EVALUATION OF THE TRANSECT AREA - METER METHOD OF MEASURING MAP AREAS¹

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ABSTRACT

Planimetry of map areas was studied to find a more efficient method in terms of speed and accuracy, than those currently in use. A transect method was developed using a simple map measurer which was adapted to scan the transects, to mark area covered, and to store accumulated lengths of transects scanned. The modified version of the instrument, called a transect area meter was tested against the dot grid and the polar planimeter used as standards of speed and accuracy respectively and found to be both faster and more accurate than conventional methods.

RÉSUMÉ

L'auteur a étudié l'utilisation du planimètre pour mesurer des superficies sur des cartes, en vue de trouver une méthode plus rapide et plus précise que les méthodes actuellement en usage. Une méthode a été mise au point, selon laquelle on se sert d'un simple planimètre modifié de façon à balayer des bandes transversales de l'aire à mesurer, à rayer la superficie balayée et à additionner les longueurs des bandes transversales. L'appareil ainsi mis au point, qu'on appelle planimètre à bandes transversales, a été mis à l'essai et comparé au graticule pointillé et au planimètre polaire en tant que modèles de rapidité et de précision, respectivement; le nouvel appareil s'est révélé beaucoup plus précis que les appareils classiques.

INTRODUCTION

The surface area measurement of many irregular shapes such as occur on forest type maps is a slow and tedious task. Frequently it is a costly bottleneck in a forest survey program and one which may retard progress of the entire project. The need of a faster and less tiresome method of planimetry is clear. However, the search and trial of faster methods, particularly those based on a sampling system, is usually bound to the difficulty of obtaining sufficiently accurate results. Accordingly, the performance of a method must be judged on the basis of how rapidly it will function within certain specified limits of accuracy.

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A study was made to evaluate the speed and accuracy of a transect method of planimetry which employed an instrument developed by the writer called a transect area-meter. The method was tested against the following two established methods: the dot grid, used to judge speed performance; and the polar planimeter, treated as the criterion of accuracy. The MK area calculator (Rideout, 1962) was retested and compared with the transect method. Also considered was the degree to which wider transect spacing would accelerate planimetry without introducing significant amounts of error.

THE TRANSECT PRINCIPLE

The basic theory (Spurr, 1948) of the transect principle is as follows: linear measurements are directly proportional to area measurements when lines called transects are parallel and uniformly spaced across an area.

The relationship can be expressed by the proportion: $\frac{a}{A} = \frac{l}{L}$

where, a = the area of a topographic feature such as a lake or a unit such as a forest type;

A = the total area of all units such as on a map sheet;

l = the total lineage³ of transects in a specific unit; and

L = the total lineage across the map sheet.

The principle is readily adaptable to the measurement of areas on maps because the map scale and the spacing of transects can be used to convert lineage to acres, hectares, or whatever measure of surface area desired. For example a map of scale 1 inch to 1320 feet and with dimensions of 30 by 36 inches contains 43,200 acres; and a series of uniformly spaced transects 1/5 of an inch apart across a map has a total lineage of $30 \times 36 \times 5 = 5400$ inches. The two totals provide a conversion factor, $43200 \div 5400 = 8$ which can be used to translate unit lineage directly into area. A lake on the map for example has a lineage of 25.2 inches which represents an area of $25.2 \times 8 = 201.6$ acres (see Figure 1).

MODIFICATION OF TRANSECT MEASURING TECHNIQUES

Transect methods have not received much attention in the past because the laborious task of measuring transects line by line has made these methods prohibitively slow. The time consumed stems from the operation of scaling each line and then adding the measured length of all the transects in an area. A method was required then, that would employ a scanning process to reduce measuring time and that would also accumulate the length of transects as they were scanned.

This led to the idea of adapting a small, simple gauge called a map measurer to the measurement of transects. The instrument was designed originally to measure the length of curved, meandering lines on maps such as rivers or roads. It consists of a small wheel which runs over the map and a series of reduction gears in a clock-work like mechanism which transmits the travel of the wheel to a recording dial. The dial is calibrated to record distance travelled in feet, miles, meters, etc. When applied to the

³The word lineage refers to the combined length of all transects in an area.

Figure 1 — Map Transects.

transect principle, the measurer is run across all the transects in an area and registers the total distance scanned. The dial can be calibrated to read directly in measures of area, such as acres, hectares, and square miles, according to map scale and transect spacing.

For the test of the method a map measurer was obtained⁴ which had a large storage capacity (1000 feet lineage) and a cancelling button. The button zeros the hands and greatly reduces operation time. A pencil was attached to the measurer to facilitate scanning, to mark the progress of the work, and to avoid skipping or double scanning of transect lines. Tension was also applied to the scanning wheel to avoid errors introduced by overrunning a transect and inadvertent movement of the wheel while off the transects. The modified version of the map measurer was named a transect area-meter (Figure 2).

No references were found that referred to this use of the map measurer or, for that matter, any scanning wheel with either a mechanical or electrical means of registering distance scanned.

TEST PROCEDURE

The transect area-meter was tested against the speed performance of the dot grid and the accuracy standard of the polar planimeter. The MK area calculator was also tested on the areas for comparison purposes.

Portions of forest type maps of scale 1320 feet to the inch were selected

⁴Obtainable from wholesale or retail stores stocking engineering and forestry supplies.

Figure 2. The Transect Area-Meter

to represent as completely as possible all the shapes and sizes likely to be encountered in a planimetry job. Two blocks were used as test areas: one with small types (average size 27 acres) and the second with large types (168 acres). The block of small types consisted of 35 types on a total area of 945 acres and the types sizes ranged from 2 to 85 acres; the block of large types consisted of 20 types on a total area of 3360 acres and type sizes ranged from 10 to 600 acres. The tests were made as comparable as possible by using a dot grid density of 25 dots per square inch, a transect spacing of 1/5 of an inch and every second line of a No. 100 MK area calculator grid.

Another separate test was made to determine the length of time required to measure individual areas of varying size by three methods. The polar planimeter was removed from this test because of its slowness. The transect spacing was increased from 1/5 of an inch to 2/5 and 4/5 of an inch to illustrate the economy of wider spacing.

RESULTS

1. Speed Test

Speed is expressed as the time taken to measure the two test blocks; relative speed is expressed as per cent of work done in a given period of time compared to the work output of the dot grid in the same interval (Table 1).

TABLE 1
RESULTS OF TIME TAKEN TO MEASURE TWO BLOCKS OF AREAS
RELATIVE SPEED (DOT GRID AS STANDARD) SHOWN IN PER CENT

Method	Block 1		Block 2	
	Test area: 945 ac (23.625 sq. in.)		3360 ac (84.00 sq. in.)	
	Number of types: 35		20	
	Average type size: 27ac (0.675 sq. in.)		168 ac (4.200 sq. in.)	
Polar planimeter	270.0 min.	(-94%)	120.0 min.	(-83%)
Dot grid	16.0	(0%)	20.0	(0%)
Transect area-meter	16.0	(0%)	13.2	(51%)
MK area calculator	23.5	(-32%)	17.7	(13%)

Table 1 shows that the area-meter planimetered the block of large areas about 50 per cent faster than the dot grid and that the MK area calculator operated 13 per cent faster than the dot grid. On the block of small areas the dot grid and area-meter operated at the same speed while the MK area calculator was about 30 per cent slower. The polar planimeter was extremely slow on both blocks. The MK area calculator tested by E. E. Rideout (1962) was 22% faster using the No. 100 grid than the dot grid on areas of average size of 270 acres. The tests indicated a gain of approximately 21% on such areas.

2. Accuracy Test

The term "accuracy" may include both bias and precision in measurement but in this experiment bias (about -0.1 per cent) was removed because all the map areas comprising a map sheet were adjusted in proportion to their size such that their total equaled the total of the map sheet. Therefore estimates of error used herein reflect only the variability of measurement of area by the methods about standard values. This variability is influenced mostly by instrument error, operator error and sampling error.

Precision was tested and expressed in comparable terms by using the sample standard deviation of difference (Snedecor, 1959). This is the square root of the sum of squares of differences between standard and measured areas (corrected for bias) divided by the number of areas measured minus one (one degree of freedom lost). In this experiment, since bias was removed, the standard error of estimate was equivalent to the sample standard deviation of difference.

The standard error of estimate of these methods expressed in acres, square inches (actual surface area of type) and as percentage of the acreage is shown in Table 2. Each plus-minus figure means that an individual measurement by a method is not expected to deviate from the actual by more than the stated figure (one standard deviation) two-thirds of the time.

The results are also graphed to illustrate more clearly the accuracy performance relationships (Figure 3).

TABLE 2
STANDARD ERROR OF ESTIMATE OF METHODS TESTED ON TWO
BLOCKS USING THE POLAR PLANIMETER AS STANDARD

Method	Block 1 Average area size 27 ac. Standard error of estimate in absolute and per cent terms			Block 2 168 ac.		
	Area		Per Cent of acreage	Area		Per Cent of acreage
	acres	square inches		acres	square inches	
Dot grid	±3.84	±0.086	±15.26	±2.42	±0.061	±2.13
Transect area-meter	±1.09	±0.027	± 6.57	±2.64	±0.066	±1.66
MK area calculator	±1.41	±0.035	± 8.49	±2.80	±0.070	±3.57

The percentage columns of Table 2 indicate that the area-meter was approximately 3 times more precise than the dot grid and 1.5 times more precise than the MK area calculator in the block containing small areas. In the block having larger areas the area-meter was about 1.3 times more precise than the dot grid and 2 times more precise than the MK area calculator. Figure 3 also illustrates these relationships graphically.

3. Test of time required to planimeter individual areas of different sizes.

The three fastest methods were tested on areas of various size to indicate the relative speed efficiencies as affected by area size. The graphic presentation of results in Figure 4 shows that the transect method was faster than all other methods tested for areas larger than 35 acres (0.875 sq. in.), and that the MK area calculator was faster than the dot grid on areas larger than 130 acres (3.250 sq. in.).

On average-sized areas (about 150 acres or 3.750 sq. in.) the area-meter was about 45 per cent faster than the dot grid. An additional reduction in time was achieved by the use of wider transect spacing. Doubling spacing increased speed a further 40 per cent, and when spacing was quadrupled speed was increased by 80 per cent (Figure 4).

DISCUSSION

The results presented in Figure 4 illustrate the speed relationships of the methods and indicate specifically at what area size one method is faster than another. However, to understand why the speed of one method changed in relation to another on various areas requires an analysis of time elements involved. For example, the fact that the area-meter was slower than the dot grid on small areas and faster on large areas can be explained as follows: the time required to scan the line segments was only a small proportion of the total measuring time, and also the time taken to scan a transect was nearly constant for any length. The time required to measure an area therefore varied in closer relationship to the number of line segments than total length of transects or area. Dot counting time, on the other hand, varied almost directly with area because the rate was controlled principally by how quickly the operator could count and mark dots. Thus as area size increased, the

rate of the area-meter increased while that of dot counting remained nearly constant.

The precision of the methods can be explained in a similar fashion. The reason that transects spaced $1/5$ of an inch apart yielded more accurate measures of area than dots spaced $1/5$ of an inch from each other was as follows: A dot is a discrete point which represents 1.6 acres (0.04 sq. in.), whereas a transect is a continuous sample of an area, $1/5$ of an inch representing 1.6 acres and fractions of $1/5$ of an inch representing corresponding fractions of area. Thus in one direction the transect sampled fractions of area and the dot provided a yes or no answer only.

In addition to the sampling errors which became proportionally less as the size of an area was increased, was the aspect of instrument and operator error. Considering instrument error, bias (approximately -0.1%) was removed in the area-balancing procedure and thus the only concern was how accurately the instrument could be read. The instrument can be read to ± 0.05 inches which in this test was equivalent to ± 0.4 acres (± 0.01 sq. in.). Since the instrument was read only once for each area the "reading" error was constant for all areas and thus its effect on precision of measurement diminished as the area size increased. Operator error on the other hand, was more difficult to define because it varied according to the skill and experience of the user. A test was made on several areas to find out how consistently an operator could remeasure an area. The results were that the operator used in this experiment could measure an area within ± 0.10 inches (± 0.80 ac; ± 0.02 sq. in.), 95% of the time. The variation was somewhat less on smaller areas because consistency of measurement depended partly on the number of changes from one transect to another.

The net effect of instrument and operator error remained practically constant with change in the number of transect lines. The decrease in precision then, resulting from tests of wider transect spacing (or dot spacing), was chiefly due to sampling error. Since this category of error was proportionally large it was important to understand its relationship to spacing of lines or dots. Theoretically, precision of measurement, as influenced by sampling error, is inversely proportional to the square of the transect interval or the spacing between dots. Thus, if transect or dot spacing was doubled, precision declines four times; if spacing is quadrupled, the precision declines sixteen times. Actual tests of wider spacing bore out this relationship and similar effects of wider transect spacing were reported by Winkworth (1956).

The increased speed resulting from wider spacing of dots or transects was gained at the expense of precision. For a given spacing larger areas were measured more precisely than smaller areas by dots or transects because of the greater number of sampling units. Thus on large areas the spacing of dots or transects can be greater than on small areas for equal precision. The problem then was to define exactly how much spacing could be increased. The answer was provided by knowledge of the accuracy performance of the method on various areas, the relationship between spacing and precision, and the degree of precision specified for the planimetering job.

As an example, let us assume that areas had to be measured to a precision of $\pm 4.0\%$ two-thirds of the time, and that the transects spaced at $1/5$ of an inch were used. Consulting Figure 4, areas less than about 35 acres would not meet the standard. This is where the area-meter precision curve for $1/5$ -inch transect spacing crosses the horizontal $\pm 4.0\%$ line (Figure 3). Likewise, if the interval is doubled to $2/5$ of an inch, the minimum area that could be measured is $2^2 \times 35$ or 140 acres to remain within the specified accuracy limit. This procedure could be used to define minimum area measurable for any transect interval and standard of accuracy.

CONCLUSIONS

1. The transect area-meter is a rapid method of measuring area because it can scan lines rapidly and retain the accumulated length of transects in its "memory".
2. Errors caused by missing or double measuring areas are avoided by the use of a marking pencil.
3. The area-meter is less tedious to use than the dot grid. It marks progress of work and stores distance scanned in one operation and therefore obviates dot counting, marking, and retention of figures in the head.
4. The transect method is simple. A dot grid of density 25 dots per square inch run through a copy machine with the map sheets makes an excellent guide for the area-meter. No further lines are required.
5. The area-meter itself is easy to manipulate and requires no special additional equipment or facilities. It could be taken into the field and used on the job with little difficulty.

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FIGURE 1. Metal shield — glass sleeve protection of thermocouple sensor against radiational errors. Both shield and sleeve are coated with non-hygroscopic white paint.