quired in the field. Until the location and grade stakes have been set, the local people and property owners will be subject to little or no disturbance. Also speculation regarding the highway location will probably be avoided.

Throughout the construction period the availability of the photographs, maps, profiles and cross-sections will greatly facilitate the work and will save much time and effort.

When the construction of the highway has been completed another aerial survey along the route at a large scale and covering the right-of-way width would prove to be of great value. The construction accomplished can be checked in most cases. The amounts of earth moved and perhaps other work can be measured for payment. It is important to note that in former procedures, once the construction has been accomplished the record of the original appearance of the terrain along the route exists only in survey notes and profiles or in cross-sections plotted from them—all subject to human error. But, in the photogrammetric approach, we have the large-scale photography with its faithful rendition of the original terrain; it can be checked and rechecked as often as desired.

In summation, aerial surveys and photogrammetry provide:

a. In reconnaissance, assistance in studies of topography, surface geology and soils, drainage patterns, land use, property ownership, traffic requirements.

b. A considerable reduction in field surveys, for reconnaissance, final location and construction. Little if any field survey is necessary except on finally determined route.

c. The larger scale and more precise photogrammetric data and measurements for assistance in planning, in design, in estimates, in construction, in determining payments and later, in maintenance.

For all engineers and specialists whose work is in one way or another related to the earth's surface and what is taking place on it, Photogrammetry offers assistance. I urge you to consider it and use it. It will save you time and effort which you will need in view of the magnitude of the job and the manpower and fund shortages.

# *Using New Methods in Highway Location**

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ABSTRACT: *Photogrammetry and airphoto analysis combined with computers can and will become the most important tools which the highway engineer has at his disposal for the complex job of highway route selection.*

## INTRODUCTION

THE location and planning of today's modern highway has become a job of tremendous complexity. Our way of life depends on a delicate balance of economy. This economy centers largely around the ability to transport goods and people quickly and cheaply. Today a larger proportion of the total economy is going into the building of highways than ever before. Also, we are more largely urban than previously. Urban planning and development are almost by definition more complex and difficult than rural. With the rising cost of urban land the engineer is steadily being forced to use less desirable locations. The public demands highways of higher standard today than ten years ago. These de-

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mands combined with higher construction costs have increased the costs per mile of highways.

Limited access express highways place on the engineer a stringent requirement that the facility be located optimumly, from the standpoints of construction cost and also traffic service. To determine the desired location highway engineers must gather and analyze large masses of data. The amount of time and effort that goes into gathering and analyzing all these various forms of data is tremendous. In fact, it is generally the limiting factor in approaching the optimum location. The engineer must be aware of and be ready to use any new tool or process which allows him to gather and analyze more data before he makes his decisions. We have just such a set of tools available when we combine photogrammetry, airphoto analysis, and electronic computers (1).

## The New Tools

In the past few years *photogrammetric methods* have greatly aided the highway engineer (2). The use of such methods in compiling topographic and planimetric maps is now standard practice for most highway departments. The private photogrammetric firms have made a significant contribution to highway engineering by furnishing such maps and advancing the general acceptance of the photogrammetric method.

*Airphoto analysis* is another of the new tools which the location engineer is finding useful. The amount of information that can be obtained from good aerial photos is limited only by the skill and ability of the interpreter (3). Airphoto analysis can give the location engineer such important information as:

- land use
- geology
- soil distribution and properties
- sources of borrow and aggregates
- location of landslides, peat bogs, and other problem areas
- drainage characteristics and requirements
- clearing and stripping amounts
- good bridge crossings of streams and rivers
- location of access and construction roads

Lastly, the *electronic computer* represents a brand new tool for the highway engineer. Its many possibilities in highway engineering are just beginning to be explored.

When these three tools are integrated into one smooth system, the possibilities that exist far exceed those of any individual part. In such an integrated system, *aerial photography would be the basic data collection system, photogrammetry would be the quantitative or metric data system, airphoto analysis would be the qualitative or classified data system, and the electronic computer would be the data reduction and evaluation system.*

## Highway Location Considerations

As subjects become increasingly more complicated, engineers find it convenient to break them down into their component parts and analyze the parts separately. This method seems to be particularly applicable to highway location. All that is necessary is to find a way to express all the variables in terms of a common unit. It might be helpful to think of this unit as a common denominator. The most readily obtainable common denominator is economic value or cost. It seems reasonable to think that most of the engineering considerations can be analyzed and expressed using cost as the common denominator.

*Highway costs* can be analyzed and approached in many different ways. For our purposes the easiest approach seems to be to divide them into two major heads. physical and financial.

*Physical costs* can be broken down into:

- cost of right of way
- construction cost
- cost of utility adjustments
- contingencies

*Financial costs* consist of:

- preliminary expenses
- cost of engineering
- legal and administrative expenses
- interest and financing costs

The physical costs are directly related to the variable conditions over which the highway is built. These costs can all be grouped under the following headings.

Land—The cost of acquiring the land and buildings.

Land preparation—The cost of preparing the land for the construction process.

Earthwork—The cost of constructing the embankment.
Pavement—The cost of surfacing the embankment.
Structures—The cost of crossing streams, roads, and railroads.
Additional—The miscellaneous additional costs which contribute to the cost of the completed highway.

The second group, financial costs, are not of interest to the location engineer because they are proportional to the physical costs of the project. Therefore, they can be disregarded in the location phase.

Perhaps before we go further we should take a closer look at the *variables that affect the location.* It is necessary to know what the variables are before we look for ways of reducing them to the common denominator. We can list the most important ones as follows:

traffic desire
land use
land cost
soil conditions
earthwork quantities
hydrologic conditions
stream crossings
geologic conditions
material availability
natural phenomena such as rainfall, snow, or fog
clearing and grubbing
others depending on conditions

It is believed that need exists for a method which will take each of the variables, or like groups of variables, analyze them separately as to the effect they will have on the engineering costs, and then reduce them to a unit cost per one hundred feet of length, for a road built using them. To clarify the method, we will look at some of the more important variables and show how they would be analyzed.

### LAND COST

Land cost is a relatively simple, straightforward variable which is easily represented using cost as the common denominator. First, a medium-scale base map of the area is obtained. This can be made by photogrammetric methods. Using this map as a work sheet, the land cost-estimator analyzes aerial photographs of the area, makes field trips, and obtains all possible sources of information. On this base map he then delineates the land costs of the different areas. He will be able to outline areas of equal cost. The number that is actually recorded on the map is the land cost per one hundred foot station of a highway running through this land.

Some assumptions will have to be made relative to the width of right-of-way and limits of taking. Also, it will be necessary to take into account the damages that occur when corners are cut off property holdings or access rights are infringed upon. Using this method either very detailed analysis of land costs or merely indicators of the general values can be obtained. For a first approximation, general values are all that are necessary. At a later time this base map will be gridded with an appropriate sized grid and the data punched into cards for computer reduction.

### SOIL CONDITIONS

With the aid of the rapidly expanding science and art of airphoto analysis, a good soils-interpreter would be able to translate the soils of the region into numerical values which would represent the cost of building on the material present, or the cost of replacing it with suitable material (4). The amount of work or expense involved to bring the sub-base to the required standards will vary with the quality of the material. By evaluating the soils with numerical values, it will later be possible, after computer analysis, to compare the poor soils of one region to the high land costs of another region and to be able to compare their relative values as a route location.

Airphoto analysis will be one of the most powerful tools available to the soils engineer during his survey of the ground. Using it he would be able to locate not only the type and quality of the soils, but also borrow material and gravel deposits. Unfavorable geological conditions, such as fault zones and slide areas, would be assigned high unit costs corresponding to the high cost of building on them.

All these land forms and soil changes would be located spatially in the stereoplotter and their unit costs placed on a base map, like that used for land costs.

### HYDROLOGIC CONDITIONS, DRAINAGE, AND STREAM CROSSINGS

The engineer who is responsible for the drainage section of the study would analyze the drainage conditions present and relate them to the cost of the road. He would then delineate them on his base map. In well-developed drainage systems, this would result in the selection of appropriate values for stream crossings, and for bridges and culverts. In poorly developed drainage, the cost of subdrains and remedial measures would be evaluated. Once again aerial photos would be the chief source of information, airphoto analysis the chief tool for analyzing the conditions as they exist and photogrammetry the spatial locator.

From each base map, cards will be punched containing the unit costs for use by the computer. Highway and railroad overpasses would be handled in this same fashion.

EARTHWORK

The volume of earthwork which will be necessary on any given project is highly variable and is usually quite difficult of determination until a location is chosen. The most desirable method for estimating earthwork in a system such as this would be one which would give the earthwork quantities at all points so that the best route could be chosen. A method such as this would be analogous to having the engineer stand at any point in the model and estimate, if a road was built through the place where he was standing, whether the grade-line would pass over his head or beneath him and how much. The engineer would estimate this on the basis of judgement.

Knowing the general direction from which the road was coming and knowing where it was headed the engineer would look in both directions and get an idea of about what the mean terrain elevation was. And, he would use this in his evaluation of the elevation of the grade-line.

This procedure may be duplicated to a certain extent by machine methods. A method for doing this which is different from the methods employed in the evaluation of the other variables might work in somewhat the following manner: If you have a three-dimensional model of terrain which has long slopes without any steep hills, a road could be built along the surface if the grade restrictions were not violated. In a model containing rough terrain a road could not be built along the surface because it exceeds the grade requirements. However, if this same terrain model could be smoothed in some manner, then it would be possible to build the road on the surface. This smoothed model could be compared to the actual model to obtain the amount of cut or fill at any point. The problem is that of smoothing the model so that the maximum grade requirements are not exceeded.

The first and most obvious method of smoothing the surface is by taking the mean elevation of the actual terrain model as the smoothed model. In this case the smoothed model would be a horizontal plane. If the two models were superimposed one upon the other, and differences between the two considered, then a positive difference would be cut and a negative difference fill. (See Figure 1.) Using this plane as the smoothed model would satisfy the grade requirements, but would cause too much cut in the hills and too much fill in the valleys. Continuing along this line of reasoning the mean elevation could be computed for smaller segments of the model, such as 2,000 foot squares. If the mean elevation, which is actually the surface of the smoothed model, were considered to be concentrated at the center of the square then it could be compared to a small section of the ground directly beneath it. If this segment or influence zone over which the mean terrain elevation is computed were free to move about, then the mean elevation of the zone would be constantly changing as the ground changed, but much more slowly. The smoothed model-surface would be the locus of mean elevations of the ground within the influence zone. If a large zone of influence were used, it would have the effect of greatly smoothing the actual terrain model while a small zone would have less smoothing effect.

After the elevation of the smoothed mean terrain surface has been established, it would be possible to subtract the mean terrain elevation from the actual terrain elevation to obtain the depth of cut or fill at any point. This can be done point by point with a digital computer. The steps in applying this system might be:

1. The terrain elevation would be obtained from contour maps at each point on a 100 foot grid along the area to be analyzed.

2. These data could be punched into cards and placed in a computer which had been programmed to perform the calculations.

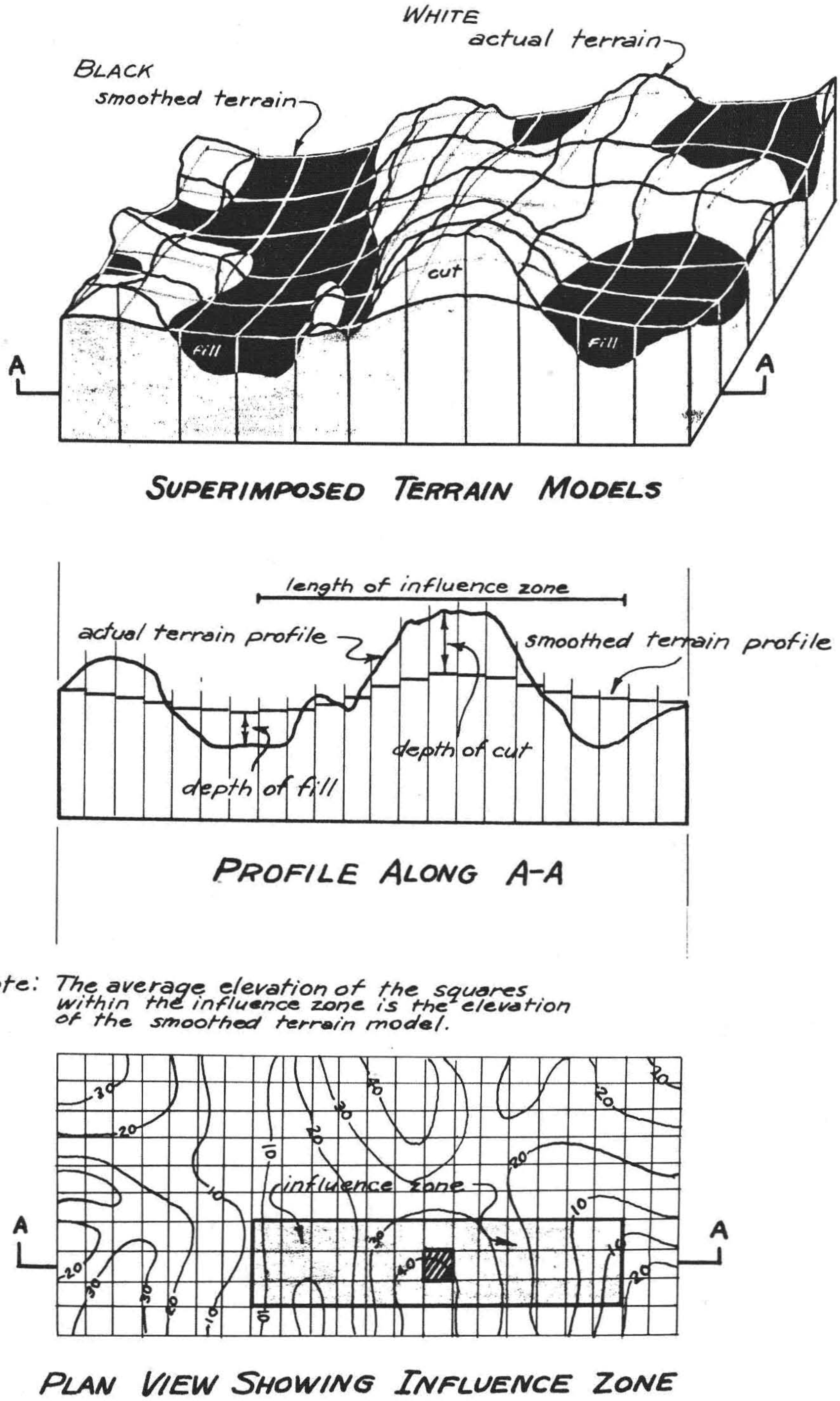
WHITE
actual terrain
BLACK
smoothed terrain
cut
fill
fill
A
A
SUPERIMPOSED TERRAIN MODELS
length of influence zone
actual terrain profile
smoothed terrain profile
depth of fill
depth of cut
PROFILE ALONG A-A
Note: The average elevation of the squares within the influence zone is the elevation of the smoothed terrain model.
influence zone
A
A
PLAN VIEW SHOWING INFLUENCE ZONE

FIG. 1

3. The computer would compute the amount of cut or fill at each point in the model, and then convert this figure into the cost of earthmoving at each point by finding the volume in cubic yards and multiplying by the unit cost per cubic yard.

4. The output cards containing these cost figures would then be integrated with the cost figures for the other variables.

Another very important variable in earthwork is the amount of rock-cut that has to be made. Rock-cut is very expensive and for that reason locations where rock will be encountered are undesirable. A well-trained airphoto-analyst can frequently make a very intelligent guess at the amount of soil cover there is at any particular place. Seismology is another means of bedrock location. If the airphoto analyst could place the depth to bedrock on the base map, then this information could be punched into cards with the terrain elevation and both earth and rock cut handled simultaneously by a special program.

#### TRAFFIC DESIRE

Traffic origin and destination is a very important factor in the final selection of a route. The desire between two cities will of course be a straight line between the two cities. The location engineer must know the amount that the actual route can deviate from true desire. It has been shown that the trip length in metropolitan areas averaged 25 per cent greater than the actual desire (5). Of course, the longer the trip the less desirable is local deviation from desire. The location engineer then must take into account the increased cost of vehicular travel and the resultant loss in time when the highways are planned. This can be done by setting up a desire map in which isolines have been placed around the additional cost of travelling. This whole isolinal chart may be multiplied by the number of cars expected to use the facility in order to obtain the total cost of driving the additional distance.

The isolinal chart is finally reduced to numerical values and placed on the base map. In many cases the engineer may find that this step is unnecessary because of the short length between terminal points.

#### OTHER VARIABLES

Variables other than those already considered will doubtlessly be important. Interference with present land-use is one that would have much weight in some cases. Another variable which should be considered in many instances is weather; snow or fog may hamper the highway and should be evaluated. Relocation of utilities may frequently constitute a considerable portion of the costs. All of these variables can be evaluated and shown on additional base maps.

### INTEGRATION OF RESULTS

The separate base maps, each one containing the analysis of one or two variables, are then gridded with a grid of suitable size. The grid coordinates would coincide on each map. These separate maps representing all the variables to be considered in the route location would be punched onto punched cards or on punched paper tape for use by the computer. The number representing the cost per one hundred feet for a highway would be placed in each grid on the computer. The computer would then add all the variables for each coordinate and obtain totals at each coordinate point and store them for future use. The sums of the variable could be shown as a complete map of the study area containing isolines or contours of equal costs. Or if the preference is to let the imagination wander, then it could be shown as a relief model, where the relief is cost instead of elevation (see Figure 2). The valleys of the model would represent points of low cost, and high costs would be represented by mountains or hills. The total cost of building a road between two points would be the area under the line connecting the two points.

If the study has been made for route reconnaissance, one can pick the band of least cost from the model by inspection. In most cases a more detailed analysis would be made by the computer. Using linear programming techniques the computer can be made to pick the most economical path through the model given the alignment specifications as the limiting criteria.

The relief model, as produced by the computer, would be very flexible. The variables could be studied independently or in any variety of combinations. The method is also quite flexible. It can be undertaken as a very detailed study of all variables, or it can be very sketchily and quickly done. The important elements in the system are the ability to gather a lot of

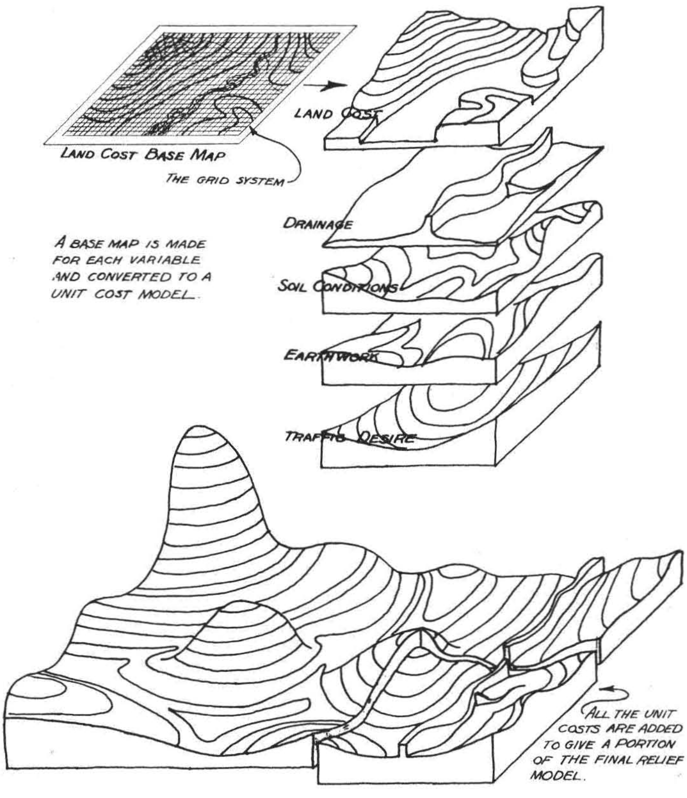


FIG. 2. Final economic relief model.

data quickly and easily, and the ability to assimilate and reduce the data to a form which is more easily worked by the highway engineer. Photogrammetry and airphoto-analysis make possible this quick and detailed data gathering and analysis. Computers make integration of obscure data possible. Together they make feasible a method which would greatly aid the highway engineer who is searching for an optimum location.

Today's world is rapidly becoming a world of specialists. Projects have become so large that it is impossible for one man to do all the work. A method such as described in this paper would lend itself to the highway route location engineer who can surround himself with a staff of specialists. It makes possible a more integrated design. There can be more communication between members of the staff. A method of this nature lends itself to the planning of large controlled access highways like those currently being proposed by the Bureau of Public Roads as a part of the interstate highway system. It is more applicable to rural than to urban location problems; however, portions of the system might be adapted to help clarify urban planning.

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