation 5.

ANALYSIS OF MULTILOADER-TRUCK FLEET PERFORMANCE

To get a general picture of the multiloader-truck fleet design problem and to examine the sensitivity of the optimal solution to variations in the key variables, optimal loader-truck combinations for various project conditions will be investigated. The optimal loader-truck combination for a given project is defined as the combination that minimizes Equation 24 and in which the dump clearance of the loaders at full lift is greater than the loading height of the trucks selected.

In the following analysis, f and b_f in Equation 24 are assumed to be equal to 1. The results can be adjusted easily for other values of f and b_f. To calculate the productivity and unit cost of production for various loader-truck fleets, the following basic loader cycle times are used:

Rated Bucket Capacity [yd³ (m³)]	*Basic Cycle Time (min)*
1–2 (0.76–1.5)	0.50
3–4 (2.3–3.0)	0.55
5–6 (3.8–4.6)	0.60
7–8 (5.3–6.1)	0.65
9–10 (6.9–7.6)	0.70

The basic loader cycle time includes loading, dumping, maneuvering, full cycle of hydraulics, and minimum travel.

The effect of the size and number of loaders on the production cost of a multiloader-truck fleet will be examined first. Figure 3 shows contours of minimum cost per cubic yard of production for various bucket sizes for a number of loaders used in an example project. The project layout is given in Figure 4. If it is assumed that $\alpha = 0.8$, $t_d = 1.1$ min, and $b_f = 1$ and that the following speed factors are used (*5*):

Section	*Speed Factors*	
	Hauling (β_i)	*Returning* (β_i')
1	0.90	0.95
2	1.00	0.93
3	0.93	0.90

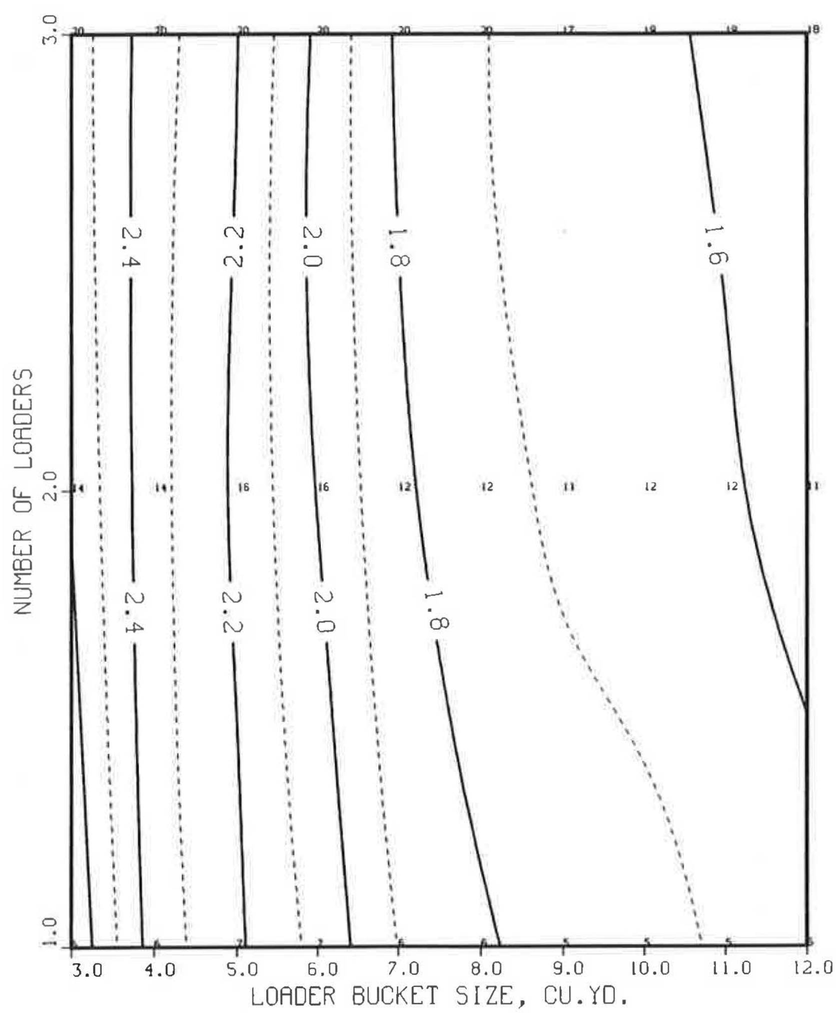

FIGURE 3 Optimal number of trucks (small integers) and contours of minimum unit cost ($/yd³) for example project.

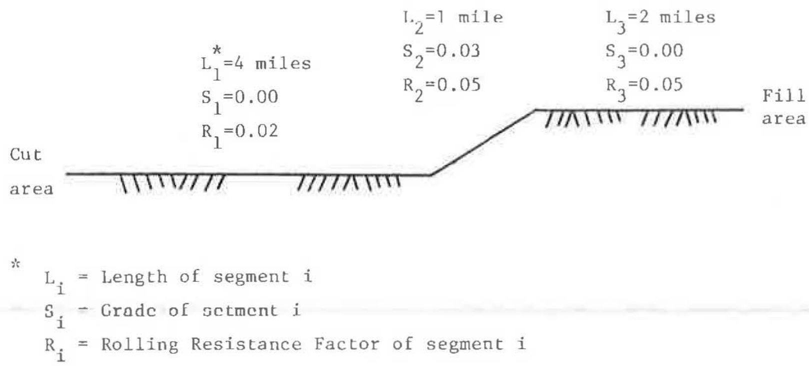

FIGURE 4 Layout of haul and return road for example project.

then the project factor, λ, for this project is about 25 min.

Figure 3 shows that both the bucket size and the number of loaders used affect the cost of production. However, the effect of loader bucket size is more significant than the effect of the number of loaders used. The cost per cubic yard of production decreases as the bucket size or number of loaders increases. Figure 3 also gives the optimal number of trucks (small integers in the background) that should be used with various number of loaders for the example project shown in Figure 4.

Figure 5 depicts the productivity variation for various loader bucket size and number combinations. This figure also gives the optimal truck capacity (small integers) that should be used with each loader combination for the example project.

To examine the effect of haul road characteristics on the

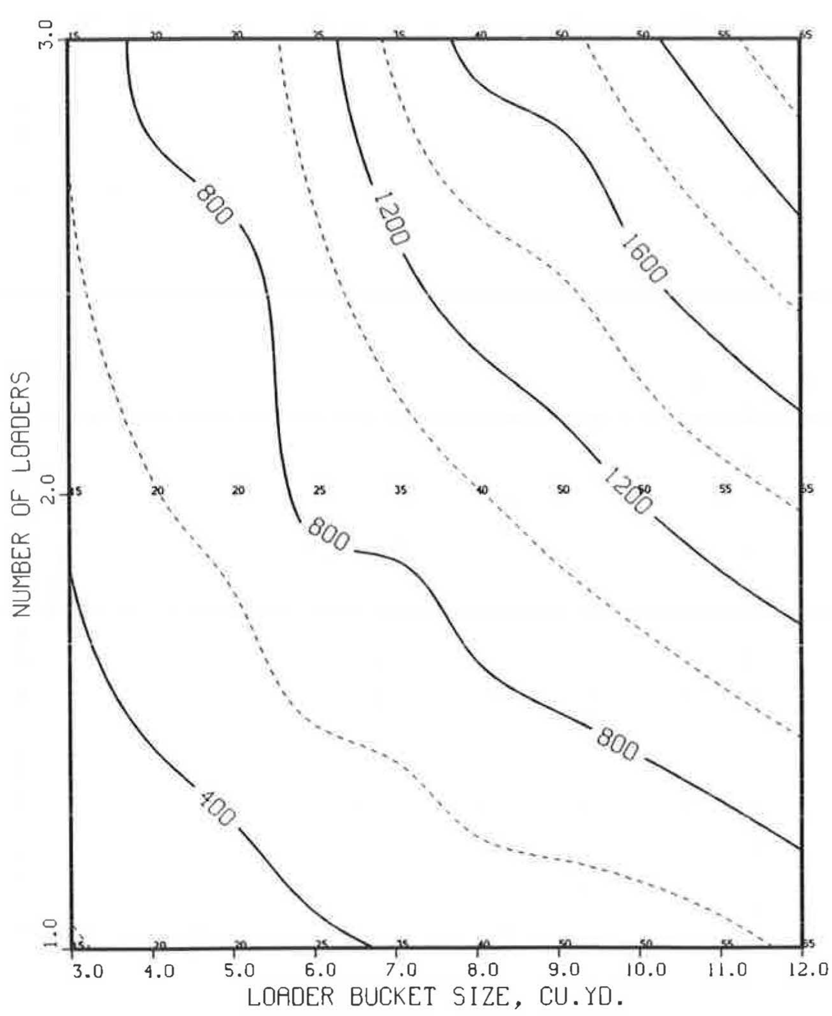

FIGURE 5 Optimal truck capacities (small integers; yd³) and contours for hourly productions (yd³) for example project.

production cost, Equation 24 was used to plot contours of minimum unit costs of production for various combinations of project factors and loader bucket sizes. Figure 6 shows such a contour map for a fleet consisting of one loader and several trucks. The optimal truck sizes for various combinations of project factors and loader bucket sizes are also given. Figure 6 confirms that the conclusion drawn for the example project in Figure 4 is valid for various road characteristics. That is, in general, the unit production cost decreases as the loader bucket size increases.

The production for each combination of project factor and loader bucket size is given (in cubic yards per hour) in Figure 7. This figure also shows the optimal number of trucks (small integers in the background) that should be used with each loader bucket size in a project.

Hourly productions and minimum unit costs for a fleet consisting of two loaders and several trucks are shown in Figures 8 and 9. The same information for three loaders and a number of trucks is given in Figures 10 and 11. A comparison of Figures 6, 8, and 10 confirms that the optimum truck capacity is independent of the number of loaders used in a project. That is, the optimum truck capacity is mostly a function of the loader size. These figures demonstrate that to reduce unit production cost, the largest practical size loaders must be used.

DESIGNING A MULTILOADER-TRUCK FLEET

Figures 6 through 11 can be used in designing optimum loader-truck fleets for projects with positive road resistance. The design process is demonstrated by the following examples.

Example 1

Problem

What is the optimal truck fleet to be used with a single 4-yd^3 (3.1-m^3) front-end loader for loading and hauling material with a bucket fill factor of 0.8 in the example project presented in Figure 4? A 0.83 job efficiency is assumed.

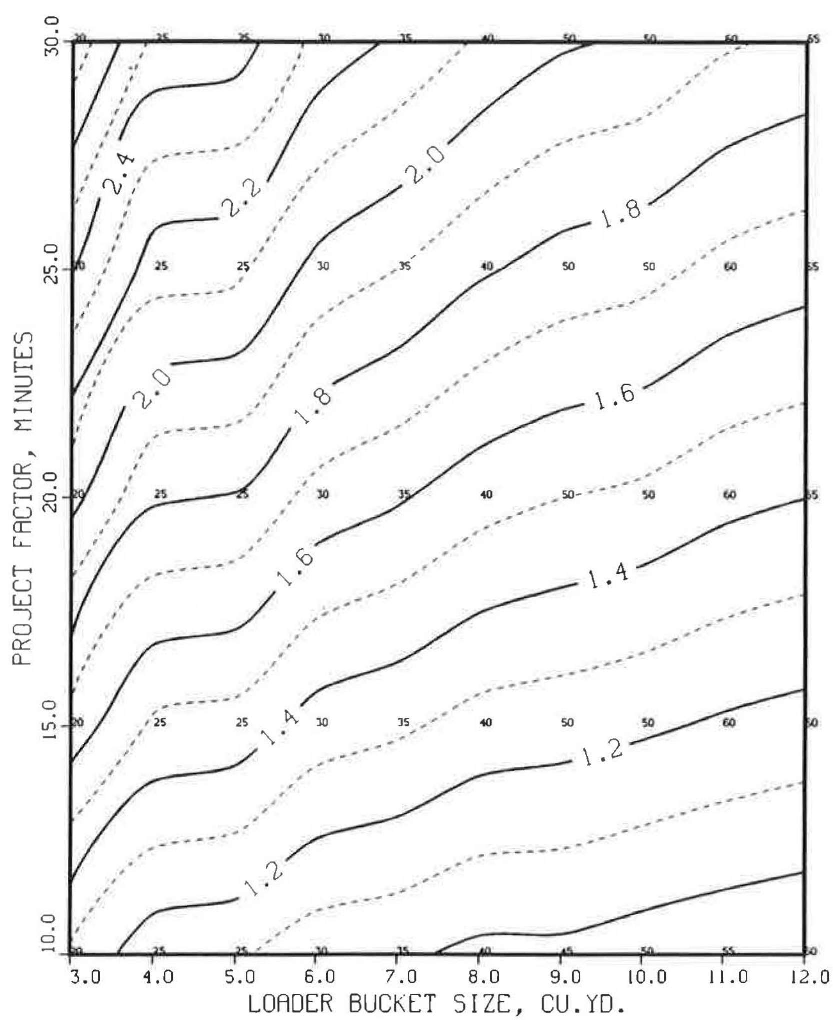

FIGURE 6 Optimal truck capacities (small integers; yd^3) and contours of minimum unit costs($/yd^3) for a single loader.

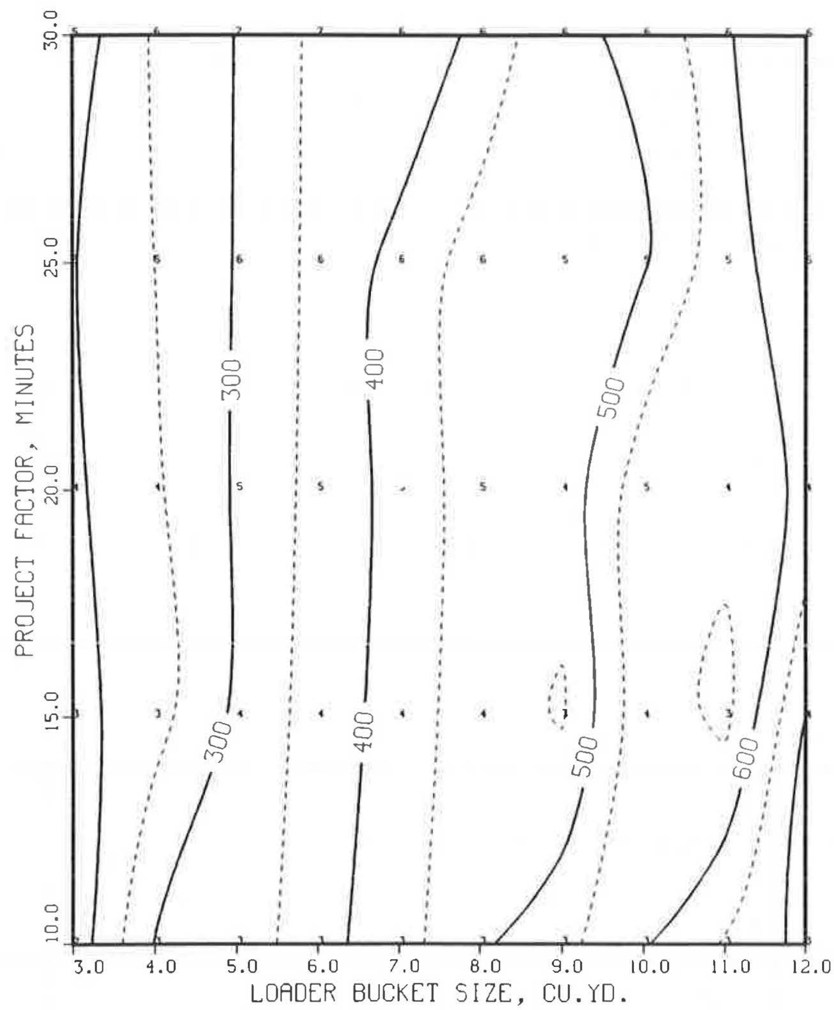

FIGURE 7 Optimal number of trucks (small integers) and contours of hourly productions (yd^3/hr) for a single loader.

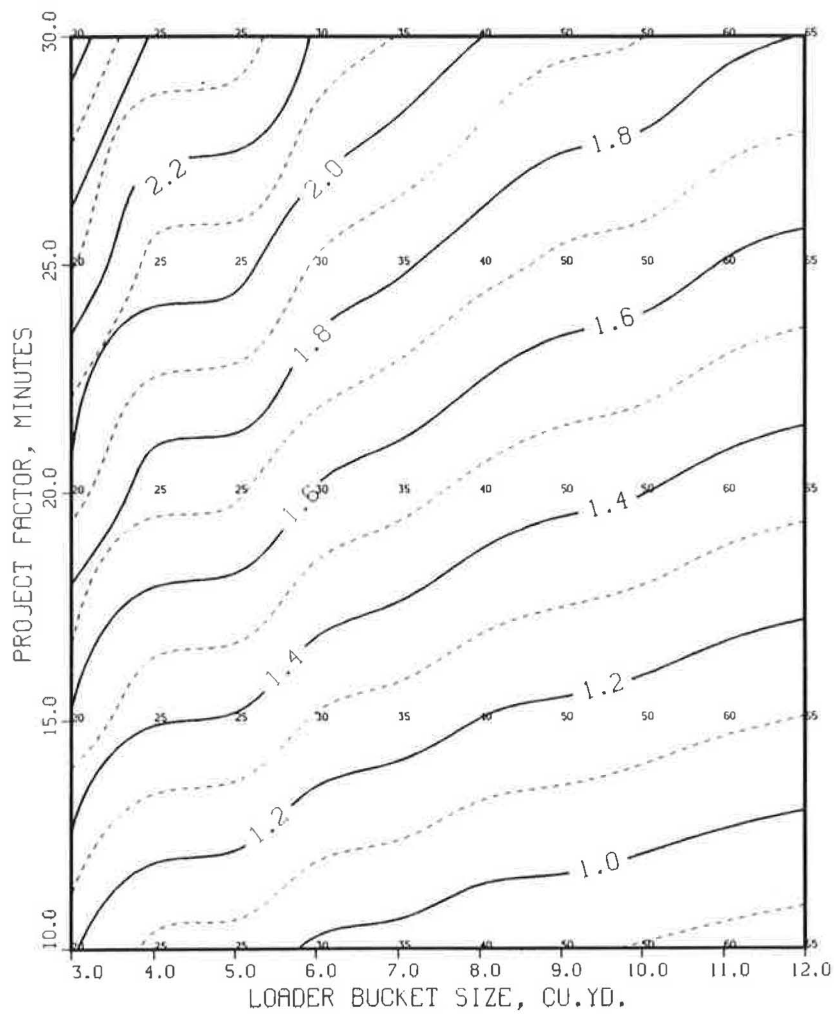

FIGURE 8 Optimal truck capacities (small integers; yd³) and contours of minimum unit costs ($/yd³) for two loaders.

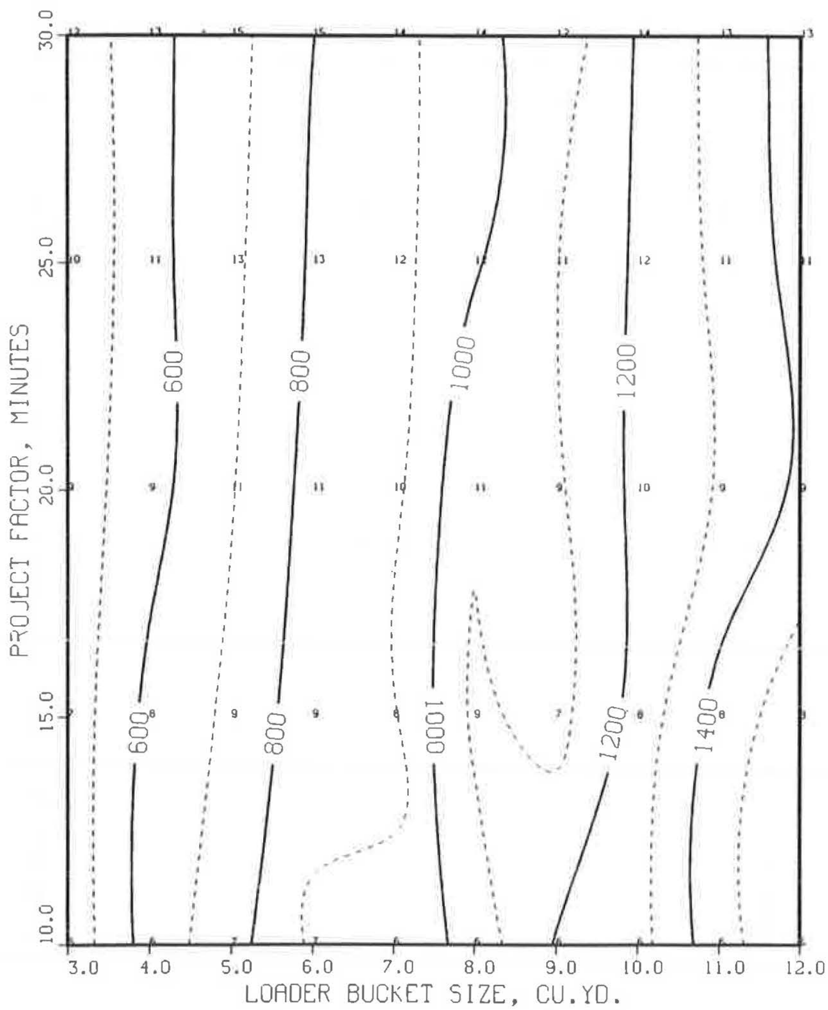

FIGURE 9 Optimal number of trucks (small integers) and contours of hourly productions (yd^3/hr) for two loaders.

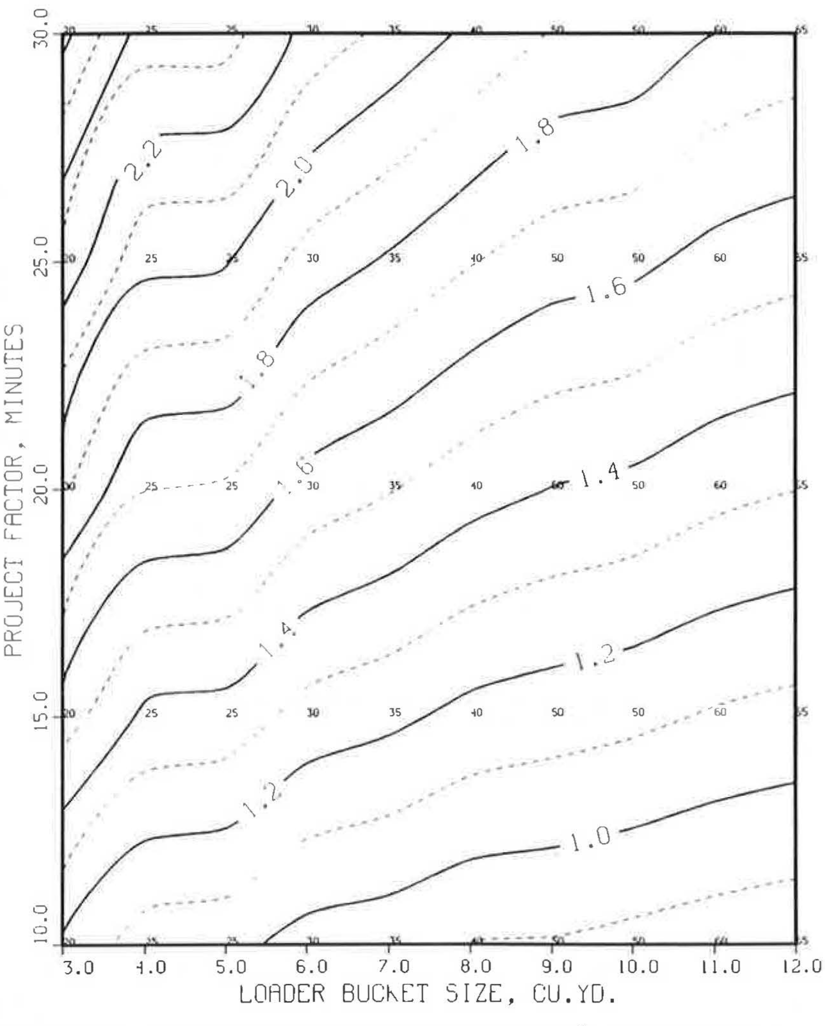

FIGURE 10 Optimal truck capacities (small integers; yd^3) and contours of minimum unit costs ($/yd^3) for three loaders.

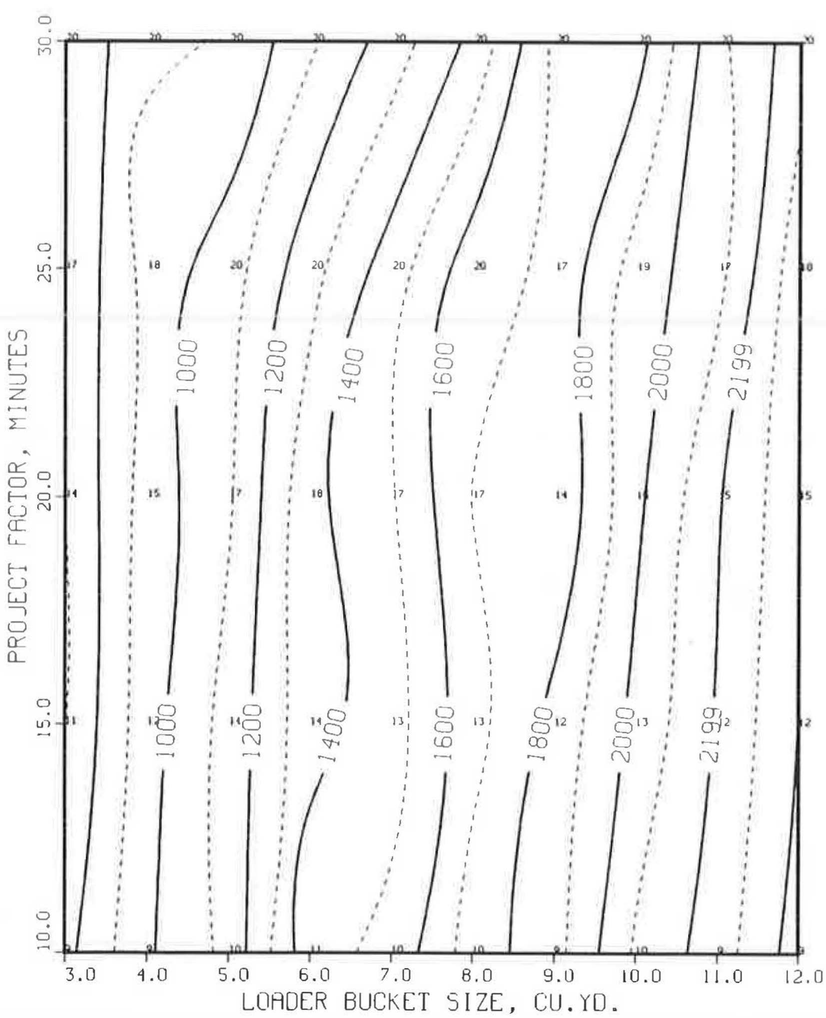

FIGURE 11 Optimal number of trucks (small integers) and contours of hourly productions (yd^3/hr) for three loaders.

Solution

The project factor for this project is 20 min. For a 4-yd^3 bucket, Figures 6 and 7 show that four 25-yd^3 (18.8-m^3) trucks should be used in this project. For f = 1 and b_f = 1, the fleet production would be about 250 yd^3/hr (191 m^3/hr) and the cost per cubic yard of production would be about \$1.82 (\$2.38/m^3). After adjusting for project efficiency and bucket fill factor, fleet production and unit production cost would be 166 yd^3 (127 m^3) and \$2.74/yd^3 (\$3.58/m^3), respectively.

Example 2

Problem

Determine the optimal loader-truck fleet for an 800-yd^3/hr (612-m^3/hr) production for the example project depicted in Figure 4. It is assumed that $f = b_f = 1$.

Solution

From Figures 8 and 9, a production of at least 800 yd^3/hr (612 m^3/hr) in a project with a project factor equal to 25 min requires two 6-yd^3 (4.5-m^3) loaders with thirteen 30-yd^3 (22.6-m^3) trucks. The unit cost of production would be about \$1.9/yd^3 (\$2.5/m^3). Figures 10 and 11 demonstrate that the same 800-yd^3 production can be accomplished with three 4.0-yd^3 (3.06-m^3) loaders and eighteen 25-yd^3 (19.4-m^3) trucks. The unit production cost, however, will be increased to about \$2.02/yd^3 (\$2.64/m^3). Thus this example also verifies that it is more economical to use the largest loaders that are practical for the given job conditions.

SUMMARY AND CONCLUSIONS

The 1986 owning and operating costs and specifications for several front-end loaders and off-highway trucks were used to develop an optimum multiloader-truck fleet design approach for earth moving. The trucks used were off-highway, rear-dump, diesel-powered vehicles. The loaders are front-end wheel-loaders equipped with the standard buckets. The approach developed here is applicable to projects with positive road resistance. The main conclusions of the study can be summarized as follows:

- Given the current cost-capacity relationships for loaders and trucks, the largest practical loader sizes must be used to minimize the cost of earth-moving projects.
- The optimum truck capacity is mostly a function of the loader size and is almost independent of the number of loaders used: the larger the loader size, the larger the optimum truck capacity.
- The optimum truck capacity is not affected significantly by the project factor.

The graphical solutions presented provide a general picture of the multiloader-truck combination problem and make design of the optimal multiloader-truck fleet for a project simple and fast. The main conclusions drawn remain generally valid as long as there is not a substantial change in truck and loader specifications and as long as the costs of trucks and loaders change proportionally. The minimum unit cost curves must be updated regularly by using the latest equipment owning and operating costs.

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