AN INTEGRATED SYSTEM OF HIGHWAY LOCATION ANALYSIS USING PHOTOGRAMMETRY AND ELECTRONIC COMPUTERS

by

Paul O. Roberts, Jr.
B.S., Agricultural and Mechanical College of Texas, 1955

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science

at the

Massachusetts Institute of Technology

June 1957

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Cambridge, Massachusetts
May 20, 1957

Secretary of the Faculty
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Cambridge 39, Massachusetts

Dear Sir:

In partial fulfillment of the requirements for the degree of Master of Science, I submit this thesis entitled: AN INTEGRATED SYSTEM OF HIGHWAY LOCATION ANALYSIS USING PHOTOGRAMMETRY AND ELECTRONIC COMPUTERS.

Respectfully submitted,

Signature redacted

Paul O. Roberts, Jr.

ABSTRACT

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Submitted to the Department of Civil and Sanitary Engineering on May 20, 1957, in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering.

The object of the thesis was to explore the possibilities of entirely new approaches to the problem of locating modern highways. The synthesis of a possible new system of data procurement, evaluation and presentation was attempted. The variables which influence highway location were analyzed and summarized. Conventional methods of approach were evaluated and new equipment and techniques were reviewed. These new tools were then used in the development of a new system for locating highways. A test project was used as a means of developing the system.

The scope of the thesis has been limited to exploring and experimenting with new methods of highway location analysis and not the development of a completely practical and operational system. The emphasis has been placed primarily on rural rather than urban location.

Two major conclusions can be drawn from this study. First, using the system as conceived it is possible to determine the costs for a road built in any location and to find the cost for the road built on the optimum location. Secondly, the practicability of the system can be evaluated only after a full scale test project has been performed to determine if the savings will be significant.

Thesis Supervisor: Charles L. Miller
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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to Professor Charles L. Miller for the help and guidance which he has given in the preparation of this thesis. His ability to inspire has been a constant source of aid and encouragement. His willing cooperation has made this thesis possible.

Akcnowledgement is made to the Joint Highway Research Project of the Massachusetts Institute of Technology and the Massachusetts Department of Public Works for the financial backing which they provided. A special thanks is given to the personnel of the Joint Highway Research Project, especially Egons Tons, Siegfried Breuning, and Kenneth Weiner, for their ideas and encouragement and to Mr. James Freeman and Mr. C.E. Whitcomb of the Massachusetts Department of Public Works for the assistance and information which they contributed.

A special thanks is given to Mr. D.R. Schurz and Mr. D.H. Robbins of the M.I.T. Photogrammetry Laboratory for the helpful ideas and suggestions which they offered and to Mr. Arliss Whiteside of the M.I.T. Electrical Engineering Department for the ideas which he contributed.

Thanks are also extended to Professor Saul Namyet, Professor A.J. Bone, Professor T.W. Lambe, Professor James Roberts, Professor A.S. Lang, Professor J.M. Biggs, and Professor H.P. Aldridge of the Civil Engineering Department and to Professor J.T. Howard of the City Planning Department for the technical assistance which they provided.

Finally, the author would like to thank Miss Bette Anne Farmer for her cheerful cooperation in the preparation of the manuscript.

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The scope of the thesis has been limited to exploring and experimenting with new methods of highway location analysis and not the development of a completely practical and operational system. The emphasis has been placed primarily on rural rather than urban location.

1.4 Conclusions

Two major conclusions can be drawn from this study. First, using the system as conceived it is possible to determine the costs for a road built in any location and to find the cost for the road built on the optimum location. Secondly, the practicability of the system can be evaluated only after a full-scale test project has been performed to determine if the savings will be significant.

2 STATEMENT OF THE PROBLEM

2.1 Introduction

In the past few years the demand for new roads has increased considerably. The recognition of this demand is reflected by the Congress of the United States in the enactment of the Federal Highway Act of 1956. This demand has also created a problem for the highway engineer. He must now plan and construct these highways under the pressure of time. While the demand for highways has increased, the location problem has become more complex. With the rising costs of land the engineer is steadily being forced to use less desirable locations. Since 1952 the cost of right of way in California has more than tripled, and since 1945 the amount spent for right of way has increased from $7,110,224 to an estimated $160,000,000 for 1957-1958. (9) In addition, the public demands highways of higher standard today than ten years ago. These demands have combined with higher construction costs to increase the costs per mile of a highway. (34)

Limited access express highways place a stringent requirement on the engineer that the facility be located optimumly both from the standpoint of construction cost and traffic service. To determine the optimum 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 extensive. In fact, it is generally the limiting factor in approaching the optimum location. With conventional procedures, it is not practical to evaluate more than a relatively few solutions. Also with conventional procedures it is necessary to work with trial lines in spite of the fact that there are theoretically an infinite number of possible locations. Today's highway should have a careful consideration of the influencing factors in order to determine the most economical location. In order to do this the engineer must become aware of and must be ready to use any new tool or process which allows him to gather and analyze more data before he makes his decisions.

2.2 Highway Location Factors

Before major consideration is given to the problem of applying new tools to highway location a short study should be made of the factors which help to influence location. For convenience they may be grouped as follows:

- Traffic Factors
  - Volume
  - Type
  - Origin-destination
  - Service
- Highway Geometric Design Criteria
  - Alignment
  - Grades
  - Clearances
  - Space requirements
- Land Factors
  - Land use
  - Land cost
  - Economic disruption costs
- Planning Factors
  - Changing economic patterns
  - Future conditions

Maintenance of desirable city units

Land development

Psycological factors such as avoiding national parks, shrines or cemetaries

Public relations

Political influence

Construction Factors

Grades

Earth and rock excavation quantities

Stream crossings

Road and railroad crossings

Soil conditions

Material availability

Geologic conditions

Hydrologic conditions

Variable natural phenomena

The relative importance of the factors varies from one to the next. Traffic service is one which has steadily increased in importance. The feasibility of a project rests on its ability to provide this service. Public relations and psycological factors are also important. The most important factors, however, are those which have bearing on the economic justification of the project. Once the decision to build a highway has been made and the termini selected it is largely those factors which are related to the cost of the project which determine the final location. Political influence is a factor which seems to be unavoidable in many instances.

2.3 Data Collection

The job of data collecting has completely changed character since the early days of highway location. Because of the scarcity of maps and particularly lack of adequate topographic maps it was necessary to do most of the location analysis by on-the-spot field evaluation (2). Obviously this method has the severe disadvantage of limited vision. The field engineer has available none of the devices or techniques for evaluating the effects of a slightly different décision.

The development of topographic maps by the U.S.G.S. made possible more careful preliminary analysis of routes before field work was begun. A topographic map did not, however, give the location engineer all the information he needed. Soil conditions could not be obtained and in this respect the office engineer was more limited than the field man. The office engineer had to use small scale topographic maps with larger scale planimetric maps, geologic maps, and tax maps and supplement them with various kinds of data wuch as flood levels, rainfall, drainage areas, traffic engineering reports, boring records, and recent bid tabulations.

The development of aerial photography and more particularly the more wide-spread use of photogrammetry to compile topographic maps has aided the location engineer (5). These developments have enabled more of the location work to be done in the office. Data collection need no longer be a time-consuming, laborious process.

2.4 Data Presentation

No effort is currently being made to present all of the location data simultaneously in a manner in which the highway locator and his team of specialists can conveniently evaluate it and select the best route. This could be conveniently done by resolving all the location factors into one variable so that the decision could be made more easily.

2.5 Review of Current Work

Conventional Practice: There is considerable variation in conventional highway location practices. As a hypothetical case we might list the following steps as being typical of current location procedure.(5)

1. A traffic engineering study of the situation is made. The volume and location of desire is analyzed and evaluated and the results indicate that a highway should be built to satisfy this desire.

2. Preliminary route location studies are begun using small scale maps. Major points to be connected are decided upon.

3. U.S.G.S. maps are used to pick alternate routes. At this time aerial photography of any available scale is used. The alternate routes are narrowed to the best 2 or 3 by careful study. This study might include the rough estimation of earthwork quantities by scaling from the maps, approximate land cost comparisons, surveys of the foundation conditions of the various routes, or an analysis of the costs of the structures which will be encountered. In most cases the majority of the narrowing will be done on the basis of experience and judgement.

4. Aerial photography at a medium scale is taken from which photogrammetric topographic maps are made to a scale 1 inch = 200 feet with a 5 foot contour interval. Using these photogrammetric maps and using the aerial photographs as stereopairs the actual locations are established rather closely. At this time the earthwork on the various alternates is compared and the preliminary price estimates for the route worked up.

5. Aerial photography at a large scale is taken from which topographic maps are made to a scale of 1 inch = 50 feet with a 2 foot contour interval. These maps provide the data for the preparation of final plans and cost estimates. Final changes are made in alignment and grade, field parties

stake the final location, and construction bids are let.

It can be seen from the foregoing steps that the location phase is rather difficult to isolate from the design phase. But, in general, it might be said that the location analysis was virtually complete when the highway was located within the nearest 100 feet. This definition will depend on whether you are working in extremely variable conditions like urban location or in rather homogeneous rural conditions.

Current Research: At the present time considerable effort is being put into the problem of figuring earthwork quantities using photogrammetry and computers. (4), (41) In this type of system the computer essentially designs the road template given some guiding instructions and figures the quantities using terrain information as obtained from the stereomodel. The computer is so fast that several runs can be made and alternate routes can be compared quite easily by figuring the earthwork quantities for each alternate. It should be noted that in a system such as this the location analysis has been previously done and all that remains to be compared is the earthwork quantities. This system also has the limitation of having to work with finite alignment locations and with previously specified grades. It cannot select the best possibility, but merely has to compare two or more proposed possibilities. It can be concluded that this type of system is most valuable when used as a design tool or as an aid to location, but not as a location tool by itself.

Further research should be devoted to synthesizing a system which will consider the problems of location from a location rather than a design standpoint. Emphasis should be placed on selecting the best route out of the range of possible routes. A system if developed should satisfy the following criteria:

1. The system must consider the full range of location possibilities not just alternate routes.

2. It should select the optimum route out of the full range of possibilities.

3. It should give the location engineer a chance to check and use judgement in eveluating the results.

4. The system must be able to affect savings in the location in order to justify its use.

5. The system should be flexible and readily adaptable to different types of solutions and to different location needs.

3. APPROACH TO THE PROBLEM

3.1 Available Tools

In the past few years much progress has been made by scientists and engineers in the development of new tools. The professional engineer must reevaluate his problems frequently in order to ascertain for himself if any new tools are available which allow him to exercise his function faster, cheaper, or more efficiently. Air photo analysis, photogrammetry, and electronic computers are three of the new tools which fall into this category for the highway engineer.

In the last few years the development of computers, both digital and analog, has been so rapid that the highway engineer now finds he has a very efficient machine available for the reduction of large masses of data. Aerial photography has developed to the point where it is already being widely used by locators and designers. Although photogrammetry has already built up a well-established history, its full potential as a data collection system is just now being realized. Another tool which has developed very rapidly during the past decade is air-photo analysis. It has been used almost as long as aerial photos have been in existence, but now recent advancements have brought it to a stage where it is an extremely useful tool. Other tools which are being used by civil engineers for the first time in routine practice are geophysical and resistivity methods of subsurface ground exploration. (27) New surveying instruments and electronic surveying equipment which is being used more every day and the new reproduction techniques which are making possible easier copying of material might also be included in a list such as this. The potential for developing the new tools and methods which the engineer needs to perform his work is still untapped. New advances in the next few years will continue to add to the stock of tools available to the engineer.

3.2 Over-all System Components

From the list of new tools which has been presented it is possible to select those tools which would logically fit into an integrated system. What is wanted is essentially:

1. A data collection system
2. A quantitative data system
3. A qualitative data system
4. A data reduction and evaluation system
5. A data presentation system

Aerial Photographs: Since the data that is recorded on aerial photographs is a permanent record of the conditions that existed on the ground at the instant of exposure aerial photographs could function as the data collection system. Aerial photographs of the ground are easily obtained. The recording of detail is limited only by the resolution of the film. This can be controlled to a great extent by controlling the flight height. In addition photographs have the advantage of presenting the data in a visual form. The observer has a position advantage over the field observer in that he can observe over a wider area. By varying the scale of the photograph, detail can be presented in varying degrees of complexity.

Photogrammetry: A quantitative measuring device is obtained by using photogrammetry. Measurements can be made to almost any desired accuracy. The accuracy is directly related to the cost, but the cost is still well below that for field methods. The measurements can be presented in several conventional ways. The needed measurements can be made directly and recorded as numbers or they can be recorded on planimetric or contour maps and extracted as the engineer needs them. Another possible method of recording would be to tabulate the elevation at matrix points. Photogrammetry has already made its impact on highway location and design. (40). It is now a fully recognized method of obtaining the data measurement necessary for highway location and design.

Air Photo Analysis: Air photo analysis is the extracting of the data needed for location and design purposes from aerial photographs. In the integrated system it could become the qualitative data measurement system. Engineers are discovering that much of the valuable information necessary for location can be obtained from aerial photos by air photo analysis. As it was previously pointed out the aerial photo contains detail to any desired complexity depending on the scale. Therefore, the amount of information that can be obtained from good aerial photos is limited only by the skill and ability of the interpreter. Air photo analysis can give the location engineer such important information as: (50)

Land use

Property lines (in many instances)

Location of places that will be subject to loss of access or
property damage

Type and use of buildings

Approximate value of property and buildings

Geology

Soil distribution and properties

Sources of borrow and aggregates

Rock outcrop

Location of peat bogs, landslides, and other problem areas.

Drainage characteristics and requirements

Good bridge crossings of streams and rivers

Clearing and stripping amounts

Location of access and construction roads

Location of utilities and under some conditions pipelines and underground facilities

Electronic Computers; Because of their speed and flexibility electronic computers are perfectly suited to function as the data reduction and evaluation system. Computers are relatively new in civil engineering, interest in their application having developed primarily in the past year. Even this short amount of time has been sufficient to demonstrate the potential use to which the computer can be put. At present, most of the high-speed digital computers have a large storage capacity (between 1000 and 4000 words) and speeds in the range of from 1 to 50 microseconds per operation. This is adequate for most of our present problems. The cost of problems solved on these machines is very samll considering the number of operations involved. There is every reason to believe that growth in data handling capacity and speed in the near future will be as phenomenal as the present growth and that the costs of computer reduction of data will continue to decrease.

3.3 Cost as the Common Denominator

As subjects become increasingly more complicated, engineers find it convenient to break them down into their component parts and to analyze the parts spearately in terms of a common unit. This method seems to be particularly applicable to highway location. The important thing is to select a common unit or a common denominator, as it might appropriately be called. It appears that using cost as the common denominator would be feasible. Cost is a recurring variable in engineering studies. The solution which is being sought is the most economical solution which conforms to the performance specifications. Locations on which it is necessary to move large volumes of earth are undesirable because of the high cost of excavation. High land costs are also indicative of undesirable locations because the highway is displacing expensive commercial or residential functions. If we analyzed each possible route in terms of costs we should have a method of comparing two routes or for picking the best route out of the infinite number which are possible. It will be found later that a cost per unit of length of roadway will also be convenient to work with, because it can be evaluated at each point on the road.

3.4 Highway Costs

Highway costs can be analyzed and approached in many different ways. For the purpose of this thesis the costs considered will be confined to those costs usually placed under the headings "right-of-way costs" and "construction costs." Financing, legal and administrative expenses do not effect the location of the highway and can be disregarded.during the location phase. Because of the method in which the costs of building the highway are going to be evaluated and because of the logic of this kind of approach the costs will be broken down 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 roadway

Pavement - The cost of surfacing the roadway

Structures - The cost of crossing streams, roads, and railroads

Additional - The miscellaneous additional costs which contribute to the cost of the completed highway

It is interesting to look at the costs of several of the turnpikes built in this country during the last few years. A table which has tabulated cost per mile and percentage of total cost is presented as Figure 1. It is impossible to predict trends from the table, but the relative magnitudes of the various costs can be seen. As expected, right of way costs varied all the way from 3 percent to 20 percent, but even the figure 20 percent is low for urban highways. Earthwork, pavement and structures costs varied widely but always remained a considerable portion of the total. The other construction costs, of which land perparation was a portion, remained consistently less than 10 percent of the total. The table illustrates the fact that great variations in highway cost are present and that significant savings can be made by selecting the optimum location. The table also shows which costs are important and their relative importance. The thing which the table does not show is how much the location selected using present location methods can be improved upon.

Costs are a bit deceptive to analyze. For instance, in many cases it would appear that the price estimates which are worked up for a particular job are completely independent of the soil conditions. Therefore, it would be no less expensive to build on a soil with good working conditions than building on a soil subject to poor conditions. However, the bids which are submitted have taken into account the fact that poor soil conditions exist and are therefore larger. This sort of condition exists today with regard to pavement design and makes comparison of the costs and the variables very difficult.

FIGURE 1

COSTS PER MILE FOR RECENTLY BUILT TURNPIKES IN THE U.S.

ITEM	MASS. TURNPIKE	NEW JERSEY TURNPIKE * NORTH SECTION	MAINE TURNPIKE	NORTH-EAST EXTENSION PENN. TURNPIKE	OHIO TURNPIKE	RICHMOND TURNPIKE	ILLINOIS TOLL-HIWAY	WEST VIRGINIA TURNPIKE	TEXAS TURNPIKE	OKLAHOMA TURNPIKE	KANSAS TURNPIKE	SUNSHINE STATE PARKWAY (FLORIDA)
LENGTH	123 MI.	30 MI	66 MI	110 MI	241.4 MI	34.7 MI	193.3 MI	88 MI	30 MI	89 MI	236 MI	104 MI
WIDTH	4 LANES 6 FOR 12½ MI.	4 LANES & 6 LANES	4 LANES	4 LANES	4 LANES	6 LANES	4 LANES & 6 LANES	2 LANES	6 LANES VARYING WIDTHS	4 LANES	4 LANES	4 LANES
RIGHT OF WAY	74000 5.8%	166.500 5.5%	27.300 4.8%	87.600 6.6%	46.491 4.9%	308.900 21.5%	268.000 17.5%		284.000 19.7%	18.600 3.7%	31.400 6.7%	52.800 11.2%
EARTHWORK	482.700 37.7%	1.011.767 33.4%	147.900 25.8%	472.000 35.5%	300.751 31.1%	158.500 11.1%			394.000 + DRAINAGE 27.4%		82.600 17.7%	88.800 19.5%
PAVEMENT & DRAINAGE	310.000 24.2%	288.333 9.5%	203.900 35.6%	353.000 26.6%	238.611 25.5%	239.900 16.8%	ALL TOGETHER 1.220.000 INCLUDING BUILDINGS AND BRIDGES		296.000 NO DRAIN. 20.6%	ALL TOGETHER 479.300 94.4%	225.000 48.3%	138.000 29.7%
STRUCTURES	383.800 30% 2 MAJOR BRIDGES	1.414.933 46.8%	177.800 31.1%	349.000 26.3%	326.710 35.0%	658.500 46.1% +2 MAJOR BRIDGES			376.000 26.2%		97.000 20.8%	146.000 31.3%
OTHER CONSTRUCTION COSTS	29.300 2.3%	144.500 4.8%	15.200 2.7%	66.700 5.0%	22.935 2.5%	64.300 4.5%			89.000 6.1%	9.800 1.9%	30.800 6.5%	38.900 8.3%
TOTAL COST PER MILE	1.279.800 100%	3.026.033 100%	572.100 100%	1.328.300 100%	935.499 100%	1.430.100 100%	1.488.000 100%	895.454 100%	1.439.000 100%	507.700 100%	466.800 100%	464.500 100%

* TOTAL TURNPIKE LENGTH: 163 MILES. TOTAL COST PER MILE: 1.362.000
COMPILED FROM REFERENCES 32, 35, 42, 43, 44, 80 AND FROM BOND PROSPECTUSES

One approach to the problem of comparing one route possibility to another in order to obtain the optimum route would consist in evaluating the effect of the different location variables on each one of the costs of a road per unit of length. The cost values estimated from the aerial photographs using air photo analysis would be computer reduced to produce the total costs per unit of length for any road built over the variables. The best road would then be picked from all possible routes by the computer and its cost obtained by adding unit prices over its entire length. The methods to be used in doing this are described in the next section.

4. PROCEDURE

The preceding sections have been primarily concerned with demonstrating a need for an integrated location system and the principles upon which it would operate. It is the purpose of this section to present the details of such a system and the techniques of applying it.

4.1 System Steps

The steps which would be used are approximately as follows:

1. Fly photography. The scale of the photography should be commensurate with the type location analysis which is being performed. The smaller the scale, the larger the area which is under consideration, the less the detail and the more approximate the methods used in estimating the cost. A more detailed analysis of scales is covered in Appendix 1 under grid sizes.

2. Assemble the aerial photos into a stereo air photo mosaic. This is accomplished by removing every second picture from the flight strip and mounting them on a stiff board on which they are oriented carefully with the overlaps matched. The pictures which are not mounted can be placed beside the mounted picture and viewed with a pocket stereoscope to produce a stereomodel of a portion of the terrain. The stereoscopic overlap of the photos must be greater than 50 percent in order to make this possible.

3. Using clear celluloid overlay sheets and a grease pencil each of the costs is evaluated. The air photo mosaic can be clearly seen through the celluloid acetate sheet. It was found to be quite satisfactory to place the loose picture of the stereopair above the acetate and to do all the marking on the acetate which covers the mosaic. One of these overlay sheets is made for each of 6 different cost categories. The methods of evaluating these costs are presented later.

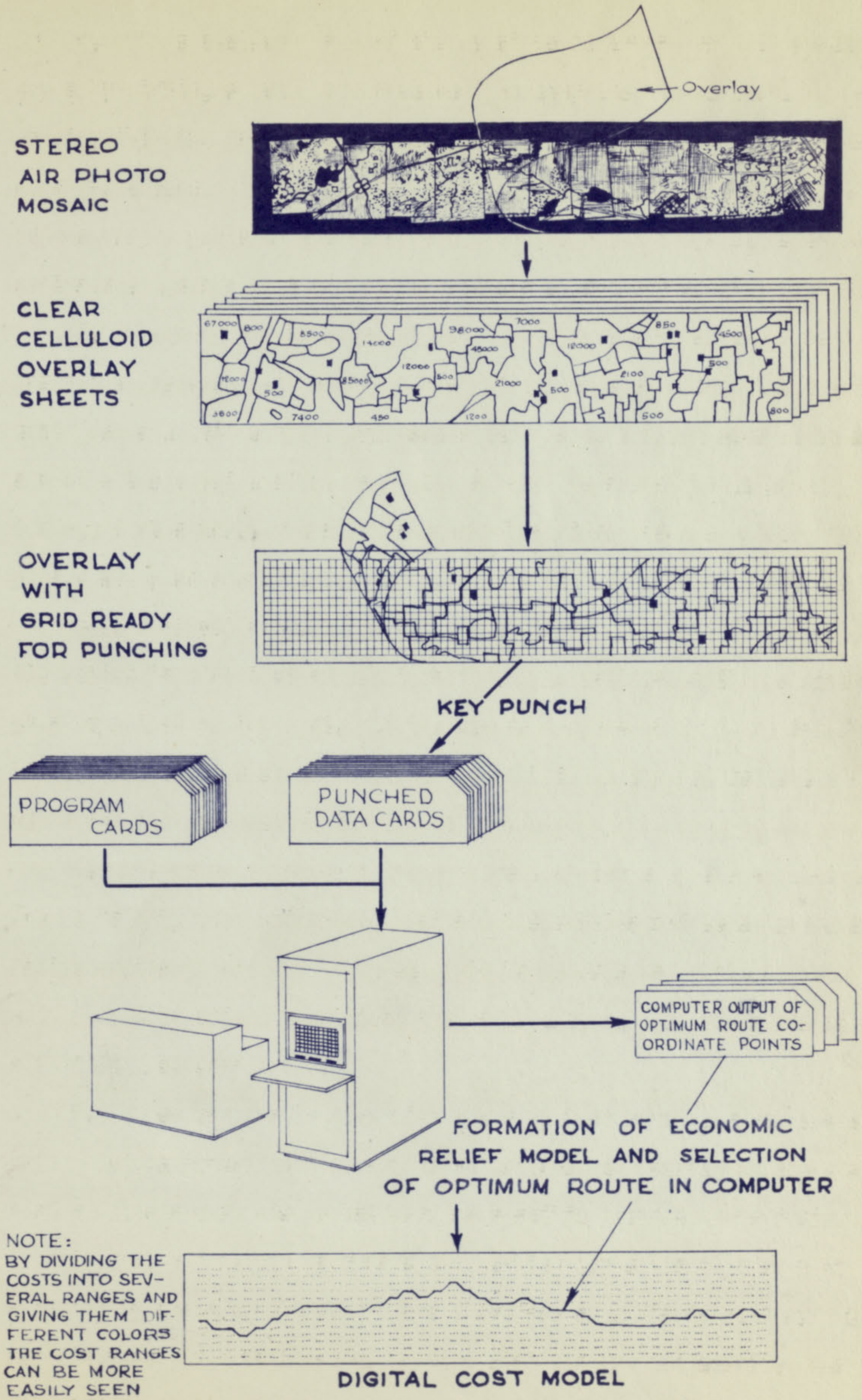
4. The costs from each of the overlays is transferred to punched cards by placing a grid over each and punching the values recorded on the overlay into the card at each grid point. The grid used can be a series of squares traced in ink on a separate overlay sheet. The size of the grid square depends on the area or length for which the cost is to be evaluated. An analysis of grid square sizes is included as Appendix 1.

5. The punched cards are placed in a computer where the cost variables for each grid square are added together to obtain the total cost for each grid square. The value that is in the computer at this stage is the total cost at each grid square for a road built going through that square. These sums can be visualized as a complete map of the study area containing isolines or contours of equal cost. Or even more realistically, they may be visualized as a relief model where the relief is cost instead of elevation. The valleys of the model represent points of low cost. High costs are represented by mountains or hills. The total cost of building a road between two points is the area under the line connecting the two points.

6. A copy of this model is punchedout of the computer so that it can be used by the engineer to evaluate the results and to show the relative values of all routes which might be under consideration. The method of converting the digital output of the machine into a visual output is discussed later.

7. A program designed to pick the very best route through the terrain model is placed in the machine and allowed to operate on the cost data. Analog methods were also considered as possible methods of producing the terrain cost model. In many ways the problem lends itself very well to solution by analog methods, however there are some disadvantages. These are discussed in detail later. A pictorial diagram illustrating the integrated system is shown as Figure 2.

FIGURE 2 PICTORIAL DIAGRAM OF SYSTEM



4.2 Analyzing the Cost Factors

Test Project: It was felt at the outset of this thesis that the use of an actual test location for evaluation by this system was desirable. For this reason a test section approximately 5 miles long was selected on the relocation of Massachusetts State Route 28. The section selected was in the Reading and Wilmington U.S.G.S. quadrangles north of Boston, Figure 3. This route was picked because of its convenience for field inspection, and because of the availability of several scales of aerial photographs which had been used by the Massachusetts Department of Public Works in the relocation studies of Route 28. The problems that were encountered in applying the system proved to be invaluable in making the establishment of technique possible.

The selection of such a short section of a route automatically limited the scope of the investigations to a rather detailed location study instead of a more hasty general study over a larger area. This was not undesirable because a general study is done in the same manner as a detailed study. It was also decided in the selection of this route that only the aspects pertaining to rural and to suburban type location would be considered. It is felt that urban location will have to be handled in a slightly different way. This tended to limit the conditions of the study to those of a controlled access highway in mostly rural surroundings.

Photography: The photography of the test section was obtained in three scales: 1:20000 from the U.S.D.A., 1:9600 flown by Jack Amman for the Massachusetts Department of Public Works, and 1:4800 flown by Fairchild for the Massachusetts Department of Public Works. Because of the convenient size and because of early availability, the 1:9600 photography was most used. It was found to be ideal for most of the uses, however it did have

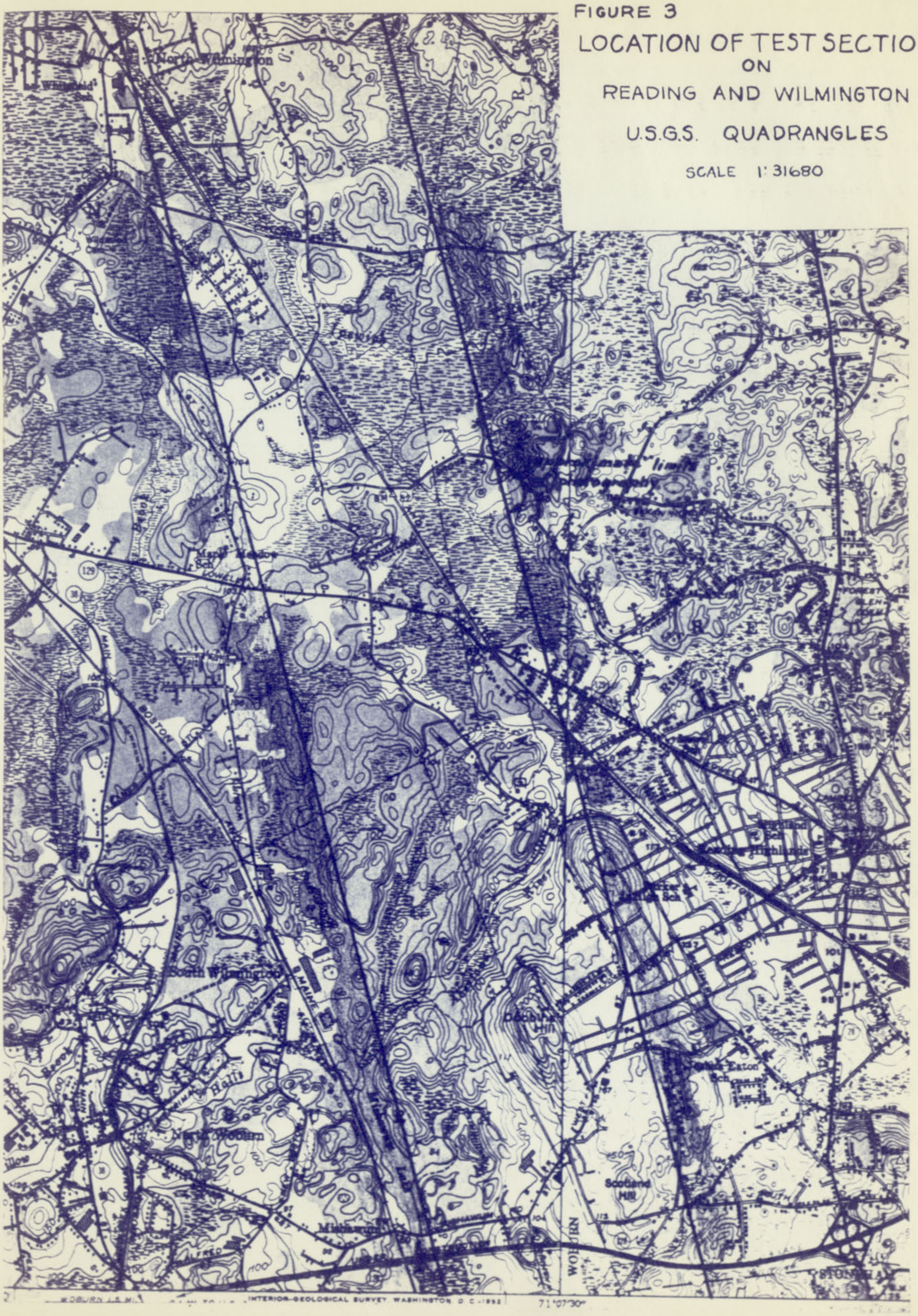


FIGURE 3
LOCATION OF TEST SECTION
ON
READING AND WILMINGTON
U.S.G.S. QUADRANGLES
SCALE 1:31680

some disadvantages and it was found helpful to supplement the information obtained with that from both of the other scales. Figure 4 is a portion of the air photo mosaic used in the examination of the 5 mile test section. The 1:9600 photography was used in its preparation. An even smaller section of the mosaic will later be shown as background for the mosaic overlays which illustrate the manner in which costs are assigned.

Method: As previously stated, each of the cost factors was analyzed and recorded on an overlay sheet. The cost of building the highway through a 200 foot square was the basic unit. This is the cost for acquiring 200 feet of right-of-way in the case of the land cost overlay and the cost of bridging a river spread evenly over the grid square on the structures overlay. Since the costs depend upon the type highway which is being considered, the following assumptions were made relative to the geometric design.

1. The route to be located is a 4-lane divided, controlled access, highway.

2. The cross section is considered to be essentially the same in all sections. For fills less than 10 feet deep 4:1 side slopes were assumed. 2:1 slopes were used when the fills exceeded 10 feet and on the slope of cut sections in earth.

3. Alternate solutions on the same location, such as the use of either structure or embankment for a particular location, were not considered. One of the possibilities was eliminated before the costs were evaluated.

In the sections that follow each of the cost factors which contribute to the total cost will be analyzed separately. First, a general discussion will condider the broader aspects and then specific reference

FIGURE 4
AIR PHOTO MOSAIC

RELOCATION OF ROUTE 28

FLOWN DEC. 3 1952 BY
JACK AMMAN PHOTOGRAMMETRIC ENGRS
PART OF CONTRACT 5244 FOR MASS. D.P.W.

will be made to the Route 28 example. Only a portion of the original overlays will be presented so that the reader can get an idea of the problems encountered. A section approximately 7000 feet long is shown in each overlay.

4.3 Land Costs

Land appraisal is an art in itself, and for that reason the highway engineer generally obtains someone who is skilled in the art of appraisal to do the work for him. A preliminary location has usually been established at the time the appraiser is first called into the job. It seems that this is the wrong time to consult the appraiser. He should be allowed to help select the route location. Land costs vary so widely that over even a short section of the highway it is sometimes necessary to ask the advice of several appraisers. Therefore, it seems desirable to have some method of incorporating the land cost data which the appraiser or group of appraisers is capable of producing into the complete highway design.

Appraisal methods are varied depending on the requirements, however, they could be divided into essentially three types:

1. Horse back appraisal in which the appraiser takes field trips and makes estimates of the land costs which he records directly on the plans.

2. A detailed appraisal on which the final estimates are made. This method involves field trips, building measurements, reference to tax maps and to recent sales and is performed on the route actually selected.

3. The actual negotiation leading to the sale of the property and the settlement of damages.

The method which most closely fits the purpose of the highway location engineer is the horse back appraisal. This method would allow an appraiser to quickly estimate the costs over a wide area. In fact, an appraiser already familiar with the area surveyed would be able to delineate the areas and costs on the stereo airphoto mosaic overlay with a minimum of field trips. The appraiser who was unfamiliar with the terrain to be analyzed would be able to make some studies and field trips and would be able to extrapolate the findings which he obtained in the study areas to the whole area to be considered by using the stereo photographs.

It is necessary to be able to handle 3 phases of land costs. First, the cost of the land without buildings. Land costs depend on many things, principally the land use, availability of road access, type and quality of land, proximity and relationship to metropolitan areas and adjacent land uses. Many of these features can be recognized and evaluated from the aerial photos. Within limited areas many of these influences are relatively the same for all pieces of land. If this is the case a table of typical costs for different land uses and positions can be used to help decide the cost of the land which is being evaluated.

Secondly, the cost of buildings enters in. It is common practice to evaluate the cost of land and building without separating them. In this case it becomes more convenient to separate them. The way buildings are handled in the system is to (1) delineate a group of buildings by circling them with a grease pencil, (2) evaluate the land cost per acre on the basis of the land use and other factors, (3) evaluate the average cost of buildings and multiply by the number to obtain the total cost (the total cost of all buildings may be evaluated directly), (4) divide this total cost by the area which is circled to obtain the unit cost of buildings over the area, (5) add this unit cost of buildings to the unit cost of the land to obtain the total unit cost. This procedure is analogous to taking the concentrated cost of buildings and spreading it evenly over the entire area which contains buildings.

The third thing to be considered is the cost of land damages. (12) Damages are very nebulous things and are very difficult to evaluate. Land damages are usually more severe on small parcels than on large parcels. Also, small parcels tend to be the most expensive on a unit cost basis. One possible method of accounting for damages is associated with the sales procedures. If the land and/or buildings are purchased by the state or agency concerned then the damages may be considered to be resolved by the resale of the building to be moved to a new location. In the case in which there are no buildings, the appraiser should add to the unit price of the land the costs which he considers to be appropriate to cover the damages.

On Route 28, opinions of various experts were asked and from their advice the following table was set up to help in evaluating the cost of the land. The unit of cost selected as the one for recording land cost was dictated by the size of grid used. Since the grid used was 200 feet on the side, this gave an area of 40,000 square feet, which is slightly under an acre. Therefore, the price recorded was the price per acre. It was felt that the figure obtained was in this way slightly conservative.

Industrial Land	$15,000 - 65,000 per acre
Commercial Land	8,000 - 65,000 per acre
Residential Land	5,000 - 15,000 per acre
Potential Residential Land	1,200 - 2,000 per acre
Farm Land	1,000 per acre
Pasture Land	200 - 1,000 per acre
Waste Land	50 - 100 per acre

The price of buildings is usually recorded in cost per square foot. It is rather laborious to scale building measurements off of aerial photographs. It was found that a sampling procedure could be resorted to. A rough approximation of the total can usually be made by the appraiser on the basis of judgment. The following collection of prices was taken from several references and adjusted to current prices by consultation with the Right of Way Division of the Massachusetts Department of Public Works. (8), (10), (13).

The test section contained mostly private residences, green houses and sheds and for that reason these prices are the only ones presented.

Residences	10 - 16 $/sq. ft.
Filling Stations	15 $/sq. ft.
Cheap Auto Shops	2 - 3 $/sq. ft.
Barns and Sheds	3 - 5 $/sq. ft.
Greenhouses	2½ - 3 $/sq. ft.

Using the costs presented above the land was evaluated and the values placed on the overlay shown in Figure 5. No allowance is made for the land occupied by roads. Its value is established later on the structures overlay. One problem which was encountered was what to do in the case of isolated houses and farms. They occupied such a small space that most could be contained within one grid square. Since it was unfeasible to individually evaluate each of the costs and write it so small they were assigned a blanket cost of 20,000 dollars per house. This included the acre of land on which it is placed. Isolated houses of this nature are delineated on the overlay by a white square over the building. The element of simplicity, especially for the card puncher, was felt to be desirable.

FIGURE 5

AIR PHOTO MOSAIC

LAND COST OVERLAY

RELOCATION OF ROUTE 28

FLOWN DEC 3 1952 BY
JACK AMMAN PHOTOGRAMMETRIC ENGRS
PART OF CONTRACT 5244 FOR MASS. DPW

Two problems were encountered at this point. These were (1) the errors introduced when curved lines are approximated by square corners, and (2) the problems associated with using 5 and 6 digit numbers as a recording device. Both of these problems will be treated later under methods of output and presentation.

4.4 Land Preparation Costs

Land preparation costs are the costs for the process of readying the land for the construction of the roadway. These costs are principally clearing and grubbing. The costs associated with the preparation of land are generally rather small when compared to other costs. They can be easily delineated on an overlay. If necessary clearing costs can be divided into several price ranges. The amount of stripping can also be isolated by using steoeoscopic pictures and by identifying the grass type. The boundaries of these costs are outlined on the overlay sheet and the cost per acre inserted.

It might be questioned whether it is worthwhile to consider an item as small as clearing and grubbing in the location study. All other items being equal, the route that would be chosen is the one without clearing and grubbing. Also, it could be pointed out that most of the time the highway is running through costs which are small. At intervals higher cost areas will be encountered. The location engineer tries to minimize the length of roadway which is travelling through expensive areas. This means that high costs estimated to a moderate degree of accuracy are multiplied by small lengths while the small costs given to a much higher degree of accuracy are multiplied by greater lengths. Thus the two costs should be carried to about the same number of significant digits whether they represent small or large quantities. It is chiefly this argument which causes the smaller costs to be evaluated. Cases could be foreseen, however, in which clearing and grubbing might represent sizeable portions of the completed cost.

In the test section the problem of delineating and assigning costs to these areas was simplified because Massachusetts advertises for bids on the basis of cost per acre for clearing and grubbing. Figure 6 shows the resulting overlay for land preparation.

4.5 Earthwork Costs

Earthwork costs are one of the major costs in building highways. Reference to the costs tabulated in Figure 1 shows that for controlled access facilities these costs vary from about 100,000 dollars per mile to 500,000 dollars per mile for the roads investigated. This represents percentages of from 10 to 40 percent of the total cost. Structures costs are about the same magnitude. In completely rural situations in which the soil types do not change radically the only variable which amounts to a great deal is earthwork, and the location engineer is justified in going to great lengths to minimize it. As our society becomes less rural the engineer is finding many more variables influencing the selection of a route and the selection of the optimum route is less influenced by the earthwork factor.

Within the category, earthwork costs, there are several sub categories. This is illustrated by a summary of unit prices of earthwork taken from the estimated project costs of the Massachusetts Turnpike. (80)

FIGURE 6

AIR PHOTO MOSAIC

LAND PREPARATION OVERLAY

RELOCATION OF ROUTE 28

0 400 800

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PART OF CONTRACT 5244 FOR MASS. DPW

Item	Unit	Unit Cost
Roadway Excavation, Earth	cu.yd.	$0.65
Roadway Excavation, Rock	cu.yd.	2.50
Roadway Excavation, Peat (including backfill)	cu.yd.	1.25
Roadway Excavation, Varved Clay	cu.yd.	1.75
Borrow Excavation, Ordinary	cu.yd.	0.60
Borrow Excavation, Gravel	cu.yd.	1.25
Channel Excavation	cu.yd.	1.75

The problem presented by peat excavation and backfill is different from that encountered in ordinary and rock excavation. Cut and fill categories cause further differences because some cut materials cannot be used as fill material. In order to make provision for the several different kinds of costs which might be encountered it will be necessary to handle them separately. Earthwork was therefore divided into 2 categories. Both require that the engineer know the soil conditions, which exist in the field. The two categories are:

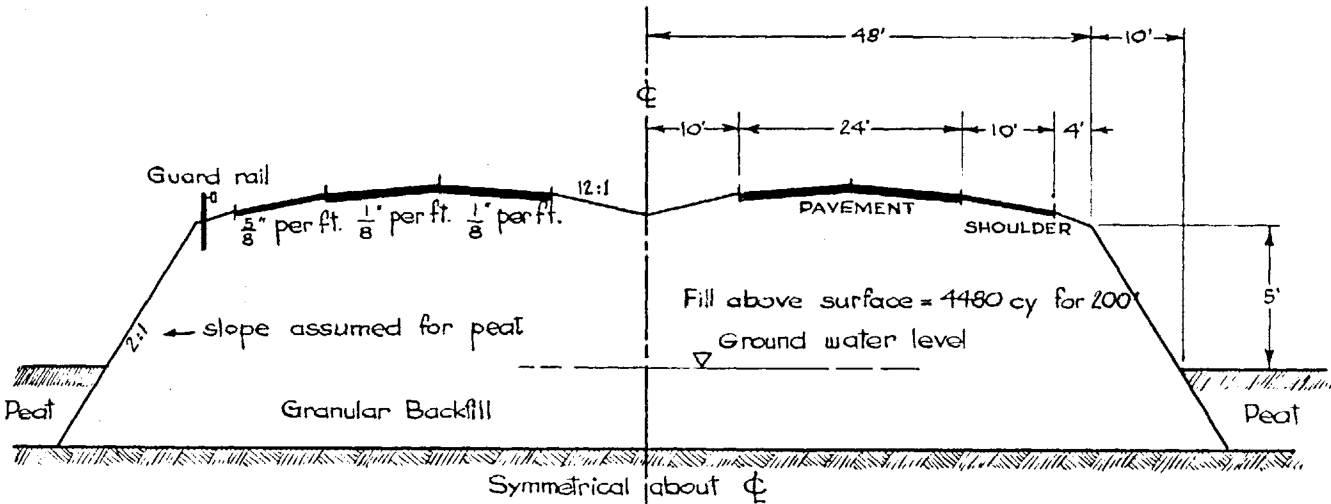
1. Peat Excavation
2. Ordinary and rock excavation

Before the costs for either are evaluated (49, 56, 58) a soil survey is prepared using air photo analysis. Section 4.6 on Roadway Pavement and Drainage will present the detailed methods by which this soil survey is obtained. From the soil survey information is extracted as needed. For peat excavation the data needed is the location and depth of peat bogs or any area which must be excavated and back filled. Air photo analysis can be supplemented by geophysical methods, resistivity tests and punchings to make the data more accurate if this is desirable. These methods can also be used to help determine rock cover depths. It is very important that the time, effort and cost for gathering this data be extended to cover a large study area rather than concentrating the effort into an intense study of a smaller area. For ordinary and rock excavation an overlay containing the location and depth to rock or other form of special excavation is used in conjunction with a contour map from which elevations can be extracted.

Peat Excavation: The major assumption in the computation of the cost of building on swampy conditions is that the method is standardized. Since the Massachusetts Department of Public Works usually excavates and backfills with suitable borrow materials when it encounters peat bogs it was felt that this method was the most logical to use in approaching the problem of highway embankment costs in swamp. There is a strong possibility that states having different swamp conditions would approach the problem in an entirely different manner.

For peat excavation the first step in figuring quantities would be to obtain an overlay delineating the areas of peat and muck and the depths within the various deposits. Using this overlay and a plot of earthwork quantities versus depth of peat the volumes of earthwork in 200 foot squares for any given depth of bog can be readily obtained. The method can be made even more direct by using the standard cross section for peat and by plotting cost versus depth using estimated unit prices of peat excavation and backfill. See Figure 7. These costs are placed on the overlay replacing the depths of peat bog. The overlay which is obtained is shown as Figure 8. It is easily seen how expensive the costs of peat excavation and backfill were in the Route 28 section which was analyzed.

Figure 7 PEAT EXCAVATION COSTS



Standard Section in Peat

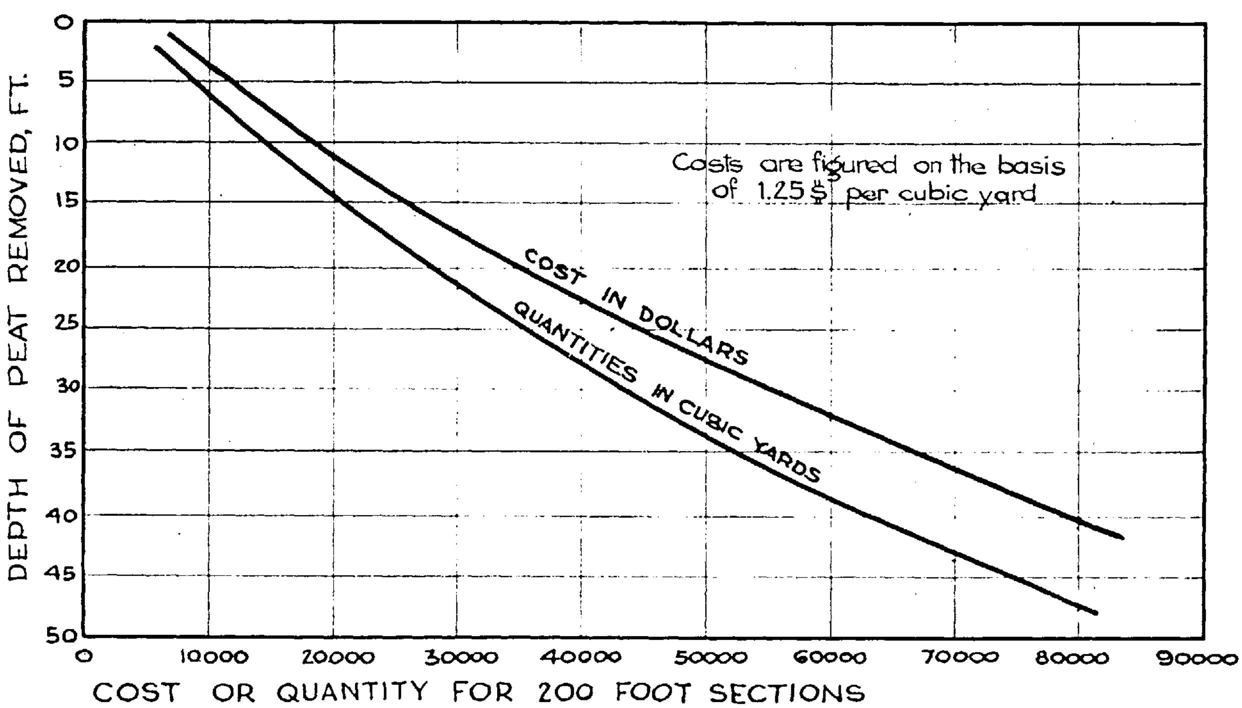


FIGURE 8
AIR PHOTO MOSAIC
PEAT EXCAVATION OVERLAY
RELOCATION OF ROUTE 28

0 400 800

FLOWN DEC. 3 1952 BY
JACK AMMAN PHOTOGRAMMETRIC ENGRS
PART OF CONTRACT 5244 FOR MASS. D.P.W.

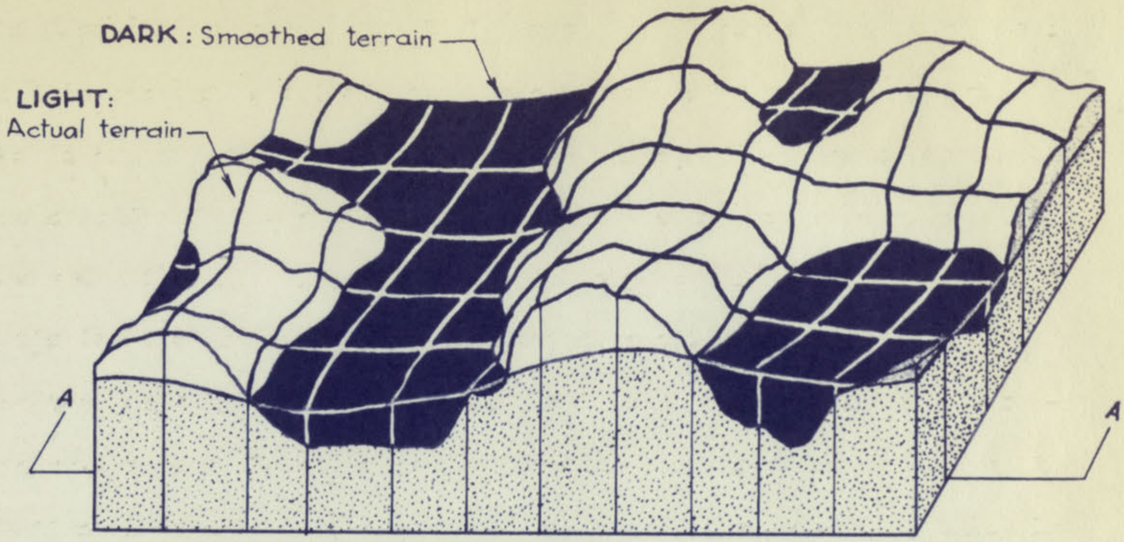
<u>Ordinary and Rock Excavation:</u> The volume of earthwork which will be necessary on any given project is highly variable and is usually quite difficult to determine until a location is chosen. The most desirable method for estimating earthwork in a system such as this would be one which would give the earthwork quantities at all points so that the best route could be chosen. Such a method would be analogous to having the engineer stand at any point in the model and estimate, if a road were 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 probably estimate this on the basis of judgment. Knowing the general direction from which the road was coming and knowing where it was headed the engineer would study the topography in both directions and get an idea of about what the mean terrain elevation was. 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 can be built along the surface if the grade restrictions are not violated. In a model containing rough terrain a road could not be build along the surface because the grade requirements would be exceeded. 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.

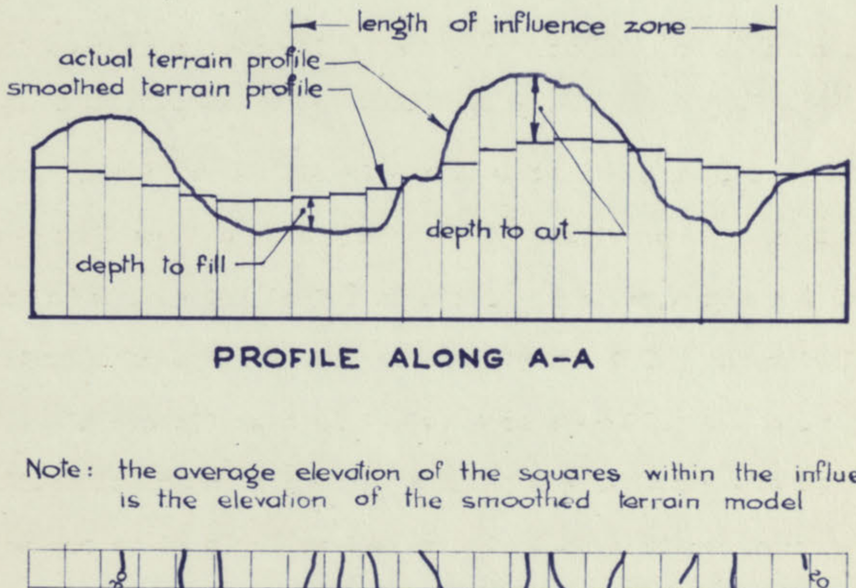
The first and most obvious method of smoothing the surface is taking the mean elevation of the actual terrain model as the smoothed model. In this case the smoothed model is a horizontal plane. If the two models are superimposed one upon the other and differences between the two considered then a positive difference is cut and a negative difference fill. See Figure 9. Using this plane as the smoothed model satisfies the grade requirements, but causes too much cut in the hills and too much fill in the valleys. Continuing along this line of reasoning the mean elevation can be computed for a smaller segment of the model such as a long thin rectangle. If the mean elevation, which is actually the surface of the smoothed model, is considered to be concentrated at the center of the rectangular segment then it can 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 is free to move about then the mean elevation of the zone will be constantly changing as the ground elevations beneath it change, but much more slowly. The smoothed model surface is actually the locus of mean elevations of thr ground within the influence zone. If a large zone of influence is used it will have the effect of greatly smoothing the actual terrain model while a small zone will have less smoothing effect.

Since it is undesirable for a highway to curve excessively it is only necessary to consider the area to the front and rear of any particular grid square and not to the side. Also, in the same manner in which the highway engineer needs to analyze the profile before he establishes the grade line, the zone of influence also needs both a "forward and a backward look" over the terrain before the grade elevation is set. The zone of influence should be shaped roughly like an hour glass instead of a rectangle because as the distance from the considered grid square increases, the probability that the road will pass through a point is diminished. See Figure 9.

Figure 9 EARTHWORK METHOD

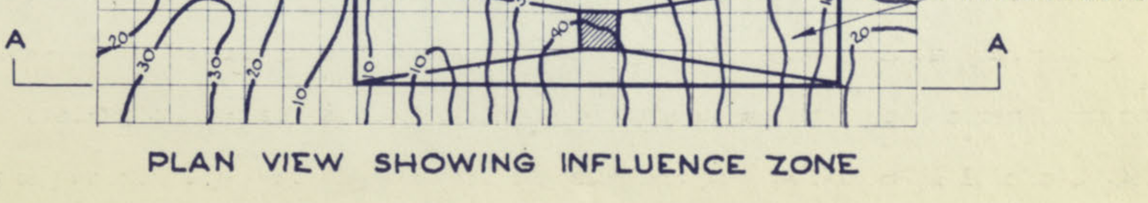


SUPERIMPOSED TERRAIN MODELS



PROFILE ALONG A–A

Note: the average elevation of the squares within the influence zone is the elevation of the smoothed terrain model



PLAN VIEW SHOWING INFLUENCE ZONE

Ordinary excavation is handled in this system by a separate computer program. The input to the program is the mean elevation of the ground surface and the depth to rock within each grid square. The output is cost within each grid square for the excavation or fill for a hypothetical roadway. This hypothetical roadway can be visualized as being constructed on the surface of the smoothed terrain model. The smoothed surface conforms to all grade specifications so that grades will not be exceeded. It is constructed mathematically by finding the mean elevation within the area of an influence zone with respect to one of the grid squares.

The volume difference between the actual terrain and the smoothed terrain over any grid square is the volume of earthwork within that square.

The steps in applying this portion of the system would be as follows:

1. Obtain mean terrain elevations for the land within each grid square from contour maps and record them.

2. Record depths to rock where the rock is reasonably close to the surface.

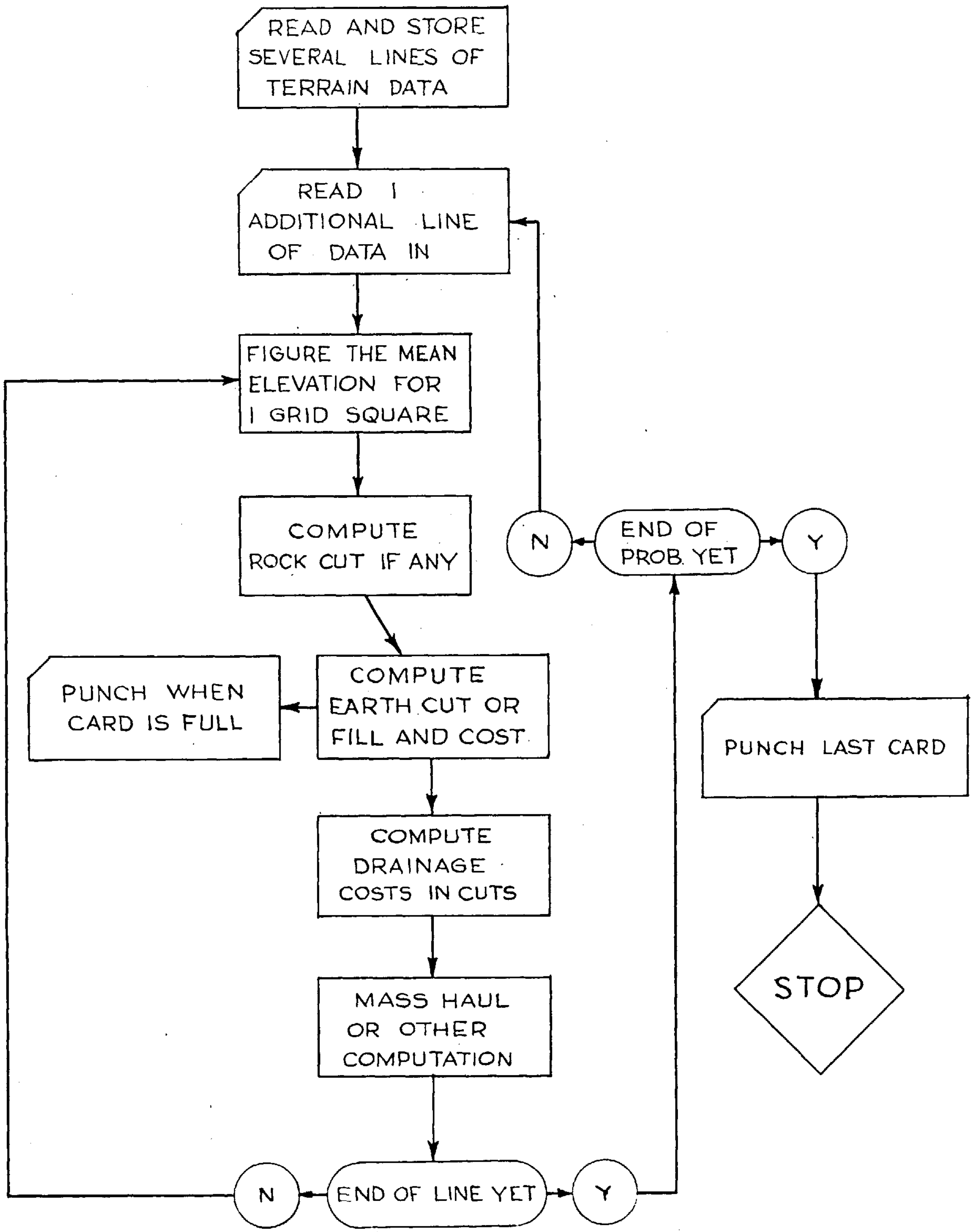
3. Punch this data into cards and place in the computer with the earthwork program.

4. The computer works through the data in the manner shown in the accompanying flow diagram, Figure 10, and punches the cost of cut or fill onto cards which can be used as input to the optimum route selection program or which can be tabulated and read directly.

<u>Assumptions and Limitations</u>: It was impossible to test this program out on a computer. However, an attempt will be made to bring out the assumptions and the limitations which this kind of system imposes and to recommend that further research try to answer the questions.

FIGURE 10_ EARTHWORK PROGRAM

FLOW DIAGRAM OF COMPUTER PROCESS



NOTE: One line of terrain data is read and processed at a time

One of the major assumptions of the earthwork program is that cut and fill balance. Since the mean elevation of the influence zone determines whether there will be cut or fill at a grid square it is safe to reason that as long as a possible roadway alignment stays within the influence zone the amount of cut and fill will be balanced. American practice is to pay the contractor for only the material excavated. Since the cut and fill balance and the material that was removed from one place would be placed in another, this would also be possible in the model. (Note that material which is commonly wasted, such as peat bogs, have already been handled separately.) However, it is felt that it would be better to pay for both excavation and fill in the model. The primary reason for this is that the program which selects the optimum route should select routes of low fill in preference to routes of high fill in the same manner that it selects small cuts over large cuts. It could not effectively do this if all fill had a price of zero regardless of the depth. Therefore, it is felt that a price per cubic yard should be assigned to the cut and also to the fill. An assumption which must be made when this is done is that rock is equally as good a fill material as earth. Usually rock can be used once it is removed, so this assumption is also valid. However, a method must be devised for weighting the cost of rock cut. This can be done by using the difference in price between rock cut and earth fill as the price for rock cut.

The size of the influence zone has already been shown to effect the amount of smoothing. It can be readily seen that the size of influence zone which would smooth mountainous terrain would be so large that it would oversmooth ordinary terrain. Also, this large influence zone would cause cuts which were prohibitive. It is felt that a size of influence zone exists which does a sufficient amount of smoothing and yet still leaves some areas too steep. These steep areas could be eliminated as possible road locations by the computer. It is not known whether it changes when different conditions are encountered. This is probably the most important thing which future research should seek to find out.

The shape of the influence zone is such that terrain surface irregularities are smoothed more in the direction of travel than normal to the direction of travel. This means that lateral movement of earth is not taken into account. It must be assumed that the difference between the mean elevation of the ground within a grid square and the actual elevation at any point is small and can be discounted. The only time the error introduced will become significant will be in side hill cuts.

The most important question that can be asked concerns a combination of all the factors which have been discussed. Will a line selected for the cheapest earthwork costs using this system be as good or better than one seeking the cheapest earthwork which a careful designer would select? This question cannot be answered at the present time.

As the computations for earthwork quantities are being done in the computer all the data necessary for making mass haul diagrams becomes available. These can be developed for any route which the engineer specifies. However, at the time that the problem is initially being run, the engineer has not determined where the alignment will be and therefore will not be in a position to specify one out of the many possible alignments which exist. Once a line has been picked, however, a mass haul diagram can be quickly produced by the computer.

4.6 Roadway Pavement and Drainage

Highway pavement costs are generally recognized as being related to the type of soil over which the pavement passes (19) (26). As the soil loses subgrade bearing capacity the cost of the pavement should rise. It is upon this assumption that the highway pavement costs for this system are evaluated. It will be found that other factors than the type of soil play a very important part in determining the cost of pavements. (29) One which has been ignored in this analysis is the long term economic cost for the pavement in which maintenance will be a major factor. A more detailed study should try to take the annual costs into account. The method proposed here attempts to relate the soil conditions of the location to the cost of a satisfactory pavement design.

In evaluating the cost for roadway pavement it is difficult to isolate the costs attributable to soils and those incurred by the drainage conditions through which the roadway passes (36). Pavement cost is dependent upon the subgrade bearing capacity. The bearing capacity is in turn dependent upon the type of soil and its in situ conditions. The most important of these conditions is its natural water content. Inability to drain allows the water content to increase and thereby causes loss of subgrade bearing capacity. If drainage does not occur naturally, the engineer must provide it. Three methods of providing drainage are commonly used:

1. Changing the cross section by raising the grade line or by modifying the side slopes and ditches.

2. Placing the roadway on a blanket of free draining material.

3. Installing a drainage system of perforated pipes or interceptor drains.

The first of these methods, changing the cross section, is best handled in the earthwork program. The computer can evaluate the slopes on which it is basing the earthwork calculations and change the cross section to conform to these conditions. The results are reflected in a change of earthwork costs.

The other two methods of handling drainage require that the designer recognize poor drainage conditions at the time that soil surveys are made and that the drainage requirements be satisfied by incorporating the costs into the design of the pavement. Since type of soil has much to do with the way it behaves as a foundation material it is felt that in most instances drainage conditions and soil type are closely enough related that they may be handled simultaneously. There is at least one exception. That is drainage of cuts. It is not known whether the grade line will be in cut or fill until after the earthwork program has been run. This can be handled in the earthwork program by letting the computer check to see if it is in cut or fill and how much. If the cut has exceeded the criterion then the cost of drains is added. Although a system such as this would not be extremely accurate, a great amount of accuracy is not necessary for location work.

The method in which the remaining costs of pavement and drainage are evaluated is as follows:

1. A soil survey is made using air photo analysis, field trips, seismic surveys and other sources such as geological maps and U.S. Department of Agriculture Soil Surveys to obtain a soil map of the area.

2. Working from the soil map and using a knowledge of the drainage conditions the terrain is divided into several typical conditions.

3. Pavement designs are made for each of these typical conditions and the costs are evaluated.

4. An overlay is made outlining the areas within one uniform set of typical conditions and assigning to it the costs of its typical design.

Air Photo Analysis: Air photo analysis is the principal tool by which the soils engineer gathers the data to compile the soils map. Using photographs, a broad view of the ground can be obtained. The photography which is used should have stereoscopic cover age. This makes possible delineation of land form and detail which would otherwise be missed. Belcher states that "unless stereovision is used as much as sixty percent of the usable detail may be lost." (50) The engineer performing the analysis can perform this job best if he has a knowledge of geomorphology, geology, sedimentology, and plant ecology; however, it is not necessary that he be an expert in all these fields. A knowledge of the terrain in which the analysis is being made is quite valuable. The more experience the analyst has the less field checking has to be done.

The basic principles of air photo interpretation of soils and rocks depend upon the identification of air photo patterns which correspond to the underlying soils. Identification of these patterns consists in recognizing the photo pattern elements which make up the pattern. These elements are land form, regional drainage, erosional features, gully characteristics, photo tones, vegetation, special elements and man-made features (63). Air photo interpretation is much too broad a subject to be treated in detail within this thesis. However, it is felt that a fundamental understanding is necessary in order that its potential as a data gathering device can be comprehended. Therefore, a short discussion of photo pattern elements will be included.

Land forms occur as a product of the material out of which they are formed, the forces which formed them and the forces which are presently deforming them. Special names are given to those land shapes which are clearly the product of special land forming processes. Dunes, drumlins, cinder cones, terraces, and eskers are good examples. These forms are easily recognizable by their shapes, arrangement and placement within their environment (46). The identification of land forms is usually the most important element of interpretation. By examining the photographs stereoscopically the shapes can be seen and analyzed unless the formations are of such extent that they extend beyond the bounds of the photograph. A knowledge of land forms enables the interpreter to bound areas of like materials and to predict some of their characteristics (45).

The regional drainage of an area is determined by the rainfall, the slopes, the character and permeability of the ground material and the vegetative cover. Most important of these is the permeability of the ground. In sandy material the water is absorbed and no surface drainage develops. In clay, however, low permeability prevents the absorption of water and extensive dendritic drainage systems occur. Land form and slope also help to shape drainage patterns. This tends to accentuate land forms and make them more recognizable. (70)

Erosional features help the soil interpreter to detect stratified or unlike soil conditions. Stairstep type structure indicates differential erosion conditions caused by different soil types. Gullies help in the identification because of the close association of a gully type with the material through which it cuts. Flash floods help to cause gullies and thereby reflect the rainfall of the area.

Gully characteristics are a great aid in identifying the textural classification of the soil. V-shaped gullies with steep gradients occur in sandy soil. On clay slopes the gully systems tend to have broad, rounded, saucer-shaped bottoms. Sandy clays and loess exhibit U-shaped cross sections. Changes in the shape of the cross section or profile indicate changes in the soil type.

Photo tones are a more subtle indicator of underlying soil. Light photo tones mean sandy well-drained soil while darker tones usually indicate clay and poorly drained land. Care must be exercised when using this a criterion because recent rains may produce tones totally unlike those of dry conditions. Shadows may also create undesirable effects.

Different plants tend to grow in different climates. Some seek wet, water-logged places. Others prefer dry, sun-parched exposure. Still others seem to be indescriminate in their selection of environment, but tend to react to it by lighter or darker colored leaves or by different shapes. Evaluation of these differences is made by the interpreter in order to deduce the conditions which produced it.

Many special elements of the terrain are often recorded on the aerial photographs. Features such as ice holes, old channel markings, braided ridges and texture of overall appearance are characteristic of glacial outwash areas and help in the identification of this type of terrain (52). Micro relief will sometimes give a clue to the mode of origin of a soil and thereby reveal its material.

In areas occupied by man many things can be observed which indicate the type of soil which exists. Large buildings and villages most often occupy positions in which good foundation conditions occur (74). Farming must take place on reasonably well-drained soil and yet positions which tend to be arid will not be selected. The type of crop which is planted is another indicator. Frequently farmers will leave unplanted rows within a crop for drainage purposes. Contour plowing and terracing are two other ways in which the soil types are revealed (62).

In preparing the soils map of the Route 28 test section from which the pavement designs were made use was made of many of the air photo elements just described. In addition it was necessary to have an extensive knowledge of the glacial processes which produced the land forms and the majority of the surface material.

Examination of geological maps (31,33,37,38) showed that the area under consideration contains bed rock, chiefly granite and gabbro diorite, which has been intensely glaciated. The last cycle of glaciation took place during the Wisconsin ice age. Very little weathering has taken place since that time so that there has been no chance for the development of an extensive soil profile. (23,24)

The following points were noted with respect to the air photo interpretation of the soils of the test area.

1. Photographs with a scale 1 to 20,000 were most valuable in identifying and analyzing the land forms which occurred in this section. However, most of the analysis was accomplished using the scale 1 to 9600 because of the immediate availability of these photographs. It was found that this scale was desirable for analyzing some of the smaller features and some of the land use factors. The large scale 1 to 4800 scale photos were of value mostly as a check on details.

2. The area was essentially a glacial outwash area containing only a few large hills.

3. The terrace areas of the outwash plain were in general light colored and contained most of the agriculture of the region.

4. The areas of glacial till were darker in color, had a distinct texture, were fairly densely wooded with small trees and contained most

of the human habitation. The depth to bed rock in these areas was often very small.

5. Peat bogs were very light in color (because of frost and frozen ground,) contained a distinctive tufty texture and were very easily recognized. On the two other scales, 1 to 20,000 and 1 to 4,800, the bogs appeared dark.

6. Kames and other gravel deposits also had a light photo tone and frequently contained gravel pits. Pine trees identified by their dark color were the most often found vegetative forms on these deposits.

7. It was difficult to identify exactly the zone of transition between glacial till and terrace. The reason for this was partially because the till was well-drained and slightly sandy in nature.

8. Rock depth was estimated on the basis of rock outcrop, geological land form and effect on tree growth.

9. Peat depth was estimated on the basis of surrounding land form, vegetation growing within the deposit and distance from the edge (73).

10. It was computed that the vertical exageration of the 1 to 9600 scale photos when viewed stereoscopically through a pocket stereoscope was equal to approximately 2.4.

Air photo analysis of the region was undertaken without the aid of surface geology maps. However, it was found that information obtained from a small-scale soil survey map of the county (24) agreed remarkably well with the soil map produced by air photo analysis. A field check of the area proved that most of the terrain was correctly marked.

The first look at the photographs failed to detect rock outcrops. The field check pointed out the error and upon further examination of the photos the rock outcrops were not only verified but extrapolated to positions which were unobservable in the field. It is felt that an analyst who has had considerable experience in similar terrain would have been able to avoid this pitfall. Also, that it would be possible for him to estimate the depth of overburden over rock and the approximate depth of peat bogs. Although expensive, it probably would prove economical to make punchings or seismic surveys on strategically located deposits especially of large areal extent.

The following categories of soil were identified on the photographs and marked on the soil map overlay, Figure 11.

Ice channel deposits - heavy granular deposits with some boulders, excellent drainage

Kame deposits - heavy to light gravel deposits with excellent drainage

Terrace - sandy gravelly soil with good drainage

Glacial till - thin deposits of bouldery well-graded till material, only fair drainage

Drumlins - thick deposits of till material containing boulders, fair drainage

Poor surface drainage - areas in which there is no peat but the soil is very poorly drained

Muck and peat - spongey organic materials in water

Rock outcrop - clearly outcropping rock

The depth to bed rock and the depth of peat bogs are also shown on the soil map. This was done by circling the area and placing a reasonable figure for the depth within the circle in the same manner as a contour line.

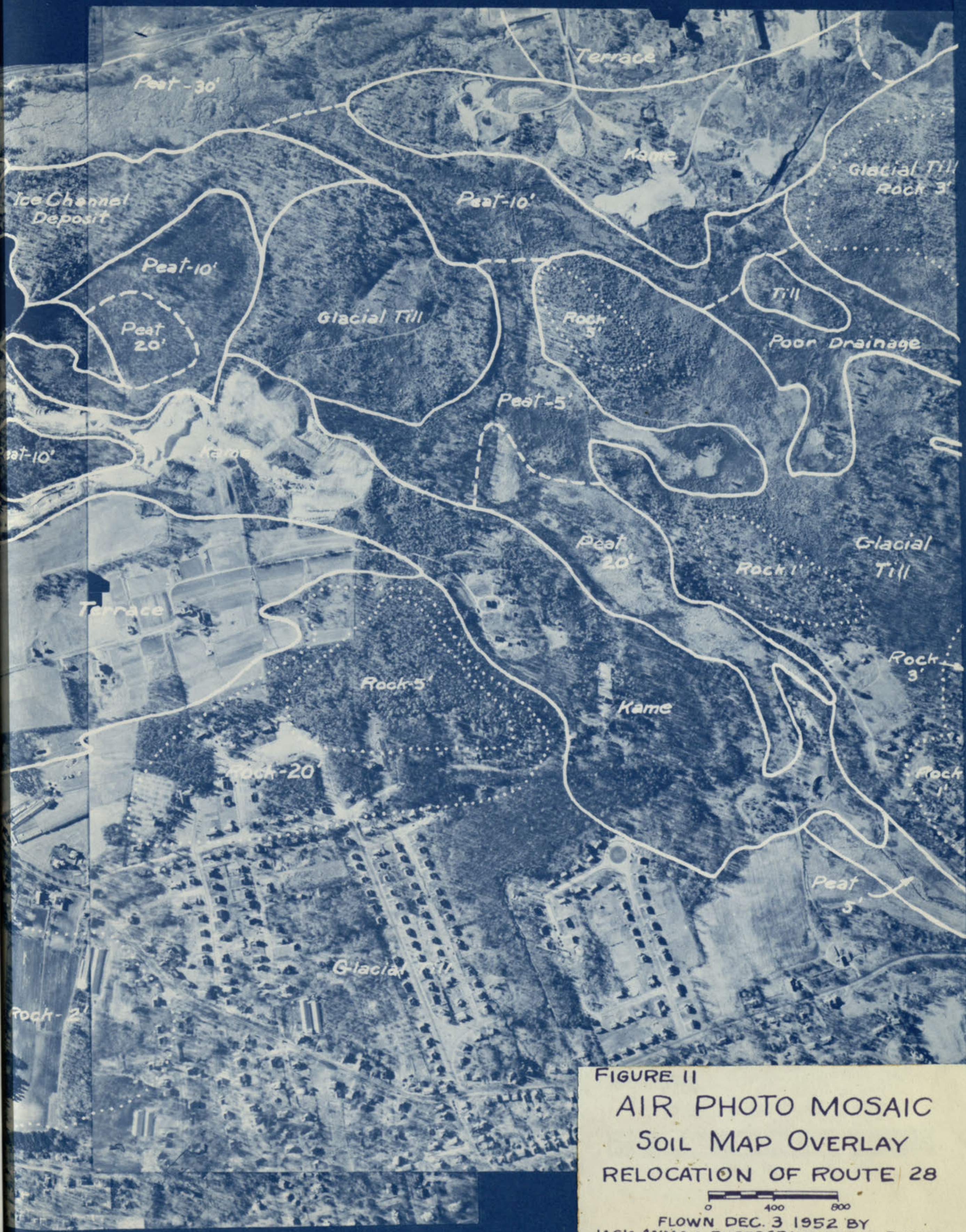


FIGURE 11

AIR PHOTO MOSAIC

SOIL MAP OVERLAY

RELOCATION OF ROUTE 28

0 400 800

FLOWN DEC. 3 1952 BY
JACK AMMAN PHOTOGRAMMETRIC ENGRS
PART OF CONTRACT 5244 FOR MASS. D.P.W.

Pavement Design: It was decided to divide the soil categories which were identified from the air photo mosaic into three groups for the pavement thickness design. These three groups are:

1. Granular soils--which include ice channel deposits and kames.
2. Sandy soils--mostly terrace.
3. Silty soils--including glacial till, drumlins, and drift material.

Flexible thickness designs were made for each of the three soil groups. The Asphalt Institute method was used. (15) Values of CBR were estimated from typical test data of glacial soils found in references 1 and 50. This method was supplemented by the Corps of Engineers frost design procedures in the frost susceptible materials. (19) The thickness of asphaltic concrete surface and penetrated crushed rock base was determined to be 8 inches. This thickness was held constant for all designs and the subbase thickness varied to meet the subgrade bearing requirements.

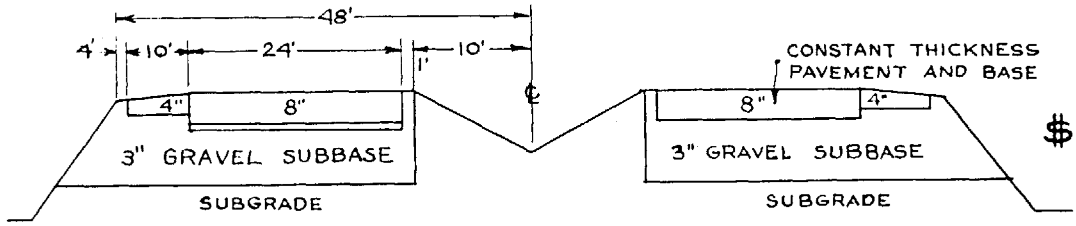
Using the thickness determined for the three soil groups the design costs were determined in each of the original soil categories. This was done by evaluating the costs for typical cross sections using the pavement thickness determined previously and providing additional drainage facilities in those sections which need additional treatment. These cross sections and the resulting costs are shown in Figure 12. The cost for additional drainage in long cuts or for cut in rock can be most expeditiously handled by the computer within the earthwork program. It is necessary to add these additional costs only if the grade line is found to fall within a deep cut or in rock.

The costs shown on Figure 12 were used to compile the mosaic overlay, Figure 13. The pavement design for areas within peat bogs is the same as that for terrace material because the material used for backfilling is

Figure 12 PAVEMENT DESIGNS AND COSTS

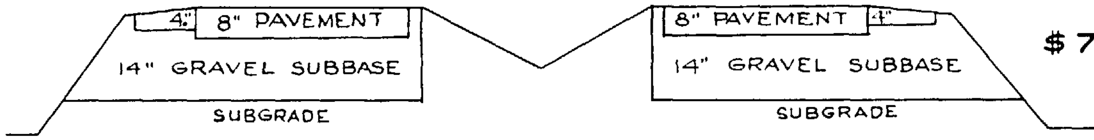
SOIL TYPE — COST FOR 200 FT SECT.

KAME AND ICE CHANNEL DEPOSITS



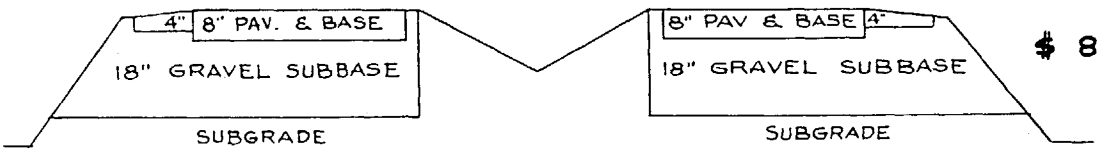
$ 5162

TERRACE



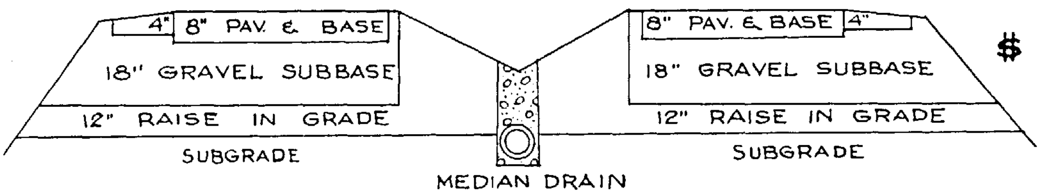
$ 7460

TILL



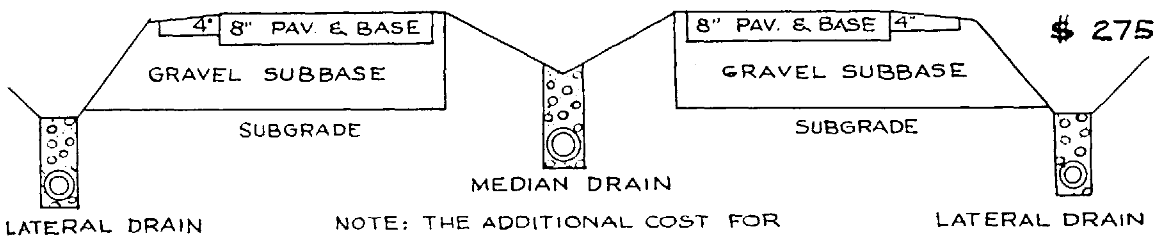
$ 8520

POOR DRAINAGE



$ 10 002

ADDITIONAL COST FOR DRAINAGE CUTS



$ 2750

NOTE: THE ADDITIONAL COST FOR DRAINAGE IN CUTS IS ADDED TO THE COST OF EXCAVATION IN DEEP CUTS IN THE EARTHWORK PROGRAM

NOTE: SEE APPENDIX 2 FOR THE PAVEMENT THICKNESS DESIGNS AND COST COMPUTATIONS

FIGURE 13
AIR PHOTO MOSAIC
PAVEMENT COST OVERLAY
RELOCATION OF ROUTE 28

0 400 800

FLOWN DEC. 3 1952 BY
JACK AMMAN PHOTOGRAMMETRIC ENGRS
PART OF CONTRACT 5244 FOR MASS D.P.W.

usually granular in nature. Note that the cost for peat excavation is evaluated under earthwork costs.

4.7 Structures Costs

The most important structures in a highway system are its bridges. The advent of the controlled access highway had made them even more important. The costs for building these structures is one of the major costs of the total outlay for highways. Structures costs amounting to one-third the total costs are not uncommon for controlled access facilities. Serious consideration has therefore been given to the problem of evaluating the cost for bridges and culverts before the actual location has been established. In this way the overall practicability can be evaluated before the location becomes "fixed."

The cost for building structures is mostly a function of the type of bridge, the length of span and the soil conditions of the site.* Also important are the alignment and the grade line of the roadway. The bridge locator can analyze many of these factors while looking at stereoscopic pairs of the bridge sites. The general direction of the roadway alignment is already known. A glance both forward and backward will indicate whether the bridge is likely to be badly skewed. The soils conditions of the site are available from the soils map or from a more careful analysis of the terrain surrounding the bridge. The probable length of the bridge can be measured with an engineers scale. The bridge type must be estimated on the basis of experience. Alignment and grade are difficult to estimate, except from a judgment standpoint, in a system such as this where the location has not already been selected.

The most frequently encountered bridge type on American roads is

* Most of the information cited in this section has obtained in conference with practicing bridge engineers.

the highway overpass. This type is built under generally uniform conditions and therefore the price differential is small for bridges of about the same length (35). The highway underpass is also a commonly occurring structure. Because of its similarity with the overpass it can be expected to vary in the same manner. The biggest price differences between bridges within these two types is found to be in the cost of abutments. Bridge prices are sometimes resolved into costs per square foot of bridge surface so that different size bridges can be compared. Large abutments raise the cost per square foot; however, the additional length required for open abutments reduces the costs in about the same proportion. Conferences with practicing engineers seems to indicate that the costs expressed in this manner are fairly consistent.

The trend in highway bridges today is to span everything possible with I beams or plate girders and to use through and deck trusses for the more difficult locations. Larger, more complicated bridges, are not as easily estimated using a rule of thumb such as this. For I-beam bridges with spans up to about 300 feet the price seems to be more or less proportional to the span.

Data was gathered for bridges in Massachusetts, New Jersey and Florida and then reduced to costs per square foot. (35,42,80) Representative figures for these bridges were:

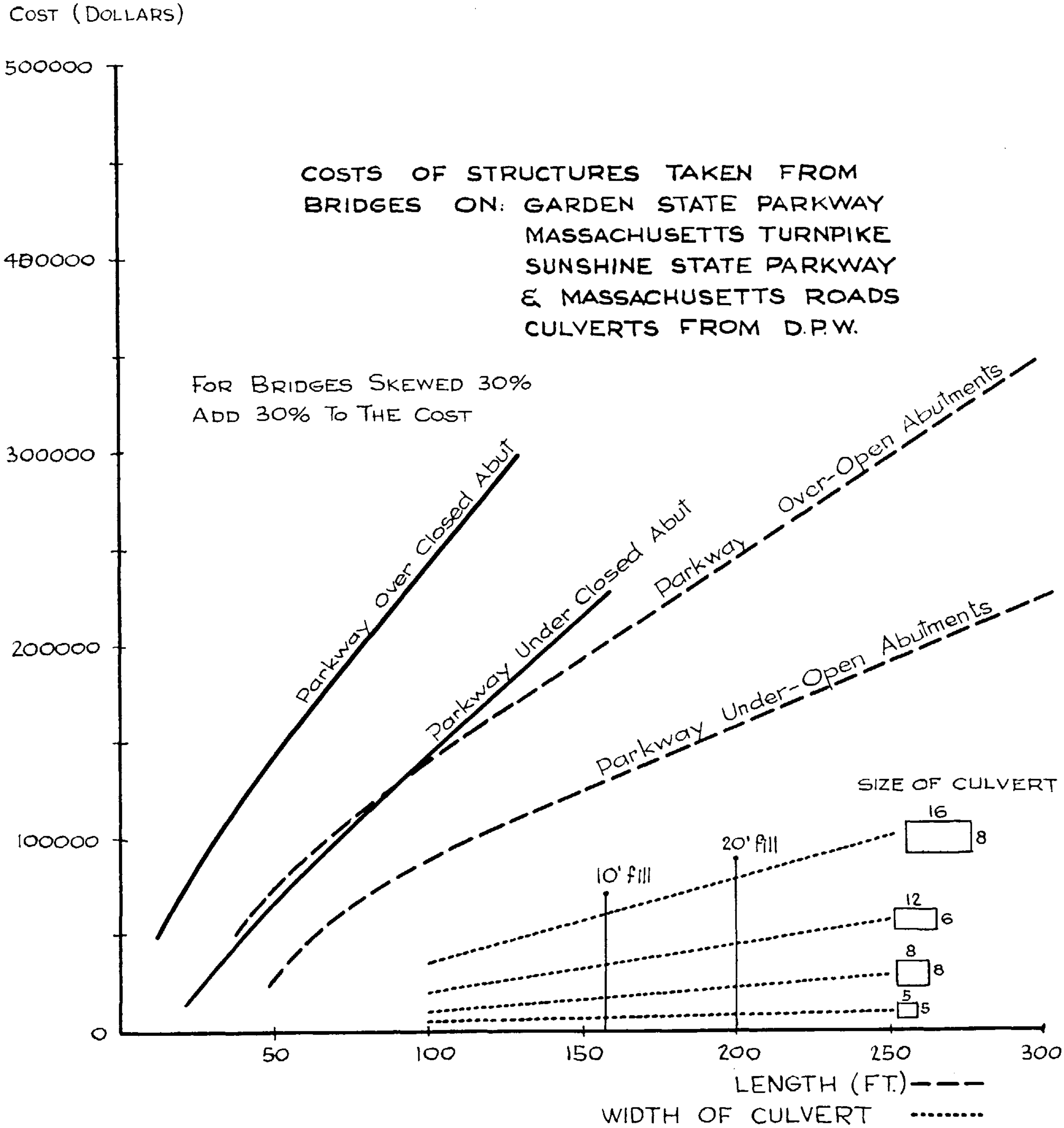
Open abutment parkway underpasses	\$17/sq. ft.
Open abutment parkway overpasses	\$14/sq. ft.
Closed abutment bridges	\$30 to \$40/sq. ft.

The figures shown are on the basis of square feet of deck area and include the cost of foundations and abutments. They do not include the cost of any modifications or surfacing which must be performed on the road being bridged or on channel improvements which must be made. These costs should be added to the total cost.

Using these costs a chart was plotted comparing total cost versus length for the various types of bridges, Figure 14. A large part of the information for arriving at the various costs presented above was obtained from a plot of cost versus deck area for open and closed abutment types. This plot was seen in the Boston offices of Fay, Spofford and Thorndike, Consulting Engineers. It is felt that cost data compiled in this manner would be quite valuable in estimating the costs of structures for location purposes. The chart can be used quite readily by the engineer to obtain base costs for different types of standard highway bridges. More complicated bridge types would have to be handled by an engineer experienced in estimating bridge costs versus deck area. This work could probably be simplified if plots could be obtained containing the basic cost data for many bridges. Changing costs caused by economic fluctuations can be kept current by applying the Engineering News Record cost index (34).

The costs for culverts is treated in much the same way as bridges. In culverts the important variables are the culvert size and the length of pipe. The length of pipe is partially dependent on the depth of fill. The engineer may find that it is necessary to know the drainage areas roughly before the culvert sizes can be estimated. Cost data was obtained from the Massachusetts Department of Public Works for various sizes of reinforced concrete box culverts in place. This data was then plotted on Figure 14 by showing curves of cost versus width of culvert. Assuming a standard width cross section, which in this case was 115 feet, and side slopes 2 horizontal to 1 vertical the culvert lengths for 10 and 20 feet of fill were computed and shown on the chart as vertical lines.

FIGURE 14 COSTS OF STRUCTURES



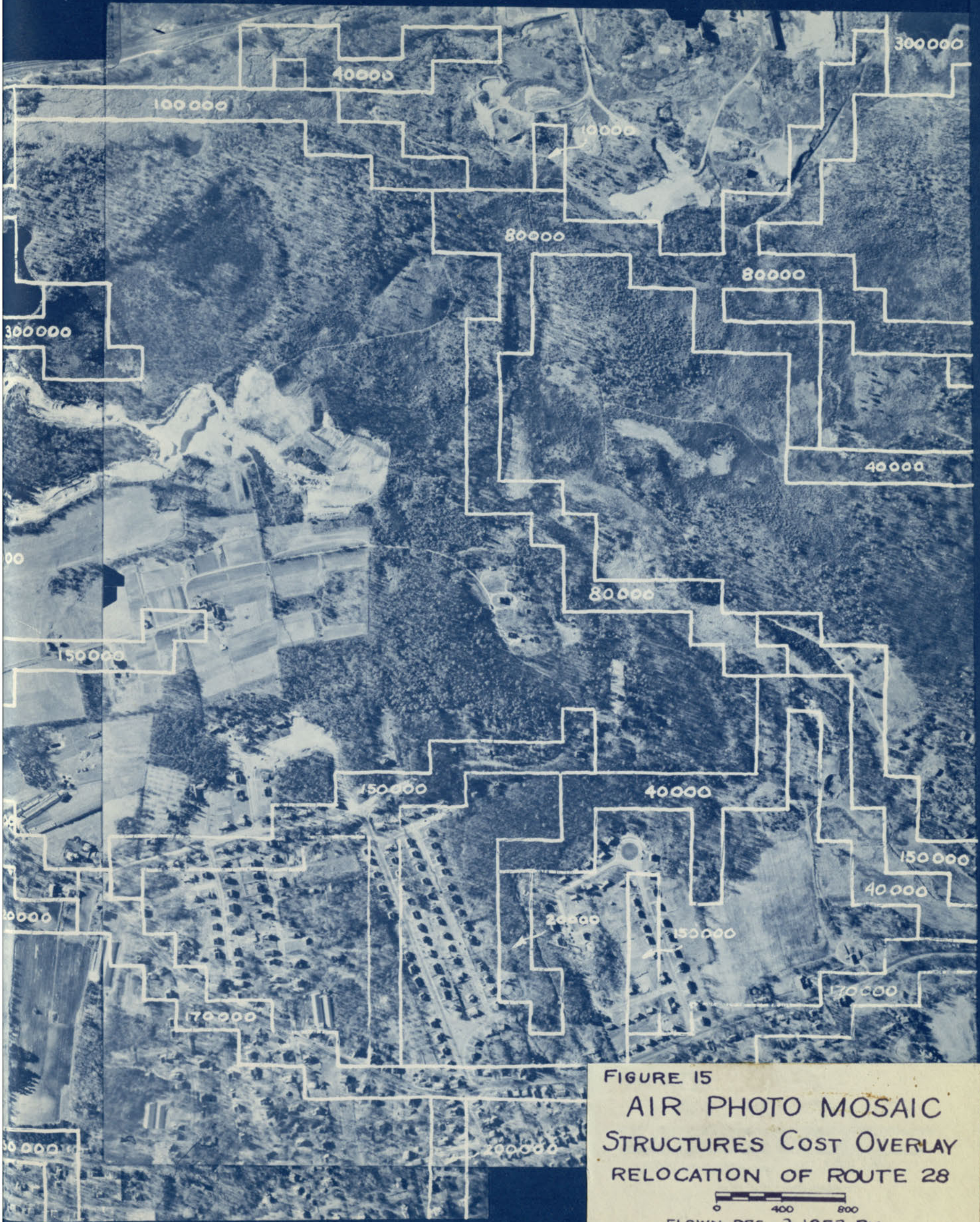


FIGURE 15
AIR PHOTO MOSAIC
STRUCTURES COST OVERLAY
RELOCATION OF ROUTE 28
0 400 800
FLOWN DEC. 3 1952 BY
JACK AMMAN PHOTOGRAMMETRIC ENGRS
PART OF CONTRACT 5244 FOR MASS. D.P.W.

Using information like that presented the bridge cost estimator can make a rough approximation of the cost of bridging streams, roads, and railroads or any barrier which has to be bridged. It is important to obtain representative values which reflect the differences in cost between one bridge site and another, as the computer will later seek the most economical route.

The method which the bridge cost estimator would use in evaluating the cost of structures is somewhat as follows:

1. The drainage system and roads which are to be overpassed are marked on an overlay sheet.

2. Using stereoscopic pairs these barriers are examined to locate crossing points and to estimate the variables which would influence the cost.

3. The costs are estimated using a diagram like that presented in Figure 14. The estimate given by the diagram should be adjusted to fit the conditions surrounding the site.

4. The estimated costs are recorded on the overlay. As the foundation conditions, length, or the type bridge which should be used changes the estimated costs change.

Figure 15 shows the structures overlay that was obtained for Route 28.. It can be seen that bridges appear as bands of high cost. Unlike the other overlays the grid squares within the band of high cost had to be individually selected to give the proper representation. The 200 foot grid size does not adequately describe the shape of roads or rivers. If the squares had not been selected situations could have occurred in which the cost of a bridge was not added into the cost of a route. This will be discussed in more detail in the discussion of grids.

Another difficulty which is present is the accuracy to which the costs of bridges can be estimated. An accuracy of plus or minus 20 percent appears to be about as good as could be expected, under ideal conditions. The present methods of performing highway location are limited to about the same accuracy, however.

4.8 Miscellaneous Costs

Beside the ordinary costs associated with the building of highways there are generally several special costs of a miscellaneous nature. These can be evaluated on separate overlay sheets. These costs can include such items as utility replacement, traffic desire, interchanges, or details like guard rail placement, right of way, fences, or grassing and slope protection. Any item which demands special attention can be placed on a separate overlay sheet. Planning factors can also be considered if they can be expressed in terms of cost.

Traffic desire will deserve special attention in some cases. In the event that a major detour is being contemplated a method which will account for the incremental costs of traffic inconvenience and time lost should be devised. This can be done by considering a cost model shaped like the backslopes of a highway cut only with much flatter slopes. The more traffic is expected the steeper the side slopes would be. In most cases however, it will be unnecessary to consider this factor because the location band within which the route is located is usually much longer than it is wide. Actually, the optimum route selection program will take into account the increased cost of construction caused by deviating from a straight line between the two terminals.

The location of interchanges is another factor which demands attention.

The engineer must decide which locations must have interchanges and the approximate cost of the interchange. If an interchange can be located at any place along the transverse road then the engineer can evaluate the cost of interchanges at frequent intervals along the transverse road and assign the costs to a price barrier on top of the transverse road. This price barrier will appear on the overlay much like a large bridge. If the location of the interchange is relatively fixed and the highway must travel through the interchange site this is accomplished by erecting a barrier which has its only breach on the location of the interchange. The square forming the breach will contain the total cost of the interchange.

Since no items of a special nature appeared in the test section it was not necessary to prepare an overlay sheet for miscellaneous costs. It was decided that since the highway was not intended to service the immediately surrounding community traffic desire would not play an important role in the final selection of the route.

4.9 Preparation for the Computer

After the separate overlays have been prepared the next step is to add the costs contained in each square of the overlay to that of the corresponding squares in the other overlays to obtain the total cost at each point. This could be done on an adding machine instead of a computer, but the time and effort required would be prohibitive. Also, it will be desirable to have these total cost figures already in the machine so that the optimum route selection can be performed.

The overlay sheets contain only the outlines of the areas in each cost range. Within each the engineer has marked the cost. In order for a digital computer to work on the data in this form it is necessary to indicate the area boundaries to the computer. This can be done by dividing the surface into a matrix or grid and recording the data within each square. This has the advantage of confining the area which is being studied and was particularly desirable in the case of bridges in which the total price of the bridge was assigned to one grid square. Individual houses also encountered the same problem.

In order to prepare the overlays for punching they are placed on a surface which has been marked off into grid squares of the proper size and oriented so that the grid corners are the same on every overlay. In this way the key punch operator can see the area which contains a uniform value and also see the grid system. The cost values taken from the overlay are then punched into the card in regular order from one side of the location band to the other and progressively along the band in the direction of travel.

Grid Makeup: The makeup of the grid was the object of considerable study. Several different patterns and arrangements were considered. Squares have the advantage of simplicity, ease of manipulation, and flexibility in obtaining different sized grids. The major disadvantage is that a square has 8 other squares around it; four which are connected to it by a side, and 4 which join it at a corner. In the optimum route analysis the computer progresses through the squares searching for the lowest costs. If two high cost squares join at the corner the computer can cross between them. Thus, for a barrier such as a river the squares must be carefully arranged so that the computer will not jump across between corners.

This problem can be solved by using a hexagon, instead of a square. The hexagon is always separated from other hexagons by a side instead of a corner so that a sinuous path such as a river can be approximated by a string of single hexagons without the possibility of a jump across the corners. The hexagons have the additional advantage that the centers of adjacent figures are all equidistant from each other even on the diagonals. The hexagons have some disadvantages, too. The method of progression in the optimum route selection program is complicated because the hexagons do not lie in a straight line from one side to the other. Every other square in the row is a whole step ahead of the ones on either side of it. If the hexagons are oriented in the other direction the optimum route could never progress straight ahead but must weave back and forth. The hexagon is also more difficult to obtain in a variety of scales than squares and is more difficult to understand and explain.

A system of offset squares in which the offset occurs on every other lengthwise row with one half a square displacement gives almost the same situation as a hexagonal arrangement. The only difference is in the shape. From a data gathering point of view the two are equal except for the ragged edge presented by the square. Circles were also considered, but were eliminated in favor of hexagons. The advantages of the hexagons would outweigh theother systems if a way could be devised to handle the optimum program difficulties. The system of squares was adopted in the practice problem because of the simplicity and because of the ease of drawing squares. It is felt that additional research would solve the problems associated with hexagons.

<u>Grid Sizes:</u> An analysis of the sizes of grids showed that a 200 foot grid was the most desirable for the final map. A 200 foot grid contains an area equal to 0.918 of an acre. This is close enough to an acre to do the estimating on the basis of costs per acre. The analysis

(shown in Appendix 1) showed that 200 foot squares produced 697 grid points per square mile. A 100 foot square produces 2,790 grid points per square mile. It is felt that the additional accuracy gained by a 100 foot grid size will not justify the additional work required to obtain it. A 500 foot square will be most valuable for preliminary, large scale photographic reconnaissance.

Cost Recording: It was impossible to record costs with a grease pencil in the small areas of the overlay without excessive crowding of numbers. The larger prices contain 6 digits while some of the smaller prices have only 2. Since the same level of significance is required for both sets of numbers a logarithmic method of recording the numbers can be used. The first 2 digits of the logarithmic number is composed of the most significant digits of the cost. The 3rd digit is the number of digits following the 2 significant digits of the cost. Thus $2,300 would be written 232 and $257,000 would be written 264. This system allows more data to be put on a card. Output is also simplified because the data can be printed out in 3 digit blocks. This form does have the disadvantage of being slightly harder to read.

If punching of the data proves to be very laborious a system can be adopted to simplify this data input. It would work in the following manner. The first cost is punched into the first word of the data card. The second word contains the number of times this cost is repeated. The third word contains the second cost and the fourth word contains the number of times it is repeated, etc. The computer can be instructed to repeat the costs internally for use in computation.

After the data cards containing the cost data of the individual overlay sheets have been punched they are placed with the output cards of the earthwork program and fed into the computer with the program for computing the economic cost model. It was found feasible to combine this program with the optimum route selection program. Therefore, a block diagram showing the computer processes of both programs will be presented at the time the optimum route selection program is discussed.

4.10 The Cost Model

After the data from the individual overlay sheets has been punched into cards and placed in the machine the computer adds the costs at each grid point to produce the total cost within each square. This total cost is the cost of building the highway through that one grid square. In spite of the fact that the actual costs in nature may take up only a part of the area within a grid square it is assumed that the costs in the model are spread evenly over the square. As was mentioned before the total cost model which is produced in the machine by adding these small increments can be visualized as being a model of the terrain where the relief is cost instead of elevation. The hills are the points of high costs and the valleys represent low costs. A river or a road presents a barrier like a wall because of the high costs for structures.

A model like this would be of great value to the highway location engineer. The relative cost advantages of one route over another can be seen at a glance. If the alignment of a trial route is plotted on the model the total cost of the highway can be obtained by adding the values of each of the grid squares through which the road passes. This can also be thought of as the area underneath the profile of the cost model. Alternate routes can be easily compared by adding the grid squares in each alignment and comparing the costs obtained.

The computer cannot be made to punch out this data in the form of a relief model. However, as previously explained, it can punch it in the form of 3 digit numbers. These numbers can be centered and spaced on a card tabulator so that they fall within a square format. The grid can even be drawn in if this is desired. In this manner about 20 grid points can be handled on one tabulated line. This represents 4,000 feet using a 200 foot grid. A picture can be taken of this format and it can be reduced to a diapositive with the same scale as the air photo mosaic. With the diapositive the costs can be superimposed directly over the ground features shown on the mosaic which caused them. The cost model in number form can then be used by the designers as an aid to locating the best route.

Even using the cost model it might be difficult to locate the most economical route. There will be cases in which the costs values will be very irregular. It is conceivable that the squares along one side of the model might contain many barriers of high cost while maintaining a matrix of low costs. It might become necessary to compare a potential route on this side of the model with one on the other which ran through a very uniform medium cost. The final answer could be obtained by adding the costs in each of the grid squares along the two routes. However, since the computer can do this more efficiently than the engineer and because the computer can be programmed to determine the very cheapest route with only one pass of the data a method for finding this optimum location has been explored.

4.11 Optimum Route Selection

When overlay cost variables have been added to obtain the cost of building through each square these total costs may be used in the selection of the optimum route. The principle of the computer program which performs this operation is simple. If the cheapest possible route to every square along a row transverse to the direction of travel is known then the cheapest possible route to each square in the next row can be computed. This is done in the following manner. Starting with the first row the cost of the most economical route through each square is the incremental cost contained within the square. In the second row the least expensive path of the three possible paths to any square is that from the square containing the lowest cumulative cost of the three contiguous squares in the first row. The cumulative cost of the square in the first row is added to the incremental cost of the square in the second row to obtain the cumulative cost of building the road up through that square in the second row. See Figure 16 for the procedure. This procedure is followed for all the squares in the second row. In the same manner the cumulative cost to any square in the third row is computed by adding its incremental cost to the least of the three possible cumulative values from the second row. This routine is continued until all the transverse rows along the prospective route have been traversed, and the cumulative cost for each square computed. At the same time that the cumulative costs for any square is computed the computer also records which of the three possible squares was selected. This information is retained so that when the optimum path is located it can be traced out.

After the cumulative cost has been computed for each square in the area to be analyzed the most economical route through the whole model is obtained. This is done by comparing the cumulative costs of the squares in the last row and selecting the one with the lowest cumulative cost. Its path is then traced back. This path is the most economical path through the model and its cumulative cost is the lowest cost which can be obtained

FIGURE 16 OPTIMUM ROUTE SELECTION PROCEDURE

THE DIAGRAM ILLUSTRATES THE METHOD OF FIGURING THE LOWEST CUMULATIVE COST FOR ANY SQUARE IN THE 2nd ROW FROM THE LOWEST CUMULATIVE COSTS OF ALL SQUARES OF THE 1st ROW

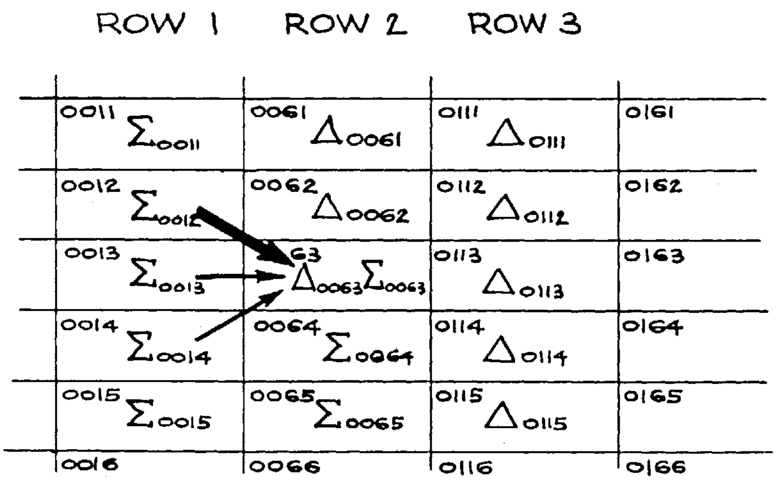


DIAGRAM SHOWING A PORTION CUT OUT OF THE COMPUTER MEMORY. THE COMPUTER ADRESSES CORRESPOND TO THE GRID SQUARES OF THE COST MODEL

GIVEN:

Σ_{0012} = THE LOWEST CUMULATIVE COST THROUGH SQUARE 0012
Σ_{0013} = THE LOWEST CUMULATIVE COST THROUGH SQUARE 0013
Σ_{0014} = THE LOWEST CUMULATIVE COST THROUGH SQUARE 0014
Σ_{0063} = THE LOWEST CUMULATIVE COST THROUGH SQUARE 0063
Δ_{0063} = THE INCREMENTAL COST THROUGH SQUARE 0063
Δ_{0062} = THE INCREMENTAL COST THROUGH SQUARE 0062

FIND:

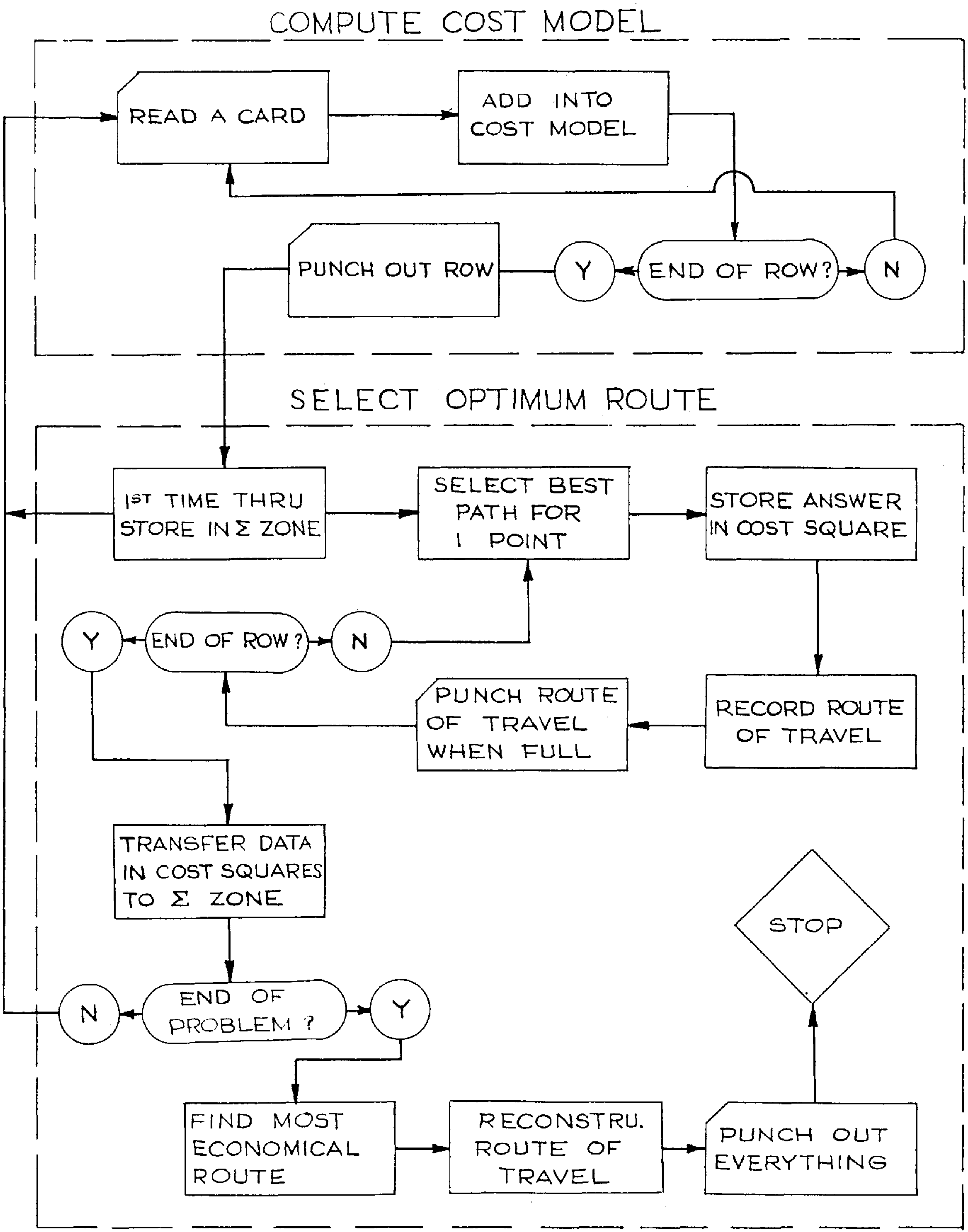
THE LOWEST POSSIBLE COST FOR BUILDING A HIGHWAY THROUGH SQUARE 0063. IN ORDER TO DO THIS; Σ_{0012} ; Σ_{0013} AND Σ_{0014} ARE COMPARED TO FIND THE LOWEST.
ASSUMING Σ_{0012} IS THE LOWEST, THE CUMULATIVE COST FOR SQUARE 0063 = $\Sigma_{0012} + (\Delta_{0063})\,1.414 = \Sigma_{0063}$
IF A DIAGONAL LINE IS CHOSEN AS IS THE EXAMPLE IN THIS CASE THE INCREMENTAL COST, Δ_{0063}, IS MULTIPLIED BY 1.414 BEFORE ADDING. THIS IS NECESSARY BECAUSE OF THE INCREASED LENGTH OF ALIGNMENT. AFTER THE COMPUTATION Σ REPLACES Δ IN THE SQUARE.

for building a road from one end to the other. The computer flow diagram is shown as Figure 17.

In performing this program the computer has been programmed so that it will always pick squares which lie within 45° of the true desire and which from a continuous chain across the model. Therefore, the route selected can never turn back on itself. Although the route could possibly switch back and forth across the model it will be restrained from doing this because of the additional length travelled. The conditions of maximum curvature are imposed by 3 squares along the longitudinal axis of the model, the middle one of which is displaced to one side. This condition gives 90° of curvature in 600 feet or 15° per 100 feet. The assumption which was made in using grid squares to represent the cost of building was that the cost was uniform over the whole grid. This is not quite true. However, using the optimum route from a machine a smooth line can be located which follows the general alignment but which is not strictly confined within the squares of the optimum route. If desirable the computer can be made to obtain an optimum band which is two squares wide instead of one. Also, more rigid requirements can be set up governing the deviation from the desire line.

An obvious disadvantage of the program as it is presented here is that it selects only one optimum path. Several alternate solutions are not selected. However, the trace of all pathes can be punched out by the computer and the engineer can select several local alternates which hold the possibility of more desirable results even though they will be more expensive. It is felt that further development will make possible a system whereby several alternate routes with their costs can be presented to the engineer.

FIGURE 17 – OPTIMUM ROUTE PROGRAM
FLOW DIAGRAM OF COMPUTER PROCESS



In order to study the operation of the system it is possible to have the cumulative costs for each row punched out. Using these it is possible to plot iso potential lines of the cumulative costs. These lines connect points of equal cumulative cost. They make it possible for the engineer to see just exactly how the machine progresses through the model.

4.12 Methods of Output and Presentation

Once the process of forming the cost model and selecting the optimum route through it has been solved by the computer there remains the problem of getting the data out of the machine in a form which is usable and understandable to the engineer.

Digital Output: The output for optimum route selection can be presented as a series of coordinate points which the engineer locates on a grid overlay and connects with a line before placing on the air photo mosaic. Although this line may twist about a good bit the engineer will be able to draw a smooth curve through the points for use as the preliminary location. As pointed out previously it may be more desirable for the machine to select a band two squares wide than only one square wide.

It is desirable for the engineer to be able to view the cost model in addition to the optimum route. Minor changes in location alignment become desirable as planning progresses. These changes are most easily made by looking at the model. To a certain extent the optimum route can be compared to alternates to see how much better it is by studying the cost model.

In order for this cost model to be valuable to the engineer he must be able to see and comprehend it. The problem of creating visual impact is quite difficult. The only thing which the computer is capable of producing is numbers. Numbers by themselves are very difficult to comprehend at a glance. It is necessary that some other form of output be adopted which is easily understood.

The most easily understood would be a wax model containing the cost hills and valleys. This could be manufactured by setting up the punched program output card so that it would become the input card for a card operated automatic cutter head. The cutter head following the coordinates of the cost model contained on the punched card would proceed to cut the wax to shape along one cross section. It would continue this operation card by card until the whole model was formed. This form of output has two disadvantages; 1. It is more qualititative than quantititative. The height of hills could be easily compared, but no figures are available for cumulative cost comparisons without further treatment. 2. The model would be difficult to make because of the lack of availability of card operated milling machines.

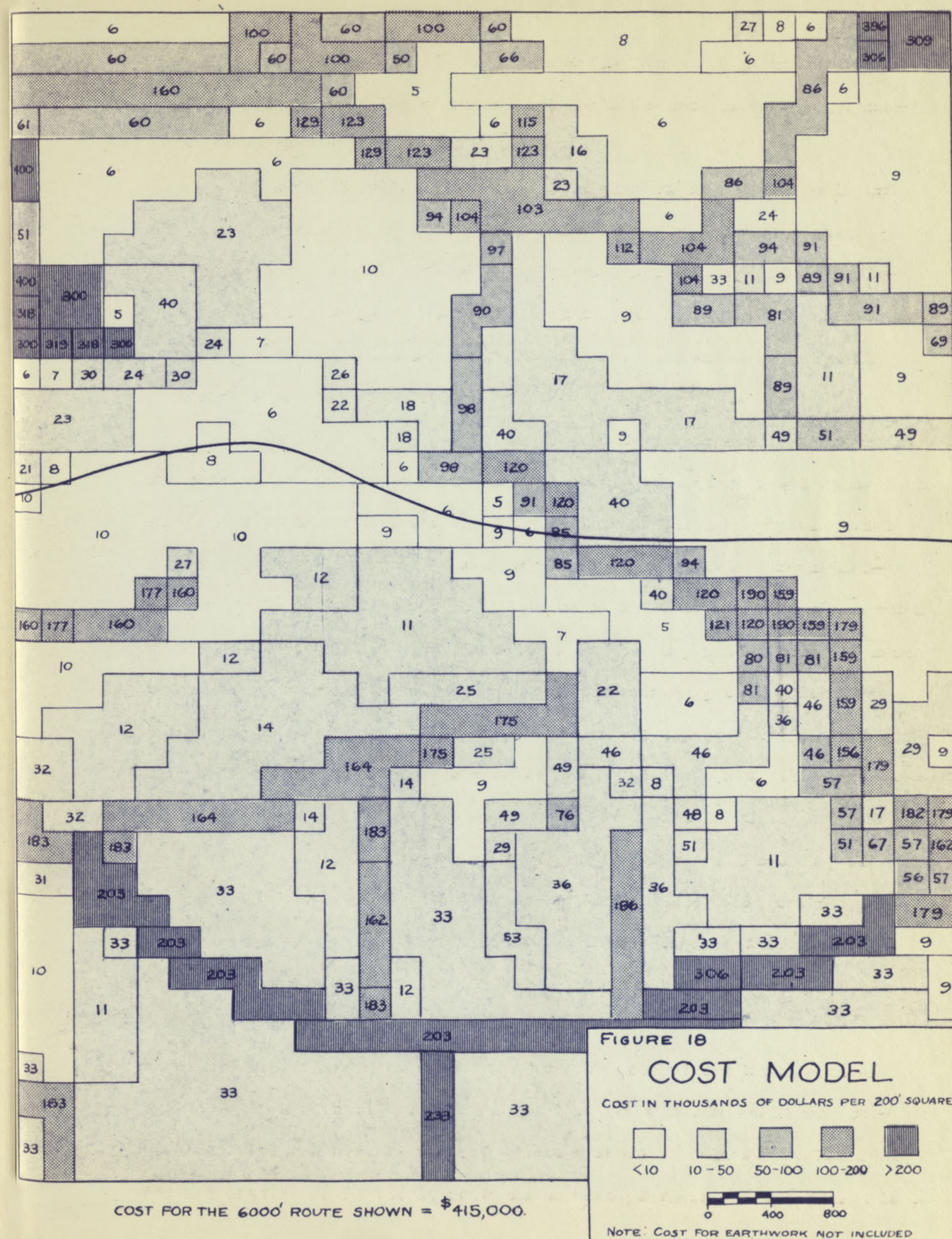
A modification of the same scheme would be to use a coordinate plotter to plot the results of each card on heavy cardboard. The cardboards can then be cut out with a pair of scissors along the plotted line and placed in a stand so they will stand side by side and slightly separated. Viewed from an angle the elusion of depth is created. The spaces can be filled with modeling clay if a solid model is desired. This method would be quite difficult and time consuming for the type results obtained.

Contour maps of the output were considered and discarded because of the difficulty of drawing contours from the digital output of the computer, and because of the nature of the cost model. The model contains many vertical faces and making a contour map would be much like making a contour map of the buildings of New York City.

A more sophisticated method of output presentation is to modify an automatic photograph dodging machine such as the Logetronic dodging machine so that it will read punched output cards and convert these impulses into brightness of light within each grid square. This brightness is then exposed onto film. After the film has been developed it will show shades of darkness proportional to the cost.

The most feasible method of using the output data from the computer seems to be to use the numbers direct. A card tabulator is set up so that it will print the output cards onto a continuous sheet of paper. A set of three digits of output for each point is placed within a space corresponding to the grid squares. The result is the reproduced grid squares of the model each containing the cost of the highway within it. The cost model can be made much easier to see and understand by the addition of color. This is done by selecting several shades representing the various levels of costs. The darker shades represent higher costs while the lighter ones signify lower costs. The addition of color will give the engineer the visual impact necessary to examine various location possibilities by eye. The numbers which remain on the sheet are valuable to the location engineer for quantitative evaluation. This sheet can be adjusted in scale so that it will fit with the air photo mosaic and the two can be used together.

This general form of output was used to present the cost model of the Route 28 test section. See Figure 18. To make the model more comprehensible the costs are presented in thousands of dollars per 200 foot squares instead of in the logarithmic numbers previously described. Also,



COST FOR THE 6000' ROUTE SHOWN = $415,000.

the costs are not recorded in each square but only once for all contiguous squares. In order to be able to reproduce the drawing shading was used instead of color. The optimum route was selected by eye and placed on the cost model as an illustration of the way the final location might look. Notice that the cost of earthwork has not been included in the cost model.

Analog Output: An entirely different approach to the problem of output was also considered. It was felt that the problem would conveniently lend itself to a solution performed in an analog manner. If the variables could be analyzed on overlays and then added by placing them one over another to obtain the final cost model it would save the considerable trouble and effort of putting the problem in the computer.

The first method considered was the use of colored overlays. It was found that using color was difficult because of the many factors which color introduces. Luminescence, hue, shade, and available light tend to complicate the problem.

The use of color as an analog adder suggests the use of more easily applied tonal colors like black and white. These can be applied by filters. The filters are cut off sheets of film. A range of tonal colors which vary from black to white at the extremes is used. The filter material is trimmed to shape and applied to the air photo mosaic. The whole mosaic is built up in this manner like a patchwork quilt. The more expensive areas are covered with darker material and the less expensive areas are left with lighter tones. After all the variable sheets have had filter material applied they can be placed one on top another to produce a varying density analog model. The filter material would necessarily have to be calibrated so that when added the results would be consistent. This can be done by assuming the filters are made out of a number of unit filters. This unit filter might be one which allows the passage of 90% of the light falling on it. Then, two of these unit filters would pass 90% (0.90) = 81%. Three would provide 90% (0.90)(0.90) = 72.9% light passage.

One of the major problems of using an analog filter model is the problem of making it. It would be quite time consuming to have to hand cut all the filters and place them on the overlay. Another objection is the large number of different shades of filter that would be necessary. This second objection can be eliminated by the use of polaroid material. If one piece of polaroid material is used as the overlay then the different tones desired can be obtained by orienting an upper sheet in the proper direction and slicing it out with a razor blade to fit the bounds of the section. The direction can be specified mathematically by this expression.

$$I_u = I_o \cos^2 u$$

where I_u is the relative intensity of the light transmitted by two superposed polarizers when the angle between their polarizing axes is u and I_o is the relative intensity of light transmitted when the angle u is zero and the two polarizing axes are parallel.

Using the formula the direction of orientation of the polarizers can be computed from the cost recorded in the section. In this method the various overlays could not be placed one on top another to obtain the final result because the polarizing effect between two overlays would observe the final result, using a non-polarized film positive of each overlay in the final addition would circumvent this problem.

The major objection to the analog method in general is the complexity of handling the many small sections used as the filters on the overlay.

The analog method also incorporates no method for computing the volumes of earthwork. Earthwork volumes would still have to be computed on a digital computer. The ability to present an easily interpreted visual output appears to be possible using the digital computer. It is felt, therefore, that the digital approach shows more advantages than the analog approach.

5. DISCUSSION OF RESULTS

Using the highway location system proposed by this thesis it is possible to determine the costs for a road built in any location. This makes possible the comparison of many alternate routes or the selection by a computer of the optimum route. The ability to select the optimum route suggests the possibility of large location savings. It cannot be predicted just how much the location can be improved upon over routes selected using conventional location procedures. It is felt that there would be both more time and more expense required to produce a study of this nature. However, more engineering expense and time would be justified if a considerable cost saving could be effected. A full scale test project should be undertaken to see if significant cost savings can be made by using a system such as this.

The data gathering which precedes the location analysis is more extensive in this system than that performed in conventional practice. The methods are more efficient, however. It is expected that the costs obtained will be more accurate than those obtained for ordinary preliminary route studies, primarily because of the additional data which it is possible to analyze. The system works best if the planning staff is made up of specialists in the various phases of highway location. Using the integrated type of system allows the location engineer to consolidate and coordinate the work of many people.

Several of the parts of the system are very useful when used alone. The study of the system parts pointed up the usefulness of air photo analysis as an aid to the location engineer. It is extremely useful in the studies of land costs, soil surveys or in bridge location analysis. The use of an uncontrolled stereo air photo mosaic as one of the chief location aids would be beneficial in many cases. The optimum route selection procedure and the earthwork approximation method may have value in other applications. They can be used together without the rest of the system to select only the best earthwork path or band. The size of the grid used can be reduced and higher accuracies obtained. The development of electronic methods of surveying will increase the opportunities for using the approach used in the earthwork method because the terrain will actually be stored as numbers or as bits which can be converted to numbers. A modification of the earthwork procedure might prove valuable as a method for selecting the optimum site selection of tanks or buildings in rough terrain.

6. CONCLUSIONS

The nature and purpose of the thesis was essentially the exploration of highway location methods and the synthesis of a system to perform this location. For that reason there are relatively few conclusions. The most significant of these are:

1. Using the system as conceived it is possible to determine the costs for a road built in any location and to find the cost for the road built on the optimum location.

2. The comparitive costs can be obtained to sufficient accuracy to determine the most economical of the alternate routes. The accuracy will probably exceed that used in conventional preliminary route studies.

3. At the present time it is not feasible to make a definite conclusion about the practicability of the system. It is felt that there would be both more time and more expense involved in using the system. At the same time it appears there would be savings in cost of location.

4. The feasibility of the entire location system should be further tested using the completed computer programs on an actual full scale test project.

5. Parts of the system may be usable outside the system. The optimum route selection procedure and the earthwork approximation method both appear promising.

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APPENDICES

APPENDIX 1

GRID SIZES

100 Foot Grid

$$\frac{5280}{100} \times \frac{5280}{100} = 2{,}790 \text{ grid points per/mi}^2$$

$$\frac{100 \times 100}{43{,}560} = \frac{10{,}000}{43{,}560} = .23 \quad \text{or approximately 1/4 acre}$$

A final map scale of 1" = 50' seems appropriate, Grid will be 2" on this scale.

Photo scale = 1/3000, 1"=250', Grid for photos = 0.4 in sq.

200 Foot Grid

$$\frac{5280}{200} \times \frac{5280}{200} = 697 \text{ grid points per/mi}^2$$

$$\frac{200 \times 200}{43{,}560} = .918 \text{ acres or approximately 1 acre.}$$

Final map scale would be 1" = 200', Grid will be 1" at this scale, Photo scale is 1" = 800', 1/9,600, Grid for photos = 0.25 in. sq.

500 Foot Grid

$$\frac{5280}{500} \times \frac{5280}{500} = 11.2 \text{ grid points per/mi}^2$$

This scale is appropriate for larger scale reconnaissance photos.

APPENDIX 2

Flexible Pavement Thickness Design

using Asphalt Institute Thickness Design Manual

Design of Upper Pavement Layers

Traffic classification - very heavy

Maximum single axle load - 32,000 lbs.

Asphaltic concrete and macadam base

1. Suggested surface thickness for very heavy traffic - 4 in.
2. Minimum thickness pavement and base = 10 in. Base = 10 in. - 4 in = 6 in.
3. If penetration macadam is used for the base the 6 in. base thickness can be reduced to $\frac{6 \text{ in}}{1\frac{1}{2} \text{ in/in}} = 4$ in.
4. Base may be substituted for surface on an inch for inch basis.

Design of Lower Pavement Layers

For subbase material CBR assumed = 60% to 30%

For CBR = 30% only 6 inches total thickness of asphalt and base needed. Therefore, this is acceptable subbase material.

Silty subgrade

CBR assumed = 7%

Total thickness needed = 15 in.

Thickness of subbase = 5 in.

Because of frost action this design will not be acceptable. The Corps of Engineers Frost Design was used.

Design Freezing Index = 600

Combined thickness of pavement and base to prevent substantial subgrade freezing = 24 in.

Base thickness = 14 in. In the case of F-4 material add 4 in. of filter material. Total base thickness = 18 in.

Sandy subgrade

CBR assumed = 15%

Total thickness needed = 10 in. from chart.

No subbase needed if frost design is unnecessary.

If subgrade is frost susceptible, base thickness required = 14 in.

Granular subgrade

CBR assumed = 25%

Total thickness needed 10 in. from chart.

No subbase necessary.

If it assumed that this material is not frost susceptible.

Poor surface drainage

The base thickness design is governed by Frost thickness.

Base = 18 in.

It is also assumed that the grade line has been raised 1 foot.

Pavement Costs Computation for the Different Soil Types

Combined pavement and base of asphalt concrete and penetrated crushed stone, designed as 8 in., (with an effective design depth of 10 in) is assumed to cost 3.00/s.y. Fourteen inches of frost-free subbase is assumed to cost 1/50/s.y. and to vary in cost linearly with depth. These costs are based on the estimated costs for pavement on the Massachusetts Turnpike (80). The depth of pavement and base is held constant and the depth of subbase varied to fit the soil type and drainage conditions. The shoulder is assumed to cost $1/s.y. Special provisions are added where necessary.

Borrow cost assumed = 65¢/cy.

Kame and Ice Channel Deposits - design based on standard pavement with 3" leveling course of frost free gravel and a subgrade of frost free gravel.

Pavement and base

$$\frac{2 \times 24 \text{ ft.} \times 200 \text{ ft.} \times 3.00\$/\text{yd}^2}{9\text{ft}^2/\text{yd}^2} = \$3200$$

Shoulders

$$\frac{2 \times 10 \text{ ft.} \times 200 \text{ ft.} \times 2.00\$/\text{yd}^2}{9 \text{ ft}^2/\text{yd}^2} = \$890$$

Leveling course

$$\frac{3 \text{ in}}{12 \text{ in}} \frac{(2 \times 40 \text{ ft.} \times 200 \text{ ft.} \times 1.50\$/\text{yd}^2)}{9 \text{ ft}^2/\text{yd}^2} = 2670 \times 3/14 = \$572$$

Extra drainage facilities = $500

Total for 200 feet = $5162

Terrace - design based on standard pavement with 14 in. of frost free gravel subbase.

Pavement and base	=	$3200
Shoulders	=	890
Subbase	=	2670
Extra drainage facilities	=	700
Total for 200 feet		$7460

Till - design based on standard pavement with 18 in. of frost free gravel subbase.

Pavement and base	=	$3200
Shoulders	=	890
Subbase $(2670) $(\frac{18}{14})$	=	3430
Extra drainage facilities	=	1000
Total for 200 feet		$8520

Poor drainage areas - design based on standard pavement with 18 in. of frost free gravel subbase, grade raise of 1 foot and median drains.

Pavement and base	=	$3200
Shoulders	=	890
Subbase	=	3430
1 foot grade raise $\frac{100 \text{ ft.} \times 200 \text{ ft.} \times 1 \text{ ft.} \times .65\$/yd^3}{27\ ft^3/yd^3}$	=	482
Median drain - 200 ft. x 5.00$/ft	=	1000
Extra drainage facilities	=	1000
Total per 200 feet		$10002

Extra Cost of Drainage in Long Cuts - Design based on standard pavement with an additional 6 inches of frost free gravel, and side drains.

6 inches frost free gravel $\frac{6}{14} \times 2670$	=	$1150
Side drains 200 ft. x 2 x 4.00$/ft.	=	1600
Total additional cost		$2750

Extra Pavement Cost in Rock - design based on standard pavement with additional 6 inches of frost free gravel.

6 inches frost free gravel	=	$1150
Extra drainage facilities	=	200
Total additional cost		$1350