Estimating Production of Multiloader-Truck Fleets

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A fast and accurate method for forecasting the production that will be achieved by a selected fleet of equipment is fundamental to the successful planning of projects involving large amounts of earthmoving. The theory of queues has been used to determine a reliable forecast of loader-truck fleet production. Application of the queuing method is time-consuming, especially when forecasting multiloader-truck fleet production. This paper presents graphical solutions of the queuing model for multiloader-truck fleets.

Successful planning of projects involving a large amount of earthmoving requires the ability to reliably forecast the production rates that will be achieved by a selected fleet of equipment and optimizing the combination of earthmovers and loaders in the interest of cost reduction. The theory of queues has been used to determine a reliable forecast of loader-truck fleet production (*1*, *2*). Actual observations and cost determinations made on operating projects have verified the accuracy of this theory (*3*). In this study, the theory of queues is applied to the multiloader-truck fleet production problem and nomographs are developed for rapid estimation of loader-truck fleet production.

MULTILOADER-TRUCK OPERATION

Figure 1 represents a multiloader-truck operation. This type of operation involves a number of loading facilities that serve some hauling units. The typical cycle of a hauling unit consists of loading, traveling to the dump site, dumping, returning to the loading area, and waiting until a loading unit is available. The parameters and assumptions used in formulation of production are listed below.

Mean Arrival Rate

The arrival rate is the number of hauling units arriving at the queue per unit of time. Because arrivals do not occur at regular intervals, a Poisson distribution is assumed to represent this stochastic behavior of arrivals. A constant parameter (λ) is defined as the mean arrival rate of any particular hauling unit. $\lambda = 1/T_a$, where T_a is the mean travel time. In terms of cycle elements previously defined, T_a is the time of all cycle elements, excluding that for loading and waiting in queue.

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Mean Service Rate Per Busy Loader

Service or loading times are expressed by an exponential distribution. The constant parameter (μ) is defined as the mean service rate per busy loader. $\mu = 1/T_S$, where T_S is the mean service time of each server. Therefore, the assumptions are as follows:

1. Arrivals of hauling units to the queue are described by Poisson distribution;
2. Loading times of a unit are described by an exponential distribution;
3. Hauling units are served on a first-come, first-served basis; and
4. The system is in a steady-state condition.

PRODUCTION FORECASTING MODEL

For the case of N_l loading units and N_t hauling units, the production forecasting can be formulated as follows:

$$Q = \frac{T \cdot f \cdot q_l}{t_c}$$

where

Q = average quantity of earth moved per unit time,
f = job efficiency,
q_l = rated loader bucket capacity,
t_c = average loader cycle time, and
T = production factor.

If P_i is the probability of i hauling units in the system, T (*3*) would be

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

P_n may be calculated as follows (*4*):

$$P_n = \begin{cases} \binom{N_t}{n} r^n \cdot P_0 & 0 \leq n \leq N_l \\ \binom{N_t}{n} \dfrac{n! \cdot r^n}{N_l! \cdot N_l^{n-N_l}} \cdot P_0 & N_l \leq n \leq N_t \end{cases}$$

where r is $\dfrac{\lambda}{\mu}$, and P_0 is the probability of an empty system,

which is calculated as follows (*4*):

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

By putting $N_l = 1$ in the above equations, the loader-truck production equations developed by O'Shea et al. (*2*) can be obtained.

To simplify application of the above formulas to practical problems, graphical solutions for various numbers of loaders may be developed. Figures 2 and 3 show nomographs (*5*) based on the above formulation for one- and two-loader fleets, respectively.

To use the nomographs for estimating production in a project, r must be calculated based on the equipment and haul road characteristics (for examples, see references *6* and *7*). After calculating r, enter the chart on the horizontal scale with the calculated r and move vertically up until intersecting the curve representing the number of trucks used. From the point of intersection, move horizontally to the right vertical T-scale. Connect the point of intersection on the T-scale to loader bucket capacity point of q_l-scale and extend the line to intersect D-scale. The intersection of this line and D-scale would then be joined with the loader cycle time on t_c-scale. The intersection of the latter line with the Q-scale would give the production per hour. The unit of production depends on the unit used for loader bucket capacity. The following examples illustrate the method of using the nomographs.

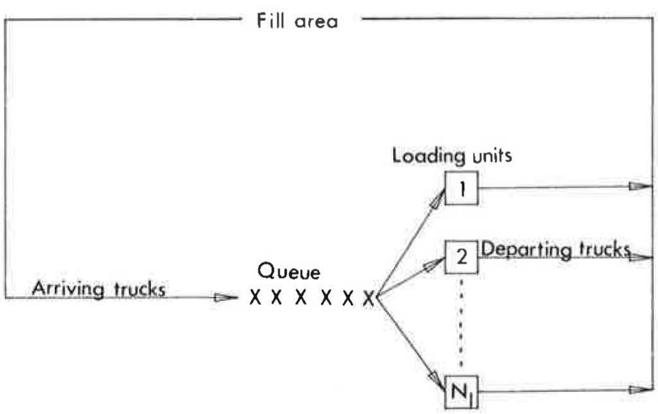

FIGURE 1 A multiserver queueing system.

1. Determine the production per hour of a fleet consisting of a 5-yd³ (3.8-m³) loader and ten 30-yd³ (22.8-m³) trucks. The average loader cycle time is 0.5 minute, and the average truck travel time is 20 minutes. Assume that the loader bucket fill factor is equal to 1 and job efficiency is 100 percent.

Solution: The ratio of truck arrival rate to loading rate for this project is 0.15. From Figure 2, production per hour for this fleet is about 560 yd³ (425.5 m³). The dashed line in Figure 2 shows the solution.

2. What would be the production per hour in example 1 if two loaders and 14 trucks were used?

Solution: From Figure 3, the production per hour is approximately 980 yd³ (745 m³). The solution is shown with a dashed line.

SUMMARY AND CONCLUSION

A fast and reliable method for forecasting production of a specified loader-truck fleet is desirable. The theory of queues

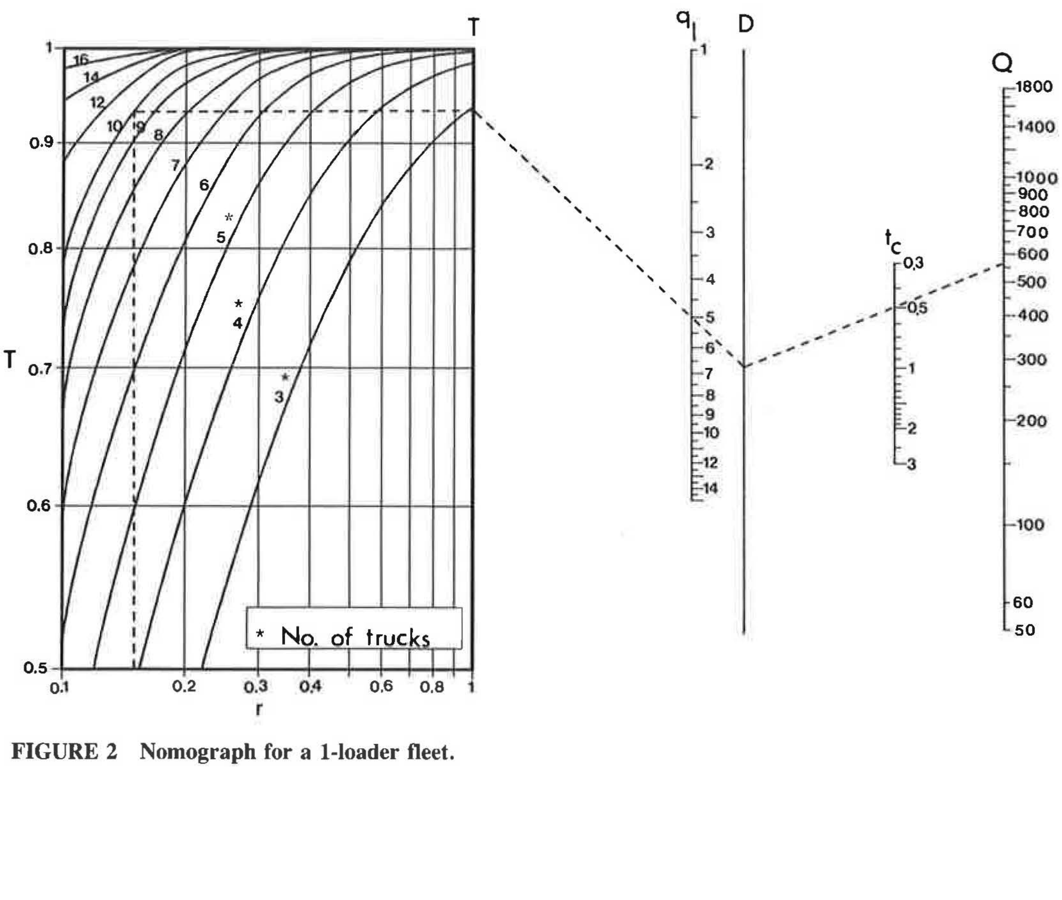

FIGURE 2 Nomograph for a 1-loader fleet.

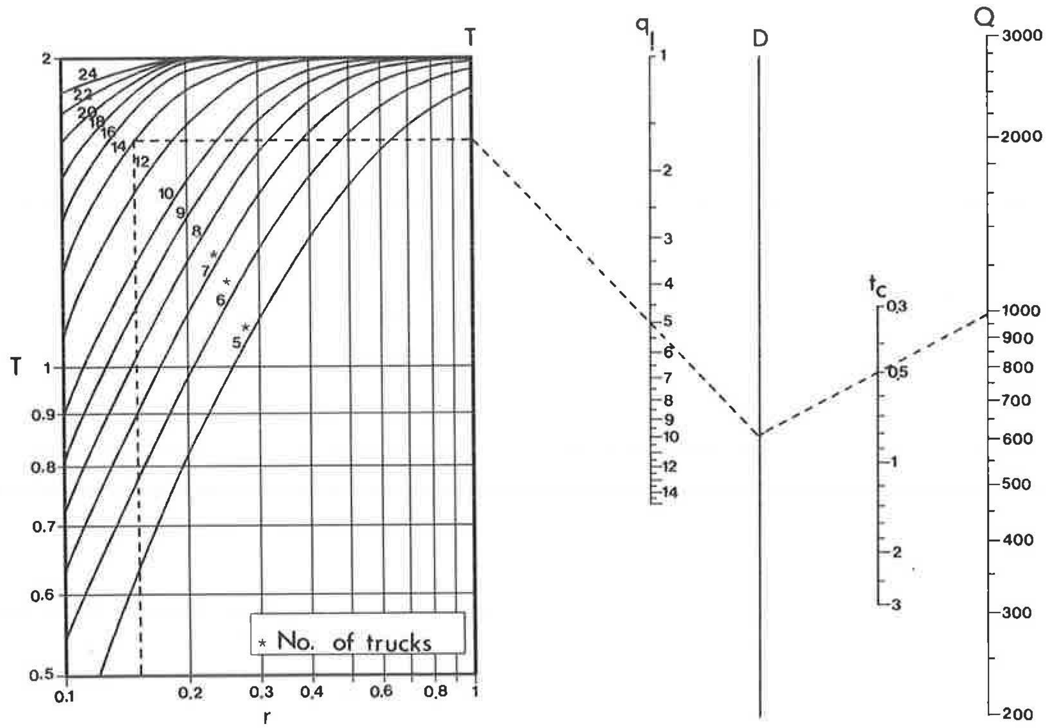

FIGURE 3 Nomograph for a 2-loader fleet.

has been used to determine a reliable estimate of loader-truck production. However, the application of methods based on queuing theory is time-consuming, especially for multiloader-truck fleet production. In this study, the general queueing formulation for loader-truck production forecasting was presented, and graphic solutions of the mathematical model were developed for a fast estimate of production for various fleets.

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