*Inventory of Large Coal Piles**

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ABSTRACT: *One of the duties of the Maps and Surveys Division of the TVA is to make frequent determination of the volume of large coal piles. A number of new techniques for making inventory of coal piles by photogrammetric methods have been developed. This paper describes a unique approach to this problem.*

INTRODUCTION

THIS subject finds a place on the American Society program because photogrammetry plays an important part in one of the current measurements. In this paper it is not my intention to dwell on the *technical* photogrammetric details (actually they are quite simple), but rather to point out some of the advantages and selling points of the photogrammetric method, and problems of inventory generally.

More and more the photogrammetric engineer will be asked to make an inventory. For such work he should know the disadvantages and limitations, and particularly should be able to recognize some of the *fringe problem* pitfalls.

The author does not know who first used photogrammetry in stock pile inventory. It is known that Robert A. Cummings, Jr., and Aero Service were using it at least as early as 1950. But there may be other users in much earlier dates. TVA first used the photogrammetric method in March 1951 shortly after the appearance of an article in the December 18, 1950 issue of *Electrical World* written by Biron Ganser, Manager, International Auditing Division, Philadelphia Electric Company and Edward A. Schuch, then Chief Engineer, Aero Service Corporation, Philadelphia. This paper then is not the announcement of a new discovery, but is a report that the procedure of *photogrammetric* stock pile inventory, as a "new idea," has been "constructively abandoned" to productive use.

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THE INVENTORY

Good business demands periodic inventory. The physical inventory of some commodities can be accomplished by walking through storerooms and warehouses and simply counting items. Some items can be weighed. But did you ever try to weigh mountains that cover up to 45 acres and rise more than 80 feet? There are eight coal piles of these general proportions in the Tennessee Valley. Some contain more than 600,000 tons. It would be simple to drive from Rogersville to Paducah once each year, count the piles and report eight mountains of coal. But unfortunately this is not an acceptable unit for an inventory. Also it will not give the order of accuracy required by the General Accounting Office.

Obviously these huge stock piles cannot be reweighed. Historically the mathematical solution of volume X unit weight has been relied upon.

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Numerous methods to determine and combine these factors are available. One phase of determining volume is accurately delineating the *shape* of the *exposed surface*. This is normally accomplished either by (1) cross-sectioning; (2) plane-table survey; or (3) photogrammetry. Field surveys and measurements have proved acceptable for years, *except maybe to the field men involved*. (Pulverized coal down the neck and in the shoes is fairly disconcerting.) Also, the shape, particularly of the smaller piles, can be changed materially between rod shots, by the rodman climbing and falling on the steep slopes.

In both plane-table and photogrammetric methods, the piles are contoured with a one foot interval on the slopes and a $\frac{1}{2}$ foot auxiliary on the tops. This is accomplished photogrammetrically by the stereoscopic plotting of the contours of the pile, from aerial photography usually taken from a height above the ground of 1,200 feet. The manuscript is drawn at scale $1'' = 40$ feet. The TVA Kelsh Plotter has a magnification of $7\frac{1}{2}$. This gives a C factor of 1,200 for a project where obviously extreme accuracy is the goal. This may be questioned by some photogrammetrists. But it has recently been brought out that C factor should not always be applied directly to the stereoplotter, but rather to the photogrammetric system and procedure of which the plotter is a part. It is believed that is true for the TVA operation. Stock pile inventory is a special case in many respects. For instance, there is no vegetative cover to contend with.

After contouring, the area of each contoured layer or slice is determined by planimeter and the volume is computed.

In choosing the method for the *contouring*, the shape of the pile, its location, the availability of surveying personnel vs. photogrammetric equipment and even the method of building the pile must all be considered. The photogrammetric method is particularly adaptable where *large permanently located* stock piles are widely scattered and must be periodically repeated. Where survey parties are readily available, and where the stock piles are smoothed off and regularly shaped, plane-table methods continue to prove just as satisfactory and economical.

Generally the photogrammetric method is *more* accurate, approximately 25 per cent *less* expensive, and certainly more convenient, *if* proper conditions exist. But obviously to tie up an airplane and the photogrammetric equipment necessary to determine the volume of a *small* isolated stock pile, would be folly (like employing a power shovel to plant a rose bush). Photogrammetric inventory becomes more feasible economically when a number of piles can be photographed on the same mission. This fact has prompted photogrammetric organizations around large industrial communities, to suggest co-operation between several customers in adopting common inventory dates, in order to reduce cost of inventory to all of them.

In TVA, in addition to the eight large coal piles there are several smaller ones and approximately 30 different raw material piles in connection with the chemical and fertilizer industry, which must be inventoried. These outdoor piles are usually photographed on the same day.

TVA uses fixed-wing aircraft which can be throttled down to a comparatively slow speed because the stock piles involved are widely scattered in a triangular area some 350 miles on two sides, from Paducah to near Kingsport to Muscle Shoals. In smaller areas, a helicopter might present certain advantages.

The actual number of photographic exposures taken represents a comparatively small proportion of the total cost. In the efforts to confine the contouring to one stereoscopic model for each pile, two or three strips are flown across each pile. Flight maps are made from last year's photographs. This often gives a choice of light, and if you are lucky the plume of smoke which invariably hovers over the pile on inventory day may shift off the pile between flights. When the piles are large and it is anticipated that the model limits will be close, rather than try to *spot* one stereo-pair, the camera is "turned loose" across the pile giving several exposures with little forward gain. From these the best centered stereo-pair can be chosen.

Photographing all of the material owned by one organization on the same date enables the organization to adopt a common inventory date. Then shape of the piles is recorded on film and is available for compilation into topographic maps at any convenient time. The photograph becomes a permanent record and the resulting inventory can be checked even by other individuals years later, should questions of audit arise or if it otherwise becomes desirable to do so.

By recording the time that the plane passes over a given stock pile, and by correlating this time with the records of receipt and use of coal during inventory, normal operations on the pile do not have to be shut down as they often do for the duration of the conventional field survey. This is a *definite* advantage on *very active* piles.

The smaller piles of *known density* and the larger piles in so far as outside shape is concerned do not require ground measurements after the first year.

Before the first photogrammetric survey is made, both horizontal and vertical control of several *permanent* identifiable points surrounding and outside the stock pile is established. These points can be used for future inventories if their position is not disturbed. However, if survey personnel is required at the site for other purposes, simple targets laid on the pile and spot elevations established furnish excellent tests on results.

The accuracy required varies from organization to organization and almost invariably has to be justified to laymen in the photogrammetric field. Tennessee Valley Authority being a government-owned corporation is very closely accountable to the General Accounting Office. The following is a portion of a statement by the Assistant Director of the GAO early in 1951.

"One of the primary purposes of taking physical inventories is to establish that the quantities shown by the accounting records are actually in existence. The taking of physical inventories of bulk materials which are stored in piles has always presented a problem inasmuch as it is impractical to determine the quantities by actual weight. The only other recourse, which is accepted practice, is to determine the volume of the pile and convert the volume into a measure of weight. The methods used in determining the volume must be such as to assure a reasonably accurate determination.

"If it can be shown that the photo method results in a reasonably accurate determination *when compared* with the results obtained by the ground-survey method, we cannot foresee, at this time, any objection to the use of the photo method."

The lack of objection in 1951 has now apparently approached the point of enthusiasm. Representatives of GAO have gone over in great detail the methods and procedures, which TVA has adopted and, as photogrammetric laymen, some of them seem fascinated. Since then they have been furnished data for talks and papers advocating the use of the photogrammetric approach to inventory.

Experience indicates the outside shape of the larger piles can be determined and *duplicated* by photogrammetric methods within an accuracy that will affect volume only some *2* to *3* per cent.

The accuracy of the topography of the top of two piles, of *different height*, but covering the same area may be identical; but the percentage of error of volume would vary considerably. The higher the pile, the greater the probable accuracy in the plateau-like stock pile.

Over 45 acres, two-tenths of a foot represents approximately 14,000 tons of coal.

In the experimental days there was a little "leg pulling" by the TVA Auditors. Without Maps and Surveys' knowledge, they chose a washed sand pile which happened to be in the midst of several chemical storage piles, and requested the using department, to neither take from nor add to this pile if they could avoid it. It developed that for three consecutive years an unchanged pile was inventoried by three different methods unknowingly. The results were gratifying to the victims of the leg-pulling.

Year	Method	Results, Tons	% Diff. between Plane-Table Method	% Diff. between Cross-Section Method
1950	Cross-sectioned	26,148	2.9	—
1951	Plane-table	25,405	—	2.7
1952	Aerial survey	26,098	2.7	0.2

The widest variance was 2.9% between the plane-table and cross-section method and the smallest is 0.2% between the aerial survey and cross-section method.

Summarizing, the photogrammetric method has several advantages:

1. It is more accurate, economical, and convenient.
2. The cut-off time of all inventory can

be set for one date—all pictures can be secured in one day.

3. Ground-control need be established only once.
4. The method provides a permanent record of the size of the pile at the time the picture was taken, and volume can be checked at any future time if any question arises as to the accuracy of the record.
5. No bulldozing or pile dressing is required as is usually done for the cross-section method.

There are also some disadvantages:

1. The difficulty of catching weather on a predetermined day and coordination with many superintendents at several plants (but these are just for one day as compared to weather problems for many days for field parties. Anticipating the photographic weather problem, usually one day is designated in advance as the preferred inventory date with a few days tolerance if weather requires).
2. A lapse between photography and the beginning of final volume determination (when plane-table survey is finished, volume study can be started; in the photogrammetric method, film must be developed, plates made and topography drawn before volume study can be started. However, this difference can be offset by shift work since these are inside operations).
3. The color of coal and problems of lights and shadows (in one area TVA has adjacent piles of coal and phosphate).

So much for the photogrammetric method, and the most obvious problem of the determination of outside shape. There are two other problems in inventory, the solution to which is more elusive. These problems continue to require ground work on the bigger piles at the time of photogrammetric survey. One is the determination of *base subsidence*, the other of *unit weight*. These are not *photogrammetric* problems, in fact the customer may wish to furnish or be responsible for these items; but they must not be overlooked.

The coal stock piles at the large steam plants represent a specific type of pile, as the type affects the problems of inventory. They are plateau-like in shape and are built in layers, in a sense. At the more modern stations the coal is crushed and stock piled by means of both rubber-tired and crawler-type tractors hauling rubber-tired scrapers. Operators are instructed to spread the coal in as thin a layer as practicable and to accomplish compaction of the coal pile by successive passages of tractors and scrapers over the newly deposited coal. The coal involved in our area is bituminous and under these stocking methods, it is surprising how completely the voids are filled with fines and how nearly the coal piles so built resemble coal in its solid state, even to the point of glistening in the sun in the wake of a bulldozer being used to reclaim the coal.

Modern stocking and reclaiming methods practically demand that the base of large piles be a plane surface with only sufficient slope for drainage. To develop such an area in the type terrain of most steam plants often requires heavy grading.

Storage areas are constructed to definite plans and grades, and detailed surveys made of them after completion.

But what happens to these *areas*, particularly the *fill* areas, when a half-million or more tons of coal are placed on top of it?

And at the time of inventory, with the coal in place, how does one determine the shape of the *bottom* of the pile, and what effect does distortion of this base have on volume?

The average storage yard base may depress under certain conditions up to a foot or more, under the weight of several feet of coal, and it may rebound some when coal is removed. TVA has actual readings of 1.8 feet of displacement.

The importance of this condition is being recognized more and more with experience. Twenty to 30,000 tons of coal might "hide" underneath such a pile, if only the theoretical base contours are used.

In the more recently established fuel piles of TVA, $6' \times 6'$ concrete slabs have been placed at selected and coordinated points, and their accurate elevations determined prior to building the pile. Settlement can then be checked by probing through the coal to the slab.

Recently it has been determined that $\frac{1}{4}$ inch steel plates laid on top of the ground serve better than the concrete slabs. The steel will likely deteriorate through chemical action over a period of years, but the plates should last long enough to establish an adequate map of the base in its probable permanent position.

This problem points up the need for careful planning and for site preparation of the storage yard. For the more valuable ores, one is often justified in constructing a rigidly paved base.

In a conical or pyramid shaped pile, an error of 0.2 foot or 0.3 foot in elevation of the base can be more serious than 2 or 3 feet error in the height of the pile.

In inventorying shallow piles over large areas, it is often the practice to dig through the coal to base contact and to measure that coal thickness.

After the yards have been in use for a few years and subjected to great loads, it is planned that as sections of the various piles become empty a resurvey of the base will be made.

It has been stated that the outside shape can be determined with 2 to 3 per cent accuracy, and although there is the problem of base subsidence, there are ways it can be determined and measured.

If value is finally dependent on weight, what good is 2 to 3 per cent accuracy of *volume*—if the unit weight used should be in error maybe as much as 25 per cent. The final accuracy of such inventories will likely be more adversely affected by lack of knowledge, or inability to determine the average weight per cubic foot of the material in storage than in the determination of the volume itself.

The average weight of coal in storage varies considerably, depending upon the type of equipment used in spreading and compacting the coal, and the degree of fineness to which the coal has been pulverized. The coal in certain of these piles (placed or reclaimed with dragline) has weighed as low as 56 pounds per cubic foot and in the more recent piles as high as 72 pounds per cubic foot.

However, as the operators develop skill in building the pile, the density becomes more uniform, and there is being found considerable equality in the densities of the piles at the several plants independent of the sources of coal. For these new piles a density of about 71 pounds per cubic foot has been found to be a good average.

The best answer comes from the largest sample. Probably the most satisfactory method for determining density occurs if measurements can be started at the time the stock pile is begun, and after a large amount of coal has been placed; then before any is used, make an aerial survey of its volume. The average density of the pile can then be established by dividing the actual shipping weights by the measured volume.

In the hard packed piles, it is not too difficult to obtain fairly accurate samples near the top of the pile by driving a two cubic foot cylinder, and such equipment as the undisturbed soil sampler can take reasonable, although *small*, samples from *deep* in the piles.

But difficulty is still experienced in obtaining adequate samples from the more *loosely* placed piles.

These last two items are brought out merely to indicate, that the survey of the *exposed portion* of the pile is only one of three major problems in accomplishing such an inventory.

In the past, most organizations doing bulk inventory have accomplished the final volume determinations using conventional calculating equipment. In recent months, research and experimentation has been accomplished in the use of electronic computers for volume determination. It is reported that several organizations have adopted electronic computer methods. So far, however, photogrammetric cross-sectioning seems to lend itself to electronic computation better than the contour system.

These reports indicate that results from elevations read in the stereoscopic models on a 10 foot grid and computed electronically are quite satisfactory.

Further research is now underway at MIT and elsewhere looking toward the scanning of profiles of cross-sections through the pile and at selected points along the profile, taking off the three space coordinates of a given point in the form of digital data, which can later be fed directly into the electronic computer.

For those organizations which have both the photogrammetric and electronic equipment required, this scheme will undoubtedly prove feasible within the very near future.