Dr. A. Keith Turner
Environment Consultants, Inc.
Lakewood, CO 80215

A Decade of Experience in Computer Aided Route Selection*

Computer aided systems, employing DTM, not only apply minimum path a algorithms but also must consider environmental assessment factors.

(Abstract appears on following page)

Dr. A. Keith Turner

Introduction

In 1966 digital terrain models (DTMs) were of considerable research interest. The quantification of photogrammetric terrain data, through retrofitting of encoders to existing instruments and by development of new instruments, promised new ways for capturing machine-processable data. Although crude by today's standards, the computers of that period were being utilized in many areas of engineering design research. Paul Roberts (1957) made some rather farsighted predictions when he proposed the use of DTMs for highway location studies. By 1966, early design programs were available from MIT; these evolved ultimately into the ICES ROADS package. Concurrently, new remote sensors were being developed and tested for many applications. Automated classification techniques were under development, partially in anticipation of the ERTS (Landsat 1) satellite.

At that time I decided to investigate methods of utilizing these new DTM data bases for transportation planning. I assumed that the mechanics of producing them would be resolved and, since MIT was well into the ICES ROADS development, I elected to concentrate on the corridor selection phase. At that time corridor selection was mostly concerned with earthwork and other engineering costs, so there was a close tie to classic DTM concepts and less to the remote sensing aspects.

Although not anticipated by me in 1966, passage of the National Environmental Policy Act (NEPA) in 1969 revolutionized the corridor selection process. Today the "best" design for a transportation system is no longer necessarily the one which produces the greatest reduction in travel time or the one which results in the lowest capital or user costs. Rather, it is the design that yields the highest social return on the transportation investment and reconciles most effectively the conflicting interests of the various groups affected by the proposal.

Location engineers are faced with analyzing larger numbers of interacting and conflicting location factors. Decisions are required concerning the number of factors and the relative importance of all factors. Sen-

* Presented at the ASP DTM Symposium, May 9-11, 1978, St. Louis, MO.

Photogrammetric Engineering and Remote Sensing,
Vol. 44, No. 12, December 1978, pp. 1561-1576.

ABSTRACT: *Experiments in computer aided route selection began in the late 1960s by combining minimum path algorithms and digital terrain models. Early applications led to progressive refinements. More advanced systems were developed and tested in 1975-76. The system is named* GCARS *(Generalized Computer Aided Route Selection).*

Design goals of the GCARS *systems include (1) machine independence, (2) economy, (3) effective man-machine dialogs, (4) system flexibility, (5) senstivity analysis capability, and (6) general compatability with existing planning methodology. Early versions only partially satisfied these goals, but most of these goals are substantially met by the current* GCARS *versions. A summary of a recent application to a 100 mile highway corridor in western New York and Pennsylvania illustrates* GCARS *capabilities.*

sitivity analyses are required. The digital computer offers an efficient means of applying models which describe the regional environment to the task of corridor selection. It should be noted that this requires the integration of a wide variety of digital models (or data-planes), each defining some component of the regional environment. The concept of a DTM should be broadened to encompass a wide variety of data, and will be so used in this paper.

The method I developed is defined as the Generalized Computer Aided Route Selection (GCARS) System. This paper traces the development of the GCARS System concepts from their applications in 1968 to the present. As shown in Figure 1, the past decade can be divided into at least three phases. Each phase contains a development-evaluation cycle. The earliest systems (GCARS I and II) were developed while the author was at Purdue. Evaluation included a number of test areas in Indiana and a short course for mid-western highway location engineers.

In Phase II, roughly 1970-73, the earlier revisions were modified to work on IBM 360 systems and an extensive series of evaluations were made in Canada, the United States, and Europe. Results of these revisions and evaluations were incorporated in a totally new system of programs called GMAPS-GCARS beginning in 1973. In these new systems the steps of model building were separated from those of corridor selection, the GMAPS programs (Generalized Map Analysis Planning System) being responsible for the former, while a new GCARS program suite was responsible for the latter.

The GMAPS-GCARS programs are designed to utilize interactive terminal dialogs in time sharing environments. The earlier GMAPS II

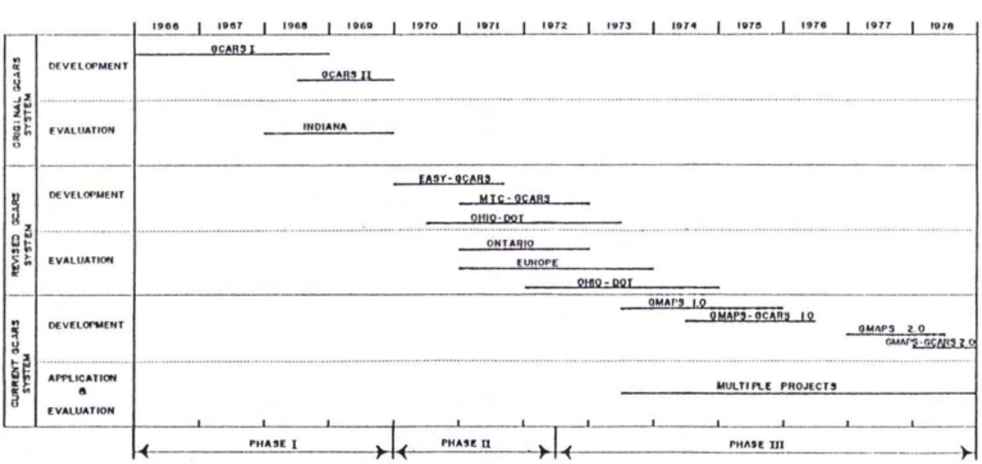

FIG. 1. Chronology of GCARS System development.

programs also operated this way, on one of the earliest interactive time-sharing systems (the Purdue PROCSY system), and had shown interactive computing to be very desirable. Lack of availability of suitable computer systems delayed the implementaton of new interactive systems until a DEC-10 System became available in 1972.

GCARS System Design Goals

The GCARS System development was guided by six design goals:

(1) The system should be *machine independent*; that is, it should be easily implemented on a variety of computers built by different manufacturers;
(2) The system should be *economical to use;* this goal was interpreted as modest computer core-storage requirements, and short calculation times;
(3) The system should provide *effective and convenient methods of man-machine information interchanges*; this goal appeared necessary in order to allow the engineer to apply his decision-making capabilities;
(4) The system should have *sufficient flexibility* to allow
  (a) suitable quantitative measures of all pertinent factors, and
  (b) the analysis of pertinent factors alone or in varying combinations;
(5) The system should have *sensitivity* to the factors being analyzed and include techniques of ranking and discriminating between the alternatives generated; and
(6) The system should have *general compatibility* with existing planning methodology and available, more detailed, design systems in terms of resolution and data requirements.

Obviously these design goals represent the ideal case; it was recognized that conflicts within and among these goals might prevent their complete achievement. Nevertheless they did represent, and continue to represent, an ultimate yardstick against which all computer-aided planning systems should be measured.

Basic GCARS System Concept

The central and most basic concept of the GCARS System was the application of minimum path analysis techniques to "numerical cost models" so as to generate a series of ranked alternatives. This concept is shown in Figure 2, where the various "numerical cost models" are shown as solid three-dimensional surfaces. In actual practice, they are stored as matrices within the computer. This concept has been described by some users as "linear programming with maps."

Desirable routes will follow the "valleys" across such "cost models." The most desirable combines directness and low "elevations" so as to obtain the lowest "total cost." Less desirable routes follow other valleys and "passes" over the intervening "high cost" areas. Sometimes such alternatives are short-

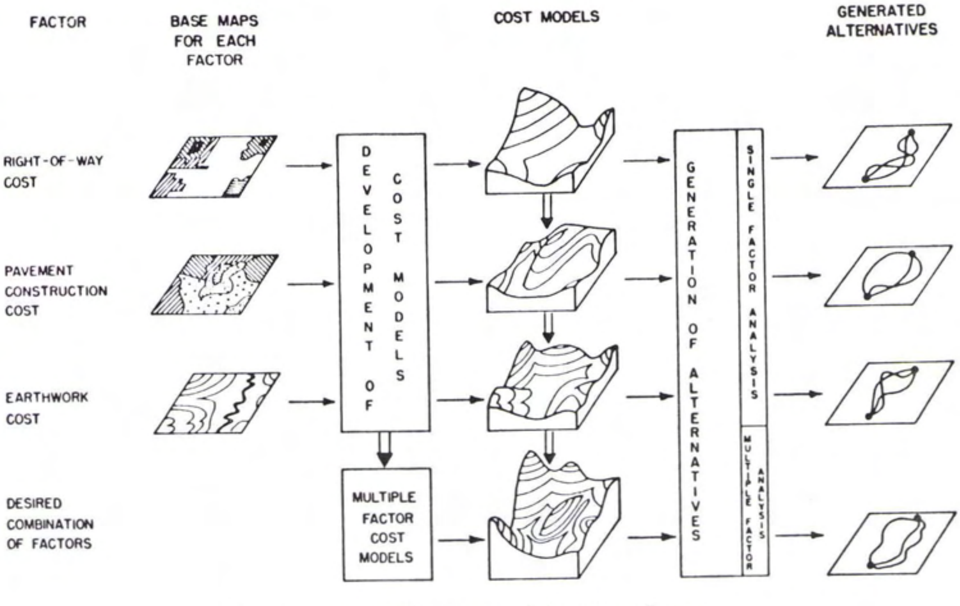

FIG. 2. The basic concept of the GCARS System.

er than the first choice and, although having a higher "cost" per unit length, may be more desirable. Thus, the various choices should be compared in terms of overall length and "total cost."

Minimum path analysis can be used to locate such valleys and alternate routes. A grid network is formed from the "cost models" matrix by joining all nodes. Each link is thus assigned the "cost" of traversing it; thus, minimum path analysis will discover the optimal path. Ayad (1967) proposed a method of generating a series of significantly different ranked alternative choices. If the central links forming the optimal route are raised in value, their re-use will be inhibited and reanalyzing the revised network will produce a second minimum—a "second best" alternative. Repeating the process will allow the generation of a ranked series of alternatives. Comparison of these paths leads to sensitivity analyses and forms the basis of impact assessments.

Figure 2 also shows that models for several factors can be superimposed and summed to produce "cost models" for any desired combination of factors. Before summation each model can be multiplied by a weighting factor, allowing it to be enhanced to any desired degree. Repeating minimum path analysis on networks derived from such combined models will generate a series of ranked alternatives in terms of combinations of factors. In the newer GMAPS-GCARS programs this model building concept has been expanded greatly and is contained within the GMAPS portion of the system.

The GCARS I System

In order to satisfy the goal of machine independence (Goal 1), all GCARS I programs were written a version of FORTRAN IV which closely followed the basic USASI Fortran standard. The programs were subsequently made to run on IBM 360 series or CDC 6000 series computers with only minor changes.

The goals of economy and interactive man-machine dialogs (Goals 2 and 3) dictated certain forms of programming and the extensive use of matrices to represent models. Graphical routines were developed which would produce contour maps on an incremental plotter or on the regular line printer. The line printer routines proved particularly useful since they were practically machine and output device independent, were able to produce maps concurrently with the rest of the job, and were economical.

Economy of computing was considered in terms of time (or speed) of computation and storage requirements. To some degree time and storage are interchangeable since greater speed can sometimes be obtained at the cost of larger storage demands. The programming methods and languages used may also affect time and storage requirements; thus, the economy and machine independence goals are somewhat contradictory. Since GCARS I required matrix representation of models and performed minimum path analysis on these matrices, storage requirements were largely associated with the matrix size while computation times depended on both the matrix sizes and the efficiency of the minimum path algorithm.

The minimum path algorithm portions of GCARS I System were adapted from Martin's FORTRAN coding of the British Road Research Laboratory algorithm (Martin, 1963). The adaptions improved by a factor of at least four the efficiency of the algorithm. It then appeared to be about as efficient as a general-purpose FORTRAN minimum path algorithm could be. Typical analysis times for maximum sized networks were about one minute per alternative. However, efficiency improved rapidly as the size of the matrix was reduced. The GCARS I system was therefore designed to analyze matrices up to 2500 points and generate five alternatives within five minutes of computer time while using only moderate core storage (around 165K bytes on an IBM/360). Thus, an analysis would cost somewhat less than $20.00 on many installations.

The goal of flexibility (Goal 4) appeared fairly easy to satisfy if one assumed that all factors could be measured on some type of value scale. The terms "costs" and "cost models" in the description of the basic system concept were placed in quotes to indicate that a much broader concept than pure monetary values was intended. At the time of GCARS I development there was considerable discussion concerning the measurement of value (Alexander and Manheim, 1962; McHarg, 1967, 1968, 1969; O'Flynn, 1968). O'Flynn (1968) discussed the problem at some length and concluded that "the most suitable approach is to outline the precise physical magnitudes of the non-market outputs." The initial GCARS System accepted this logic. Whenever possible monetary valuation schemes were applied. These were most easily determined for engineering considerations. Other factors were measured by the most appropriate measuring or ranking scheme, generally by one which reflected the physical conditions of the factor.

The sensitivity (Goal 5) of each analysis was measured in the initial GCARS System by comparing the path totals of each alternative to the first choice path total. A series of ratios were thus obtained and displayed along with the lengths of each alternative as shown in Figure 3. The engineer in charge of the study could use these ratios to measure the sensitivity of the corridors selected for any particular factor or factor combination since rapidly increasing ratios indicated a single, narrow, well-defined optimum band. However, no equivalent quantitative figure was developed to compare the routes generated for different factor combinations. The supplied sensitivity measures deliberately did not take into account any "route-dependent" factors, such as maintenance or operating costs, since after careful consideration it was concluded that the engineer was in the best position to make such judgment evaluations.

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 I       THE GCARS SYSTEM       I
 I PURDUE UNIVERSITY VERSION    I
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SEARCH ACTIVITY - PREPARATION OF THE UTILITY SURFACE.

AREA BEING ANALYZED IS NORTH

WEIGHT	FACTORS UTILIZED
2.00	EARTHWORK COST FACTOR
2.00	PAVEMENT CONSTRUCTION COST FACTOR
4.00	RIGHT OF WAY ACQUISITION COST FACTOR
1.00	O-D ZONE TRIP ENDS (SERVICE FACTOR)
1.00	NON-DUPLICATION OF PRESENT ROAD NETWORK

SEARCH ACTIVITY - GENERATION OF ALTERNATIVES.

REPEATED USE OF A MODIFIED VERSION OF THE BRITISH ROAD RESEARCH LABORATORY MINIMUM PATH ALGORITHM GENERATES AS MANY AS SEVEN ALTERNATIVES.

THE GENERATED ALTERNATIVES

CHOICE NUMBER	PATH TOTAL	RELATIVE PATH VALUE	NUMBER OF LINKS
1	887.712	1.000	41
2	942.152	1.061	41
3	982.362	1.107	41
4	1011.000	1.139	43
5	1033.446	1.164	45

FIG. 3. Typical GCARS output tables.

The GCARS I system design did not specifically consider the compatibility goal (Goal 6). However, since it was proposed to use GCARS as a supplement to normal route planning methods, it was believed that compatibility was achieved.

EVALUATIONS OF THE GCARS I SYSTEM

The GCARS I System design was tested in two Indiana test sites (Turner, 1968, 1970; Turner and Miles, 1971). Subsequently, demonstrations were given to practicing highway location engineers. Their reactions were generally highly favorable.

Sensitivity of the alternatives generated to the factor selected and factor weightings employed was often striking. The *economy* of the system was at first not as good as expected. Revision of some programs resulted in some significant improvement, however, and subsequently this goal was satisfactorily met. The *flexibility* of the system was also impressive. It was obvious that once models of various factors were developed a number of studies could be undertaken to test (1) changing priorities in factors, (2) changing projected route termini, or (3) modifying individual models by changing ranking schemes.

During early evaluations the grid nature of the models and subsequent utility networks used by the minimum path programs were questioned. However re-evaluation of these concepts indicated that they were the most practical alternative available at that time and should be retained.

DEVELOPMENT OF NEW TEACHING GCARS SYSTEMS

Due to favorable response, it was decided to present the GCARS System to a broader group of engineers and students and obtain their evaluations. Additional programming was required to convert GCARS from a research tool to a teaching tool used by a larger number of persons, some with little or no background in computer use.

The development and testing of the models seemed to require close supervision; however, once they were checked and approved, the generation of alternatives could become the subject of classroom projects. Thus, some thought was put to the development of conversational, or at least remote, entry of requests for the generation of alternatives on a simplified basis. The following systems were developed:

(1) GCARS II at Purdue University (Turner, 1969c), and
(2) EASY-GCARS at the University of Toronto

Both GCARS II and EASY-GCARS sacrificed, to some degree, the goal of machine independence to satisfy "customer convenience."

THE GCARS II SYSTEM

In 1969 Purdue University developed an interactive computing system, called PROCSY, which allowed a large number of remote terminals to create, submit, and retrieve jobs. A series of specialized computer programs were prepared which allowed users to access the GCARS I programs and data sets via the PROCSY system. These programs were called GCARS II.

GCARS II proved to be an ideal teaching tool. After ten or fifteen minutes instruction, engineers attending a short course were able to use the system to submit their job requests. The chief advantage of the system was its interactive nature—the terminal prompted the engineer during the submission procedure with a series of questions to which he responded and so prepared his job request.

THE EASY-GCARS SYSTEM

EASY-GCARS was developed in 1970 for classroom teaching at the University of Toronto. An IBM 360/65 was available, but without terminal support capabilities. It was therefore decided to develop a simplified request system which could be submitted as a series of batch jobs in the regular job stream. Since the cards had to be punched by inexperienced persons, it was desirable to have them as simple and flexible as possible. Accordingly, a FORTRAN program, called EASY, was developed which utilized the NAMELIST statement as available in the IBM FORTRAN. Each student was supplied with a set of JCL cards and submission instructions.

Although not as easy to use as the GCARS II system because the interactive features of GCARS II were lost, EASY-GCARS proved to be relatively easy to use by people having little previous contact with computers. EASY-GCARS was used successfully by students at the University of Toronto and by engineers attending a short course in London, England. In the latter case about 95 percent of the jobs submitted ran successfully.

REACTIONS TO THE GCARS II AND EASY-GCARS SYSTEMS

The users of GCARS II and EASY-GCARS were encouraged to express their opinions concerning the advantages and limitations of GCARS and to suggest what modifications they felt to be desirable.

In general the users appeared to be convinced that the concept of a computer-aided system along the lines of GCARS I would prove viable, although all found GCARS I itself to have some weaknesses. Those users who had access to the interactive terminals of GCARS II were perhaps more positively impressed than those whose "man-machine dialogs" were restricted to card input and printed output. The immediacy of the teletype responses encouraged the development of a rapport between the engineer and the data. The engineers began to design the project interactively, developing it progressively job by job.

A general consensus was reached that, *provided realistic data could be made available,* GCARS gave realistic answers and responded with some sensitivity to changes in factors. A number of limitations of the GCARS System were uncovered by the use of GCARS II and EASY-GCARS. Identification of such limitations led to proposals for changes. Some doubts were expressed about the ultimate economy of the minimum path algorithm. Proposals to improve computation times included fairly extensive modifications such as

- development of special-purpose FORTRAN algorithms,
- programming the minimum path algorithm in assembly language to optimize the program as much as possible, or
- combine both the above suggestions.

A number of engineers questioned various aspects of the use of a grid pattern for model description and the definition of the network. Proposals were made which would either refine the present computations or increase their flexibility. The following is a complete list of proposed modifications:

- Changing the shape or size of the grid;
- Allowing movement on diagonals as well as forwards and sideways;
- Utilizing the table of nodes passed through by each alternative to search and tabulate the conditions, such as soil types, land use categories, etc., encountered by each choice;
- Modifying or adding methods of ranking the alternatives;

- Modifying the central percentage of links (originally set at 93 percent) being removed from consideration before generation of the next alternative;
- Allowing for the optional complete removal of certain links in the network to prevent travel across certain areas, and
- Allowing the retention of certain links in "control sections" so that many choices can utilize a bridge or tunnel crossing site.

The GMAPS-GCARS System

The GMAPS Programs

In 1973 work began on a new system of programs which would incorporate improvements suggested by the experience gained in use of the earlier systems. The needs for environmental impact assessment required the development of much more sophisticated data base manipulation systems which addressed the need for flexibility, speed and economy, comprehensitivity, and increased quantification of data and conclusions.

The GMAPS System computer programs were designed to address these needs. A cellular mapping format was selected because such a system appeared attractive to many government and private users. Cellular mapping techniques had been applied experimentally to several studies in the western states. Because considerable investment had been made on data bases for such systems, GMAPS was designed for data compatibility with these. GMAPS differed from these existing, batch operated systems by virtue of its interactive, self prompting operation. This makes GMAPS very attractive to use because

- the programs are self prompting; they ask a sequence of questions to which the user responds thereby defining the operations and sequence of operations the user wishes to perform;
- the programs allow the user to verify and correct commands, so that meaningless operations are eliminated;
- the system is easily used by laymen; and
- the time sharing concept gives the user economical access to a high capacity computer.

The GMAPS programs utilize a composite computer mapping technique. Composite mapping has traditionally been a manual procedure involving the construction of successive transparent overlays on which values were represented by graduated tones or colored shadings that indicated the relative value of a particular factor within a given geographical area. In this manner, optimum areas were visually located with respect to some given decision criteria.

In composite computing mapping, the overlaying of tonal transparencies is replaced by the algebraic combination of two or more matrices whose elements have numerical values corresponding to the grey toned densities. The GMAPS compositing capabilities are quite extensive, and include both arithmetic and logical compositing procedures. Arithmetic compositing is a simple extension of the tonal overlay procedures, but allows much more varied analyses using combinations of addition, subtraction, multiplication, and division in conjunction with the ability to weight some components more heavily than others. Logical compositing is even more flexible because it allows a detailed examination of the conditions within each map cell and the creation of a resulting composite map which reflects these conditions.

The most important decision made in the compositing process is the determination of the relative values or weights given to two or more factors which are to be combined. Such weightings are called external weightings. All conditions shown within a single map must also be given desirability values. These are called internal weightings and range from 0 to 9.

Weights are assigned whenever possible based on known cost or established scientific relationships. On issues where a clear public preference has been established through public opinion surveys, weights are assigned to reflect these findings. When qualitative judgments are necessary, as in the case of evaluating scenic sensitivity, an interdisciplinary team is utilized. Additionally, when a difference in weights might substantially affect an analysis, a number of different weightings are used so that the results can be compared.

The GMAPS programs require no specialized computer equipment for either data input or display. The procedures were designed specifically for use by nontechnical personnel at field office locations. They have been applied to a variety of studies of many scales. Studies have been conducted in areas as small as 30 square miles while others have covered the entire United States. Optional data sources, such as census data tapes and Landsat digital imagery classifications, can be entered into the GMAPS data bases.

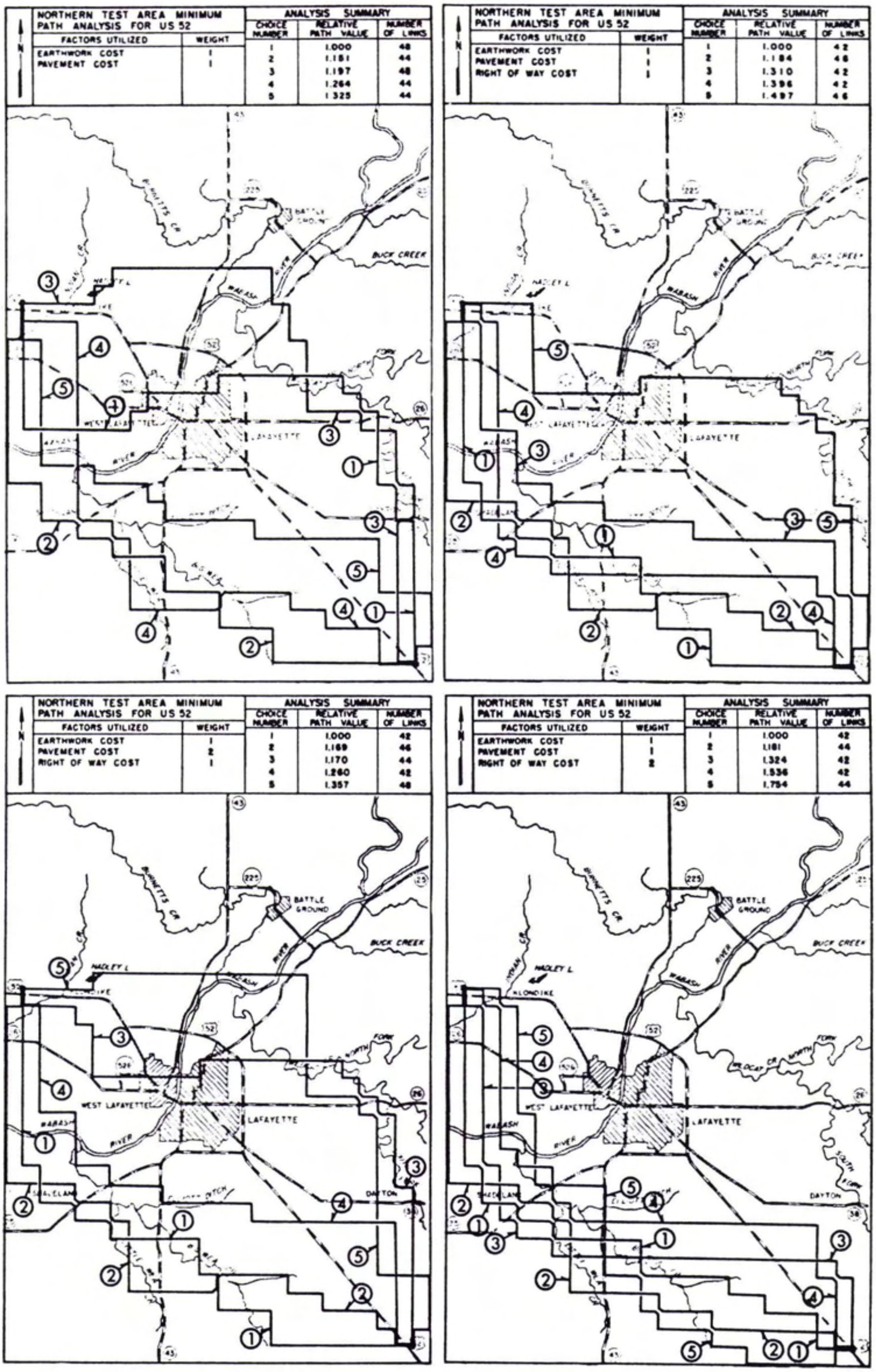

Fig. 4. Generated alternatives for four combinations of factors.

Displays are most commonly created used the standard line printer. These can be photographically reduced and printed in black-and-white or color using normal offset printing techniques. More sophisticated displays have been produced in situations where specialized equipment and needs existed. These include CRT displays, direct production of 35 mm color slides, use of electrostatic plotters, and the production of color prints from the slides via xerox, color photographic processing, or offset printing methods. Examples of standard line printer and 35 mm color slide displays are included in this paper. The color slides were produced by the author at the Los Alamos Scientific Laboratory using a modified FR-80 plotter.

THE GCARS PROGRAMS

An entirely new sequence of GCARS programs was developed to interface with the GMAPS data base. These programs incorporated all the suggested improvements outlined earlier. A new minimum path technique had been proposed by the Ohio DOT. Further research and reprogramming of their algorithms resulted in marked reductions in computation times and core requirements. The new algorithm was substituted and comparisons indicated that it was 10 to 20 times more efficient. The new algorithm had several advantages: it allowed movement along diagonal directions, core requirements were drastically reduced, and computational efficiency was a linear function the length of the corridor.

The GCARS programs produce maps of the routes, either on their own or superimposed on appropriate gray-tone cellular maps. They also produce statistical summaries which give the user the basic path totals, lengths, and comparisons needed to make his assessments. Additionally, the planner is assisted in evaluating goal achievement and cost criteria. Achievement can be measured by comparing each alternative corridor generated for some composite suite of goals to the optimal corridors produced by evaluating each goal dependently. Cost evaluations are made by overlaying the generated choices on a construction cost model.

GCARS Applications

In order to demonstrate how these systems have evolved in the past decade, examples of an early GCARS I project are compared to a recently completed GMAPS-GCARS project.

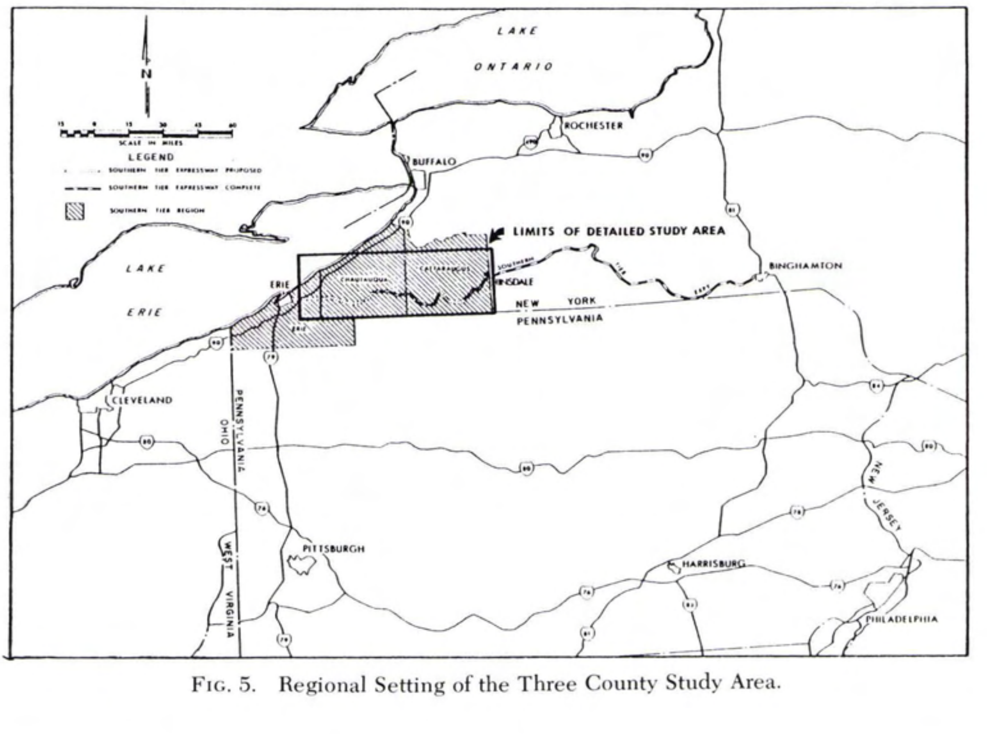

FIG. 5. Regional Setting of the Three County Study Area.

GCARS I LAFAYETTE INDIANA STUDY

The study area was 19 by 24 Kilometres (12 by 15 miles) and centered on the Lafayette- West Lafayette metropolitan area in an otherwise typically rural mid-western setting. The Wabash River valley formed the major topographic feature. A total of seven models were constructed. All utilized a comparatively large cell size of about 1 km by 1 km (½ mile by ½ mile). Over twenty combinations of factors and factor weightings were studied (Turner, 1970). Four selected corridor analyses are shown in Figure 4. While these do show how the optimal corridors shift to reflect different factor weightings, they also show the limitations of these early GCARS I programs. The movements along diagonals were not possible, resulting in inflated path totals, and the routes were only approximately located, since the 1 km cell resolution was too coarse to allow more precise definitions.

THE SOUTHERN TIER EXPRESSWAY STUDY

In 1975-76 the GMAPS-GCARS systems were utilized to aid in the environmental impact analysis of about 160 Kilometres (100 miles) of new four lane highway, the Southern Tier Expressway in extreme western New York and Pennsylvania (Figure 5). The impact assessment included a description of the transportation and transportation-related problems, resulting transportation needs, specific project objectives, transportation location alternatives, and an evaluation of potential impacts associated with each alternative. The scope of the project was therefore quite broad; it extended considerably beyond the capabilities of computer aided assessment embodied in GMAPS-GCARS. Nevertheless, the GMAPS-GCARS systems played a significant role in the analysis of location alternatives and in the assessment of each.

To develop as comprehensive and com-

TABLE 1. BASELINE, DERIVATIVE, DETERMINANT, AND COMPOSITE DATA DISPLAYS

Baseline	Derivative	Determinant	Composite
Accessibility	Land Values		
Land Use			
Pipelines and Transmission Lines	Erosion Potential	Land Acquisition Cost	
Existing Transportation			
Landforms	Existing Maintenance Conditions	Construction Cost	Highway Site Feasibility
Soil Types			
Slope			
Mean Annual Rainfall	Geotechnical Factors	Maintenance Cost	
Mean Annual Snowfall			
Water Bodies	Drainage Potential		
Ecologically Sensitive Areas	Water Quality Sensitivity		
Groundwater Yield			
Water Bodies	Erosion Potential		
Recreation		Ecological Impact	
Land Use	Vegetation Types		
Landforms		Land Use Impact	
Slope	Scenic Sensitivity		
Agricultural Districts		Energy Utilization Impact	Environmental Impact
Areas of Highway Needs	Agricultural Productivity		
Soil Types			
Historical, Archeological, and Cultural Sites	Noise Sensitiity	Cultural and Social Impact	
Population Density	Air Quality Sensitivity		
Level of Service			
Outmigration	Areas of Economic Need		
Unemployment			
Land Use	Institutions, Recreation, and Commercial Areas		
Average Family Income		Stimulate Regional Economy	
Recreation			
Population Density	Growth Centers		Social and Economic Benefits
Trip Attraction		Improve Accessibility	
Accessibility	Areas of Highway Need		
Landforms		User Benefits	
Mean Annual Rainfall	User Costs		
Mean Annual Snowfall			
Level of Service	Safety		

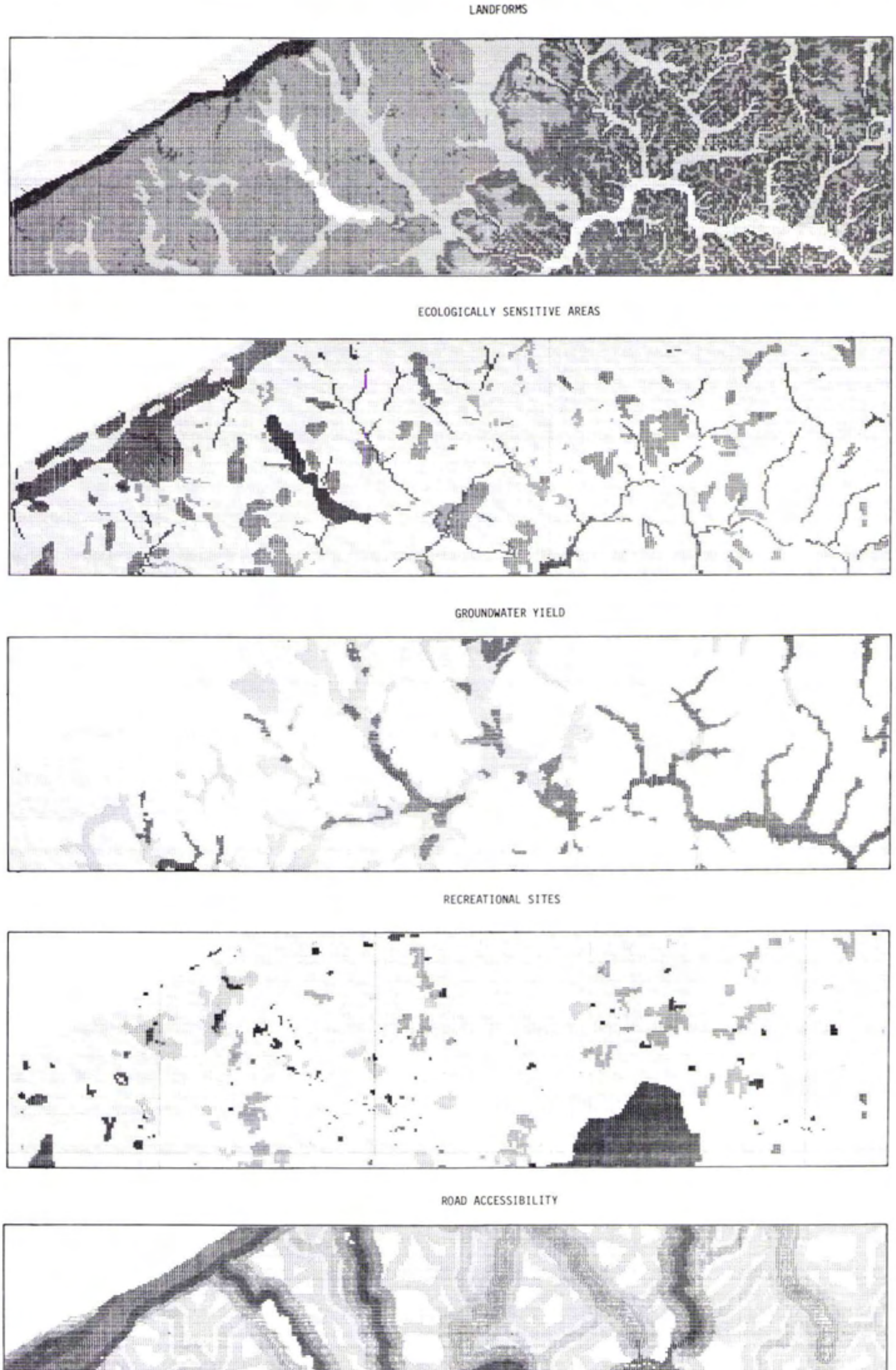

FIG. 6. Five GMAPS map displays.

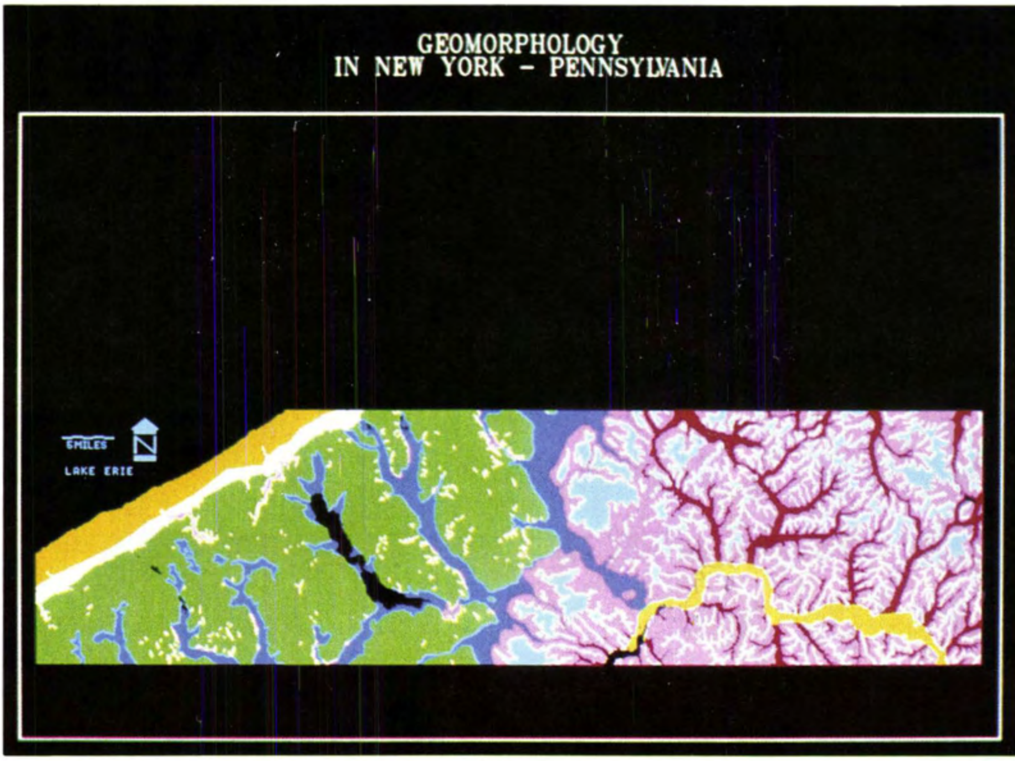

PLATE 1. Color display of geomorphology data base (Courtesy of Los Alamos Scientific Laboratory).

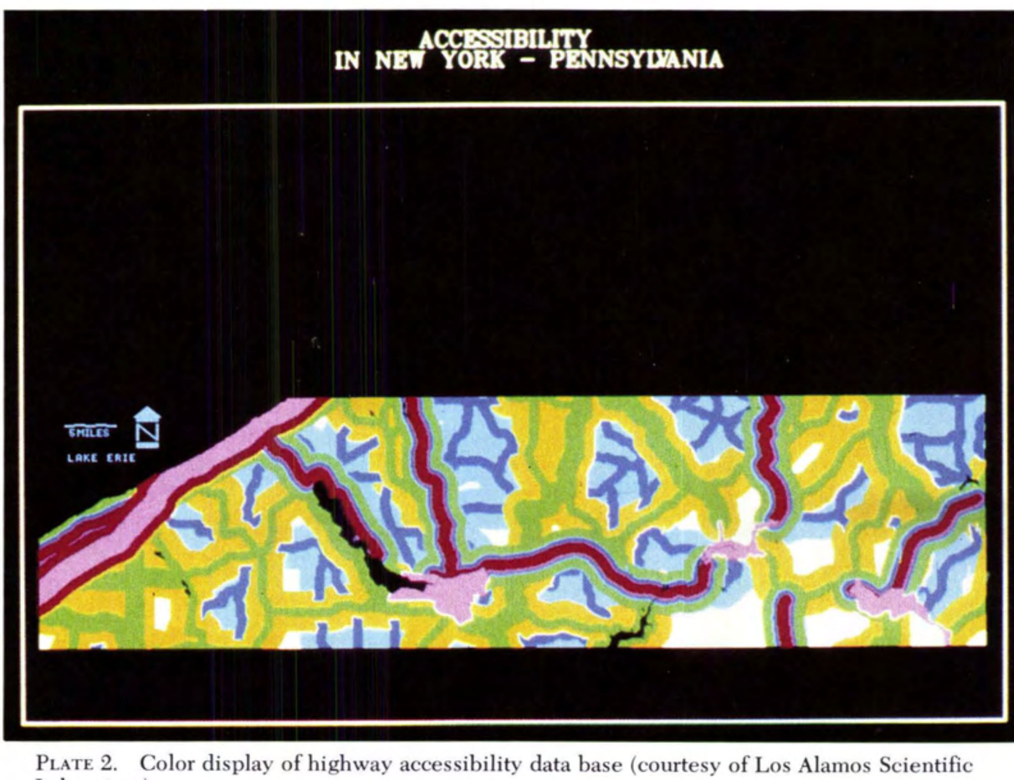

PLATE 2. Color display of highway accessibility data base (courtesy of Los Alamos Scientific Laboratory).

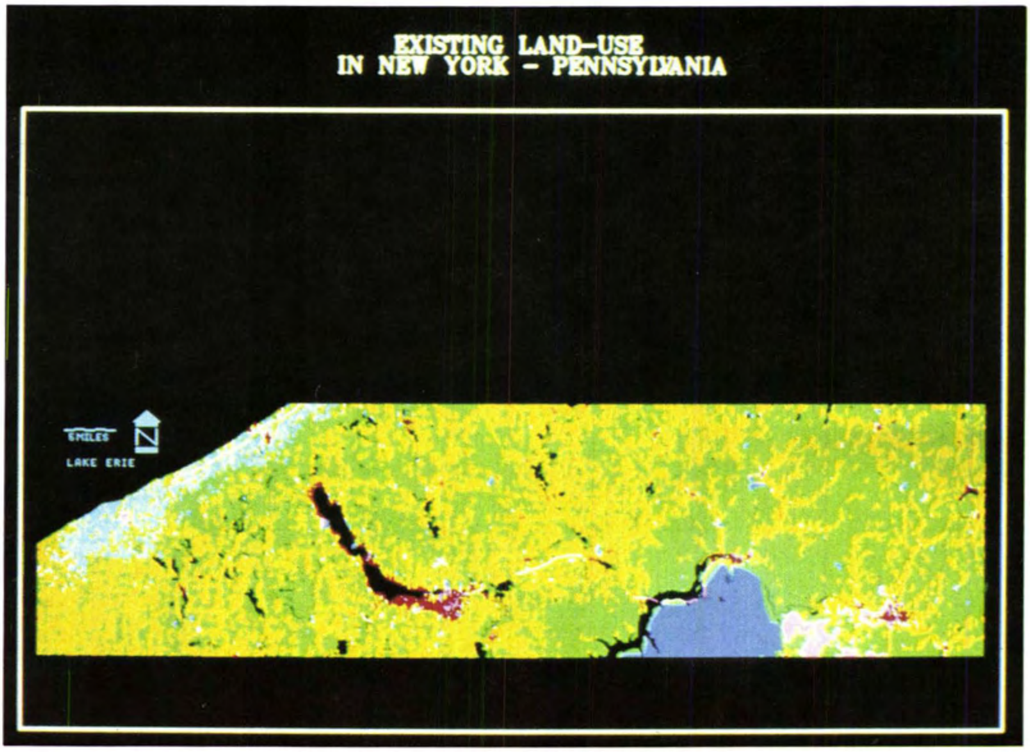

PLATE 3. Color display of existing land-use data base (courtesy of Los Alamos Scientific Laboratory).

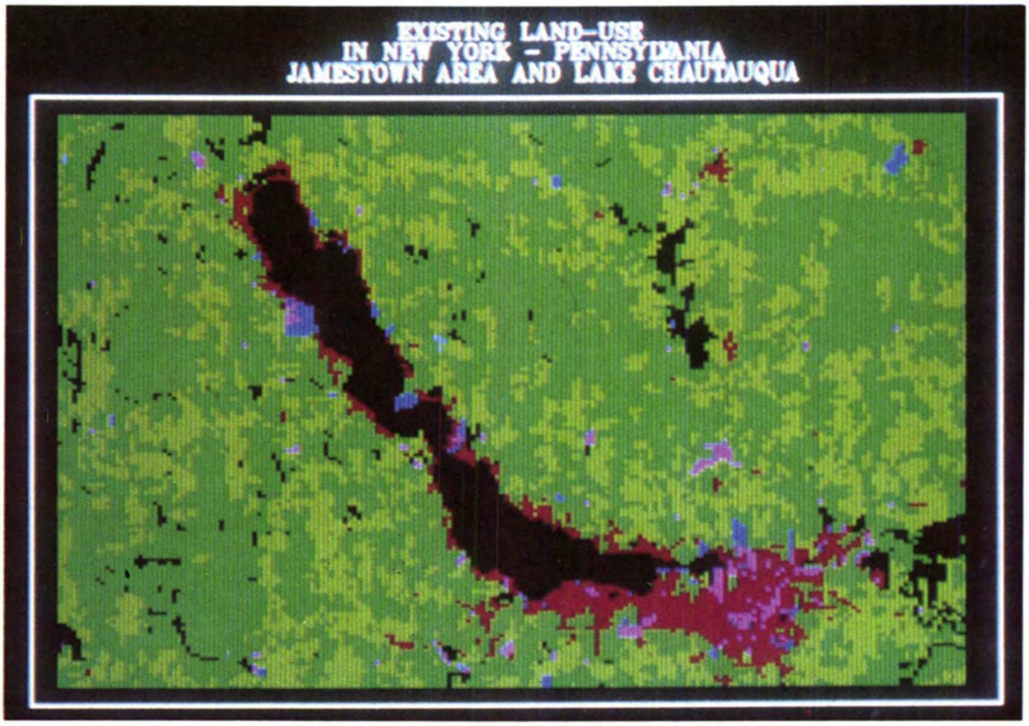

PLATE 4. Color Display of Existing Land-Use Detail in Jamestown-Lake Chautauqua Region (courtesy of Los Alamos Scientific Laboratory).

plete a group of highway alternatives as possible, the GMAPS-GCARS analyses were checked by an independently conducted conventional transportation analysis. The combination of these two procedures provided as objective a group of alternate corridors as possible.

It was important that potential highway corridors selected for detailed cost evaluation and environmental impact assessment be identified on the basis of social, economic, and ecological considerations as well as engineering feasibility. A rectangular detailed study area was selected for the GMAPS-GCARS analyses (Figure 5). This area was chosen for a number of reasons. Important considerations were that it encompassed all previously expressed corridor preferences. It incorporated I-90 and existing Southern Tier Expressway segments; it enabled all reasonable alternative corridors to be considered by embracing an area sufficiently broad to allow for any practical corridor circuity; and it was the area which earlier study had shown to be of greatest impact, influence, and interest with reference to the Southern Tier Expressway.

Data for 22 baseline maps (Table 1) describing a variety of engineering, cultural, economic, and environmental factors were plotted on 1:62 500 scale topographic base. These data were converted to a cellular matrix representation and entered into computer storage via the GMAPS programs. The resolution of this digital data was 3.16 hectares (7.8 acres) or a rectangular cell 198 metres by 158 metres (650 by 520 feet). A total of almost 180,000 cells were required.

The GMAPS programs allow for the manipulation of data bases to create new models by overlaying, or "compositing," techniques. GMAPS displayed all maps in black-and-white (Figure 6) or color (Plates 1 to 4) and GCARS-generated routes superimposed on such maps (Figure 7). As shown in Table 1, the GMAPS process produced a series of derivative, determinant, and ultimately composite models.

Derivative maps provided more refined or specific descriptions of some aspects of the regional engineering, economic, or environmental conditions than the baseline maps from which they were derived. Determinant and composite maps were increasingly complex models depicting some aspect of suitability for highway location as specified by their titles. The GMAPS process was used to produce maps which were valued to show the desirability of locating a highway corridor based on

- engineering feasibility,
- improving social and economic conditions in the region, and
- environmental impact.

These three maps were then combined to produce a sequence of highway corridor feasibility maps, such as shown in Figure 7.

GCARS procedures were applied to these models. In each case a sequence of corridors were determined, such as shown in Figure 7. After many such analyses were run, a general pattern emerged with five major alternatives dominating. Although the computer analysis could assure an unbiased corridor identification process based on a given set of criteria, conventional analysis permitted the transportation planners to compare and evaluate suggestions and opinions concerning specific corridors of interest developed by public opinion surveys.

Subsequently the results of both techniques were combined and analyzed. Certain conclusions were obvious:

- in general major alternatives selected by each process were identical,
- each procedure had identified several routes or segments which could upon qualitative inspection and analysis be discarded from further consideration, and
- several additional logical routes were identified by comparison of results requiring the addition of only small corridor segments.

As a result, 12 alternative corridor locations were developed utilizing various combinations of 31 segments.

These corridor locations were re-entered into the GMAPS-GCARS programs. Computation of the levels of impact of each alternative on any baseline map or derived model was possible, and allowed for the rapid comparison of all alternatives.

The use of computer-aided techniques reduced the time required for the study. First, they allowed for a more rapid generation of a very large number of alternatives reflecting a variety of constraints. This resulted in a draft Environmental Impact Statement (EIS) being prepared in just over one year, rather than the two years normally expected. This occurred in spite of the complexity and controversy surrounding this project.

Furthermore, the final EIS was produced within a further six months, or about 18 months from study initiation, rather than the

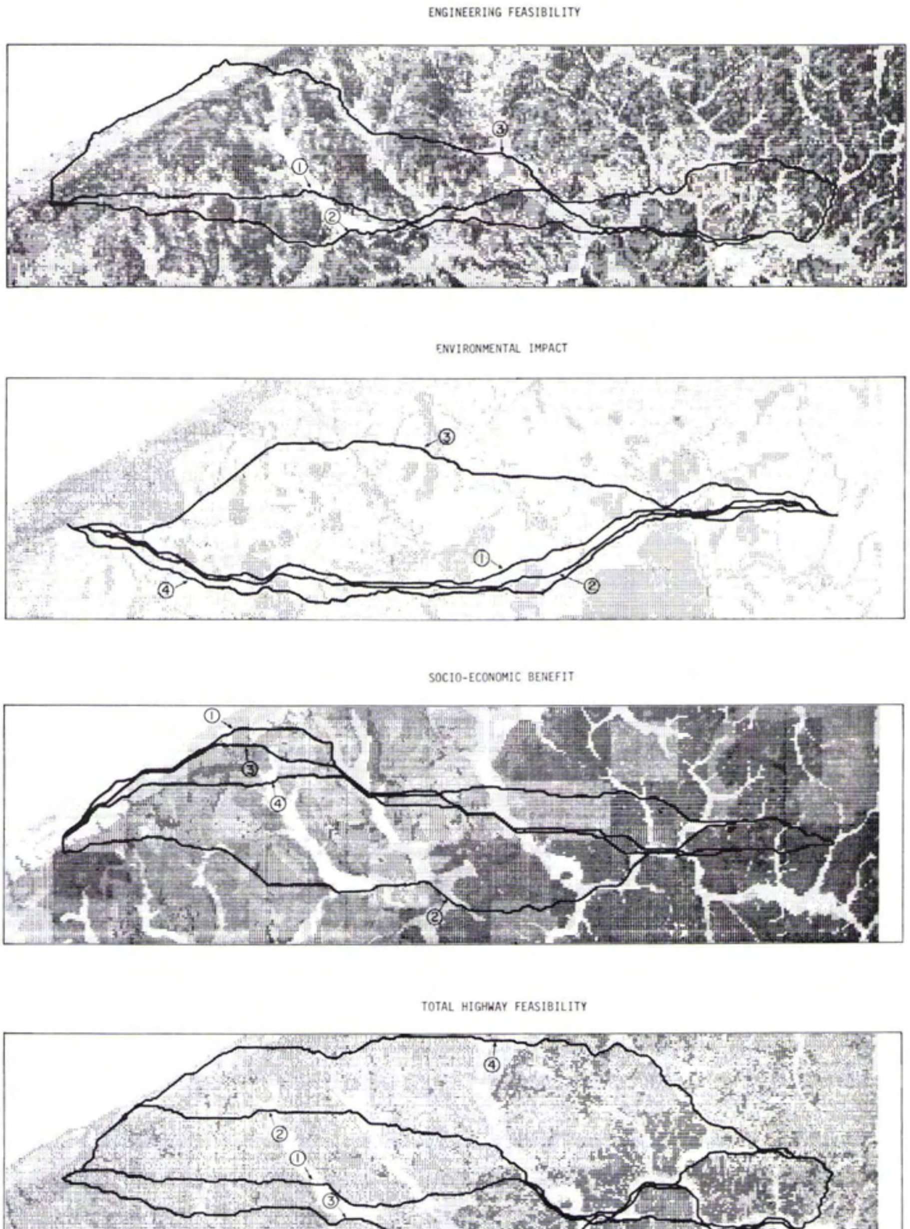

FIG. 7. Four GCARS alternative route analyses.

more normal two to three years. Final government approval for the project occurred in slightly over two years from study initiation. Within this period a contentious situation was transformed into one where there was substantial agreement.

CONCLUSIONS

It seems probable that computer-aided planning systems incorporating at least some of the GCARS System elements will have a large role to play in future planning methodology. Computer-aided systems are particularly attractive in analyzing complex on ambiguous factor interactions, and the trend to greater complexity and ambiguity of location factors seems well established. Recent studies have shown that, in the highway field at least, early project planning is constrained by environmental assessment considerations. Although new highway construction appears to be on the wane, demands for new electrical transmission lines and for oil, gas, or coal slurry pipelines seem to be on the rise. The location analyses for these transportation forms can be ideally handled by these GMAPS-GCARS systems.

The prediction of increased importance and acceptance of computer-aided planning systems such as GMAPS-GCARS is based on three trends presently underway:

- the availability of good quality, computer-processable "data banks;"
- the development of "companion" computer systems to handle other aspects of transportation planning and design; and
- the widespread installation of "time-sharing" computer systems with interactive terminals.

ACKNOWLEDGMENT

The computer generated color displays (Plates 1-4) were produced by the author while he was engaged as a visiting staff scientist at Los Alamos Scientific Laboratories, Los Alamos, New Mexico. The author gratefully acknowledges the use of LASL equipment in applying advanced computer graphics techniques to composite mapping procedures.

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