TECHNICAL NOTE

DETERMINING SAMPLE SIZE FOR HARVESTING COST ESTIMATION

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ABSTRACT

Sampling design for harvesting studies is usually based on estimating mean cycle times within a given level of precision. Researchers and managers are more likely to be interested in estimating harvesting productivity or costs. These require estimates of mean cycle volume as well as cycle time. A simple method for determining sample size for cost estimates has been calculated.

Keywords: time studies; costs; productivity; confidence intervals.

INTRODUCTION

Time studies have been used in the forest industry for almost a century as the basis for estimating harvesting production rates and costs (Ashe 1916; Hessler 1925). This information can be useful for production scheduling, budgeting, and in comparisons of alternative procedures and equipment.

Sampling design for time studies has often been treated casually by logging researchers in the past (Howard 1989). Olsen & Kellogg (1983) noted that time studies can be between 3 and 40 times more expensive than other procedures for collecting production and cost data, such as activity sampling or shift level studies. Efficient sampling design can help to minimise wasted resources and ensure that an acceptable level of precision is obtained. Howard (1989) described some of the challenges faced by researchers in undertaking efficiently designed studies on harvesting operations. In practice, studies tend to be done using sampling techniques, not controlled experiments.

Sample-size determination is a function of the desired level of precision and the inherent variation in the response variable. Formulas for determining sample size when only an estimate of the mean of the response variable is needed are relatively easy to use and straightforward, provided an estimate of the variance is available. The response variable frequently used as the basis for determining sample size in harvesting studies is work cycle or turn time. In this case, sample size can be calculated using the following formula (adapted from work by Freese 1962):

$$n = t^2 * \mathrm{Var}(WCT)/[E*\overline{WCT}/100]^2 \qquad (1)$$

where n = number of work cycles to be studied

t = Student's t-value

$\mathrm{Var}(WCT)$ = variance of the work cycle time

E = level of precision required (e.g., 5%)

$\overline{WCT}$ = mean work cycle time (minutes)

Work cycle time, however, is usually only an intermediate step on the way to estimating productivity (e.g., cubic metres per hour) or unit costs (e.g., dollars per cubic metre) for a harvesting operation. A simple method for determining sample size for cost estimation is presented here.

SAMPLE SIZE DETERMINATION

Given that the researcher has estimates of the following information:

$\overline{WCT}$ = mean work cycle time (minutes)

SD_WCT = standard deviation of work cycle time

$\overline{CV}$ = mean volume per cycle (m^3)

SD_CV = standard deviation of volume per cycle

X = harvesting costs ($ per hour)

N = sample size,

unit costs (*$U*) ($\$/m^3$) can be calculated using Equation (2).

$$\$U = X/60 * \overline{WCT} \;/\; \overline{CV} \qquad (2)$$

If we assume that X is fixed, let $k = X/60$, and $P = \overline{WCT}/\overline{CV}$, and assume that WCT and CV are independent, then (adapted from Schreuder *et al.* 2004):

$$\begin{aligned}\mathrm{Var}(\$U) &= \mathrm{Var}(kP)\\ &= k^2 * \mathrm{Var}(P)\\ &= k^2 * [\overline{WCT}^{\,2} / \overline{CV}^{\,2}] * [(SD\_WCT)^2 / \overline{WCT}^{\,2}\\ &\quad + (SD\_CV)^2 / \overline{CV}^{\,2}] \end{aligned} \qquad (3)$$

The sample size for cost estimation purposes can then be written in a similar form to that of Equation 1 (assumes that we are interested in confidence intervals of 95% and t = 1.96):

$$n = 3.842 * \mathrm{Var}(\$U)/[E*\$U/100]^2 \qquad (4)$$

EXAMPLE CALCULATIONS

A pilot study of a harvesting operation with hourly costs of $250 provided the following production statistics: cycle time (minutes) (mean = 7.171, standard deviation = 1.744) and cycle volume (m^3) (mean = 3.483, standard deviation = 0.782). If the aim of the overall study was to estimate mean cycle times to within 5%, only 91 cycles would be required.

If, however, a researcher wanted estimated unit costs to be within 5% of the "true" mean cost 95% of the time, a sample size of 168 cycles would be needed, calculated as shown below:

$$\begin{aligned}
E &= 5\% \\
k &= \$250/60 \\
&= \$4.17 \text{ per minute} \\
U\$ &= \$4.17 * 7.171 / 3.483 \\
&= \$8.58 \text{ per m}^3 \\
\mathrm{Var}(U\$) &= (\$4.17)^2 * [(7.171)^2 / (3.483)^2] * [(1.744)^2 / (7.171)^2 + (0.782)^2 / (3.483)^2] \\
&= \$8.06 \\
n &= (3.842 * 8.06) / (5 * \$8.58 / 100) \\
&= 168 \text{ cycles}
\end{aligned}$$

If data from 168 cycles were gathered, it would be expected that estimated unit costs would be within $0.43 of $8.58/$m^3$ 95% of the time. Some harvesting managers would prefer to estimate costs to within $0.10/$m^3$, not $0.43. The pilot study statistics would indicate that a sample size of over 3000 cycles would be required to achieve this level of precision.

One of the assumptions behind Equation 3 is that cycle time and cycle volume are independent variables. Harvesting production studies sometimes show a weak positive relationship between cycle time and cycle volume — that is, cycle time increases as cycle volume increases. The impact of this relationship is that sample size determined using Equation 3 is likely to be conservative, suggesting more cycles than would actually be needed for the level of precision required.

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