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AVERAGE YARDING DISTANCE

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INTRODUCTION

Of the various factors that influence the productivity of logging systems, one of the most important is the yarding distance - that is the distance that the logs must travel from the stump to the landing. For any particular setting it is most convenient to talk of the Average Yarding Distance (AYD). By definition, half of the timber in the setting must travel greater than the AYD to the landing and the other half less.

Much of the theoretical analysis of AYD has arisen from its interrelationship with the spacing of roads and landings. Where the costs of logging as a function of yarding distance are known, and likewise the costs of road and landing construction, it is possible to determine the optimum spacing of roads and landings to minimise total logging cost.

The first comprehensive treatment of this subject was by D.M. Matthews in 1942, and his book "Cost Control in the Logging Industry" has since come to be regarded as something of a classic by logging economists. The calculation of AYD was crucial to Matthew's analysis and his work has since inspired others to place the calculation of the AYD on a sounder mathematical footing.

This Report examines various means of calculating the AYD for different shaped settings. For more complete explanations of the methods, a list of references is provided at the end of the Report.

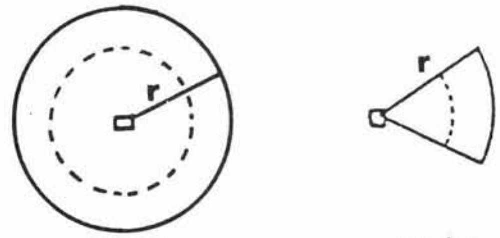
REGULAR SHAPED SETTINGS

(Refer paper by Suddarth and Herrick)

By far the easiest solution is that for the circular setting with a central landing. The AYD is simply two-thirds of the radius or

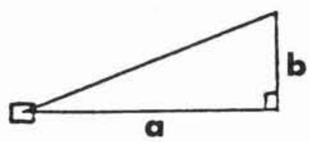
$$AYD = \frac{2r}{3}$$

The same formula also applies to a sector.



circle sector

The formula for a right angled triangle with a landing at the acute corner is rather more complicated although is straightforward to solve with any scientific calculator.



right triangle

$$AYD = \frac{\sqrt{a^2 + b^2}}{3} - \frac{a^2}{3b}\, \ln \left[\tan \left(\frac{\arctan \frac{a}{b}}{2} \right) \right]$$

In this equation, *ln* represents the natural logarithm. Arctan is the reverse of finding the tangent of a number and is indicated on most scientific calculators as "$\tan^{-1}$". As an example, if "a" were 200 m and "b" 60 m, then :

$$AYD = \frac{\sqrt{(200)^2 + (60)^2}}{3} - \frac{(200)^2}{3 \times 60} \ln \left[\tan \left(\frac{\arctan \frac{200}{60}}{2} \right) \right]$$

$$= \frac{\sqrt{43600}}{3} - \frac{40000}{180} \times \ln \left[\tan \left(\frac{73.3}{2} \right) \right]$$

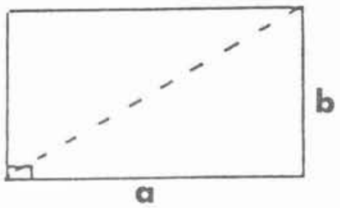
$$= 69.60 - 222 \times \ln [.744]$$

$$= 69.60 - 222 \times (-.296)$$

$$= 69.60 + 65.71$$

$$= 135.31 \text{ m}$$

The derivation of the AYD for a rectangle with a landing at one corner involves dividing the rectangle into two triangles, determining the AYD for each and then calculating an average of these, weighted by area.

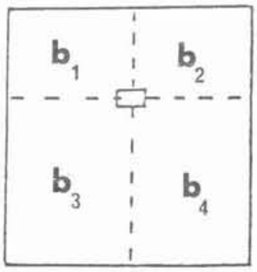


The formula derived by this process is :

$$AYD = \frac{\sqrt{a^2 + b^2}}{3} - \frac{b^2}{6a} \ln \left[\tan \left(\frac{\arctan \frac{b}{a}}{2} \right) \right] - \frac{a^2}{6b} \ln \left[\tan \left(\frac{\arctan \frac{a}{b}}{2} \right) \right]$$

As Suddarth and Herrick explain, there is an additivity property through which the AYD of a whole area can be calculated from the AYD's of individual parts of that area. This enables the AYD for more complex slopes to be determined by breaking them down into parts for which individual AYD's can be determined. The AYD for each part is multiplied by the proportion that the part represents of the total area.

In the following setting for instance, with the landing within the boundaries, the AYD is calculated using the formula above on each of the areas formed by the dotted lines.



$$AYD = \frac{AYD1 \times b1}{B} + \frac{AYD2 \times b2}{B} + \frac{AYD3 \times b3}{B} + \frac{AYD4 \times b4}{B}$$

Total area $B = b1 + b2 + b3 + b4$

IRREGULAR SHAPED SETTINGS

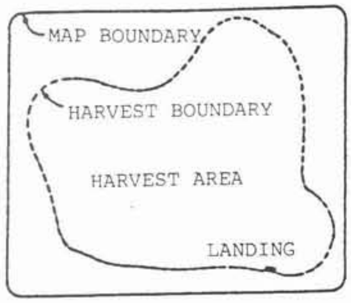
For irregular shaped settings which are not conveniently divided into regular parts, there are three approaches which could be described as; the centre of gravity method, gauge method, and computer/digitiser method.

Centre of Gravity Method

This technique is described by Koger and Webster (1984), and gives a close approximation of the AYD for area where the landing is on the setting boundary :

Step 1

- determine harvest boundary and landing location

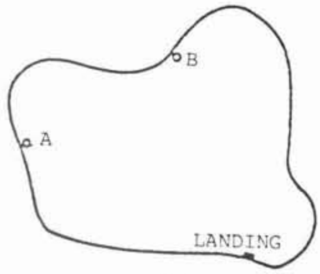


Step 2

- separate harvest area from map by cutting along boundary line

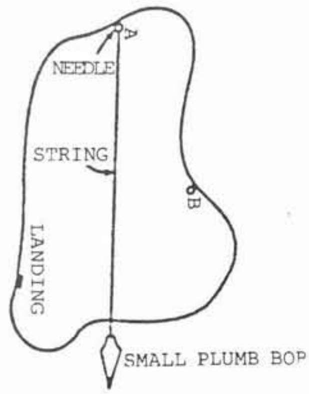
Step 3

- make two small holes near margin of harvest boundary (A & B). Separate from landing by about 1/3 boundary circumference



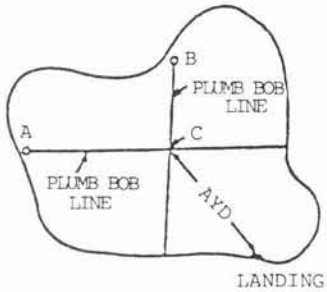
Step 4

- place a needle in hole at location (A) and make sure that harvest area cutout rotates freely about the needle axis. Attach a small plum bob to needle and mark plum line on cutout. Repeat this process at location (B).



Step 5

- the centroid of the harvest area will be at the intersection of the two plum bob lines (C). Measure the distance from point C to the landing with a rule. This distance multiplied by the map scale will give a close approximation of AYD.



Gauge Method

This technique relies on two of the principles described earlier. They are :

(1) The AYD for a sector is equal to two-thirds of the radius.

(2) The AYD of a whole area can be determined from the area-weighted AYD's of individual parts of that area.

The gauge itself is a transparency, marked as shown in the following diagram. Radial lines, spaced at a common angle are graduated at appropriate intervals for the map scale the gauge is designed for.

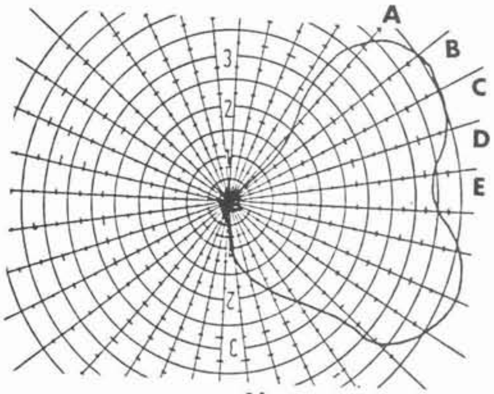
The gauge is placed on a map of the setting, and the centre is located above the landing. The distance along each radial line from the landing to the boundary is read in turn and recorded. AYD is then calculated from the formula :

$$AYD = \frac{2}{3} \frac{\sum r^3}{\sum r^2}$$

where :

r - distance from landing to boundary
$\sum$ - means "the sum of"

The following example demonstrates the formula application:



Line	r (m)	r^2	r^3
A	430	184900	79507000
B	500	250000	125000000
C	500	250000	125000000
D	485	235225	114084125
.	.	.	.
.	.	.	.
.	.	.	.
N	125	15625	1953125

$$\sum r^2 = 1835750 \quad \sum r^3 = 862802500$$

$$AYD = \frac{2}{3} \quad \frac{862802500}{1835750} = 313 \text{ m}$$

The accuracy of the technique improves as the angle between the radial lines is decreased. Gauges mostly offer 10° or 5° spacing. Clearly though, the calculations become more time consuming as the number of radii to be measured increase. Programs for hand-held programmable calculators have been prepared to streamline the procedure and an example is the "Average Yarding Distance program 2.1-432" prepared by J. Sherar and D. Nickerson of the U.S. Forest Service. This is designed for the HP41C calculator and provides not only the AYD but also an estimate of setting area. (While the original program used units of "stations" and "acres", G.N. Manners of Tasman Forestry Limited, Rotorua, has prepared a version with metric units).

Computer/Digitiser Method

Provided you have access to the necessary facilities, this is the most accurate and convenient method of determining AYD for an irregular setting. Determining the AYD involves taping a map of the setting to the digitiser, answering a series of screen prompts concerning map scale, landing location and setting slope etc., and then tracing around the setting boundary with the cursor. The AYD and setting area are displayed upon closure of the tracing.

Behind the surface of a digitiser tablet, is a grid network of thousands of fine wires and as the cursor passes over these the cursor path becomes stored in the computer as a series of co-ordinates. The accuracy of the digitiser is commonly to within a fraction of a millimetre.

Computer programs for determining AYD essentially work on the same principles as described for the gauge method. However, because it is feasible to perform enormous numbers of calculations very quickly, the angles between radiating lines can be minute. Furthermore, the programs can allow for the exclusion of inaccessible or unmerchantable areas within the settings, and landing sites within, adjacent to, or outside of the settings.

At the present time, forestry computer "workstations" with the necessary digitiser and accompanying programs are located with the Harvest Planning Group (Forest Research Institute) (Reutebuch and Evison, 1984) and at Tasman Forestry Limited, Rotorua.

LIMITATIONS

While sound in theory, the methods described do have problems in practical application:

- Where the wood volume is not distributed evenly throughout the setting, it is necessary to identify subtypes. The additivity property allows these subdivisions of the area to be analysed separately then combined with a weighting based on volume.

Donnelly (1978) has prepared a program for the HP-65 programmable calculator which recognises variable log densities within the setting. His program also adapts the principles of the digitiser approach in that instead of using a gauge, co-ordinates of points around setting boundary are keyed into the calculator.

- the AYD derived in each case assumes that the shortest distance possible is taken from the stump to the landing, i.e. a straight line distance, as the crow flies. Rarely is this the distance that logs actually travel, especially in ground-based skidding operations where stumps, broken terrain and other features lead to a wandering skid trail. Calculation of actual travel distance involves correcting the AYD with an appropriate "Wander Factor". This can be determined from field studies and is sensitive to terrain type.

Situations where there is a common extraction route (such as might be found in extraction along a ridge or gully system, or removal of thinnings along outrows) also demand modifications to the analysis. (For examples, see Twito and Mann (1979) and New Zealand Forest Service (undated).)

- The effect of slope has not been included in the formulae listed earlier. For those readers further interested in this subject, a thorough treatment and adjusted formulae are provided by Greulich (1980).

While programs for the digitiser/computer combination do provide for recognition of slope, this is generally only as one slope value for the whole setting. Perkins and Lynn (1979), however, have developed a computerised method which incorporates irregularities of terrain for greater accuracy. The more common use of Digital Terrain Models is likely to result in further such refinements.

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