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Application of Computer and Interactive Graphics

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Contents

Interactive Network Model for Analysis and Cartographic Display of Railroad Traffic Flow

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To implement provisions of Section 503 of the Railroad Revitalization and Regulatory Reform Act of 1976, the Federal Railroad Administration sponsored the development at Princeton University of an interactive computer graphics model of the U.S. rail system. The model has been implemented and applied to a number of railroad problems, including the flow of freight traffic, accident locations, flows of hazardous materials, traffic diversions, and Amtrak passenger volumes. Some of the problems encountered in the development of the network model and the data base are described, and examples of applications of the model are offered and illustrated with copies of the graphic displays produced for each case study. The interactive system used for model development and implementation is discussed. Finally, some general observations are made on the value of interactive computer graphics in rail system planning.

In recent years, the U. S. rail industry has undergone a number of major crises and significant erosion in terms of physical plant, traffic, and revenue. Because of the poor health of the industry and its vital role in the nation's economy, the U. S. Department of Transportation (DOT) has become increasingly involved in planning and systems analysis of railroad traffic. Through the Railroad Revitalization and Regulatory Reform (RRRR) Act of 1976, the Federal Railroad Administration (FRA) received a mandate from Congress to begin planning for restructuring of the U. S. rail industry (1). FRA was to consider line abandonments, corridor consolidation, and rehabilitation priorities and in general define a national system that would serve U. S. rail transportation needs.

Under Section 503 of the RRRR Act, FRA was required to identify, classify, and designate class 1 railroad lines according to priority. Each segment of the rail system was to be evaluated as to its importance as a main or branch line within the network. To facilitate this analysis, FRA turned to interactive computer graphics as a technique for communicating information about the rail network.

To disaggregate the rail system into segments of comprehensible size, 132 geographic sectors were created (see Figure 1) (2). This geographic subdivision required the development of 132 maps for the final report, each map containing several hundred kilometers of railroad line. Only through use of computer-generated maps could the Section 503 report be produced within the limited time available.

To develop the necessary computer software and data base needed to produce the maps, the Office of Rail Systems Analysis and Information of FRA awarded a research contract to the Interactive Computer Graphics Laboratory and Transportation Program of Princeton University. Princeton had previously developed a capability to interactively assign traffic to networks and display results in real time by using Tektronix graphics computer terminals.

This interactive graphic traffic-assignment capability had been tested in an October 1975 study of the financial assumptions underlying the U. S. Railroad Association (USRA) Final System Plan for Conrail (3). Under contract to the Subcommittee on Transportation and Commerce of the U. S. House of Representatives, the Princeton team had digitized the Conrail network and flowed expected traffic to indicate line traffic densities. These estimates of traffic density were used to assess the impact of seasonal variations in traffic demand.

As a result of the development of the interactive graphic version of the FRA railroad network model, many projects have been undertaken in which interactive graphic display has been the primary technique for analysis and planning for rail traffic. This paper discusses some of the steps required to set up the model, shows examples of graphic output, and describes some of the projects in which the interactive model has been used. The interactive system used by the Princeton University Interactive Computer Graphics Laboratory is discussed. The paper concludes with some observations on the value of interactive computer graphics in rail systems planning.

SETTING UP THE INTERACTIVE FRA NETWORK MODEL

The original version of the railroad network model was digitized elsewhere and provided by FRA in machine-readable form (4). When the network was displayed on the screen of the interactive terminal, it became apparent that it would be necessary to correct for obvious errors, including a New York-Bermuda railroad connection and a node in the middle of Lake Michigan. Errors such as these are to be expected in any data base as large as the U. S. rail network model, which contains approximately 18 000 links and 16 000 nodes. Such errors are corrected from the terminal by using a microscopic graphical editor—a specialized processor written in APL and designed to address localized errors in the geocoded data base. The analyst uses thumbwheels mounted on the Tektronix 4015 keyboard to control a graphical cross-hair cursor that appears over the map display. The analyst moves the cursor to the nodes to be corrected and enters appropriate commands to delete the errant point or to relocate it to the proper position on the map by moving the cross-hair cursor across the screen.

The original digitized model did not include a geographic representation of the United States in terms of state and county political boundaries or the major water boundaries. Any proposed solution to the problems of the U. S. railroads includes severe geopolitical implications. The most fundamental analytical tool required, therefore, was the capability to correctly overlay the railroad network on a political map of the United States with reasonable accuracy to the county level, to show the geographical consequences of any analysis or proposed modifications. Thus, the first task encountered was the merger of the geographic component of the FRA data base with a Federal Highway Administration (FHWA) geopolitical data base that contained digitized state and county boundaries (5).

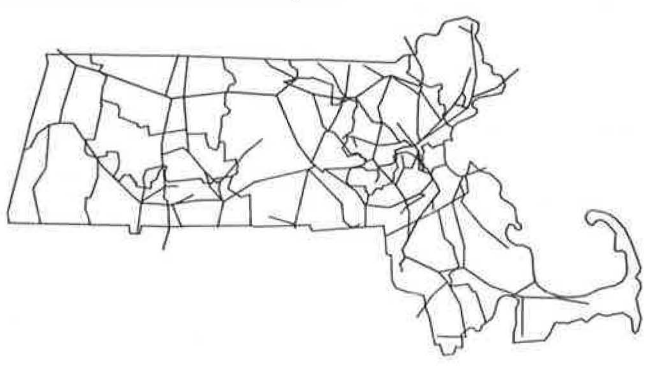
It turned out that the two data bases were produced under different cartographic projections, and the information for the projection used in the creation of the railroad model was not available. To overcome this problem, the geographic representation of the railroad system was converted to one that corresponded to the projection used for the geopolitical data base. The results of this conversion presented the first challenge to the interactive system since the two maps did not match even after the appropriate transformation had been applied. This called for the development of a macroscopic graphical editor, which is written in APL and is capable of addressing global errors in the data base (6).

A careful inspection of the two overlaid maps revealed the simple nature of the distortion and provided the basis for a very simple but accurate solution. The distortion, being unique, required a unique solution: The part of the railroad network east of Chicago had to be horizontally stretched and the part west of Chicago horizontally contracted so that the East Coast and West Coast ends of the

Figure 1. FRA map of U.S. rail planning sectors.

Figure 2. Federal railroad system.

Figure 3. Massachusetts railroad network overlaid on geopolitical data base (from multicolor original).



network matched the corresponding U. S. coastlines. This was done by means of a combination of two linear transformations in which the stretching and contraction were proportional to the horizontal distance of all points from Chicago. The resulting merged map is shown in Figure 2. This transformation survived close inspection along rivers and state boundaries and became the geographic data base for the project.

Figure 3 shows a black-and-white representation of a multicolor original in which the subnetwork of a single state is overlaid by the corresponding part of the geopolitical data base. Note that the solution to this crucial problem did not come from an available software package but rather through flexibilities of interactive graphic display and ease of programming for improvised one-shot solutions. The macroscopic editor did an excellent matching job on the Massachusetts case shown in Figure 3. However, there remain local coding errors (some links extend into the ocean), correction of which will require the use of the microscopic editor. Some of the more subtle errors will emerge only after more sophisticated analysis.

The next stage in the processing of the geographic component of the data base was the search for faults in the connectivity of the network, such as missing segments and "tunnel-link" connections. Since the network contains almost 20 000 links, it was difficult to verify connectivity by visual inspection of many expanded displays. However, inspection of the graphical flow of minimum-path trees from key nodes very quickly revealed faults of connectivity caused either by the omission of major parts of the network or by evolution through unrealistic paths. Similarly, tunnel-link effects have been discovered in the disappearance of paths off the screen and their reappearance in other parts of the country. These tunnel-link effects have been traced to inconsistencies in either the station code number level or the station abbreviation code level of the data base. Although these inconsistencies occurred on a nongraphical level of the data base, graphical methods proved to be very powerful in tracking them down.

In a study of the seasonality of traffic flow on the national network, it was necessary to flow each freight transaction in the 1 percent waybill data base available from FRA and summarize the flow over the links (7). The computer used the minimum-path algorithm to route the traffic from Detroit to New York State along the Canadian side of Lake Erie (actually, the major part of the traffic flows on the southern shore of the lake). Close inspection of the data revealed that the error occurred at the commodity level and that the Canadian link included an old tunnel that is too narrow to accommodate triple-decker automobile-carrying cars. In other words, one encountered situations in which the connectivity of the network depended on attributes other than the physical fact of a railroad track connecting two geographic points.

It took a graphical analysis of seasonal freight flows to identify this particular feature of the railroad system. This was accomplished by plotting freight volumes as rectangles on each link by direction. The width of the rectangles was proportional to the traffic volume in carloads, and direction was indicated by drawing rectangles on each side of the link to represent respective directional flows. The combined value of pictorial analysis and large-memory computers becomes apparent when one realizes that the 1 percent waybill data base used in the analysis consisted of about 600 000 records of 80 columns each. This is equivalent to 600 000 computer cards on which all 80 columns are punched.

A more complicated connectivity problem arose in another study in which the 1 percent waybill data were flowed over the network and a record was kept of track ownership along the way. After considerable analysis had been performed, execution was halted when the minimum-path algorithm flagged that it had encountered a disconnected network. This was surprising since the model was well "beaten" at this point and errors in network connectivity were not expected to occur.

In this instance, a technique known as "zoom" was applied in which the analyst selected a small portion of the display with the cross-hair cursor and commanded the machine to enlarge that portion to fill the screen. By using the zoom capability, it is possible, in several stages, to achieve any degree of enlargement desired. By using graphical zooming, the particular transaction at which execution halted was traced and the geographic location identified.

It turned out that the connectivity fault occurred on the track-ownership level of the data base. In other words, the physical network was connected through a link that represented tracks of different ownership, which was inconsistent with the record of the 1 percent waybill data. Inspection of the network in the location revealed further inconsistencies related to records of dual ownership of links and nodes. The network was edited interactively, and execution was resumed without repeating the entire costly analysis. Only a small portion of the data had to be rerun.

In a study of a hypothetical merger situation, a competitive line was added to an existing system (8). An inspection of freight flow on the combined network revealed an unacceptable pattern in which the freight flow did not take full advantage of the newly added line (see Figure 4). Graphical zooming on the display revealed a missing link that was too short to be noticed in any other way. The expanded window shown in Figure 5 clearly shows the missing link.

Figure 4. Unexpected freight flow caused by missing link (from multicolor original).

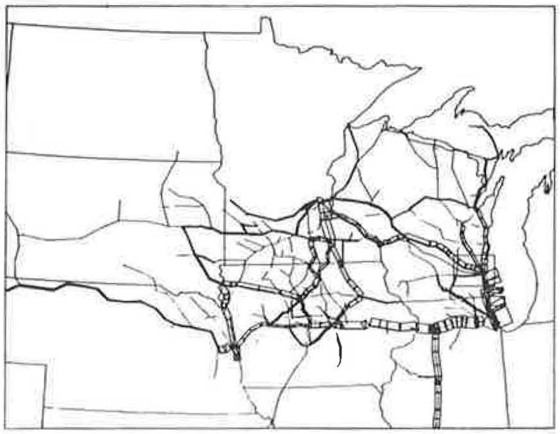


Figure 5. Missing link found.

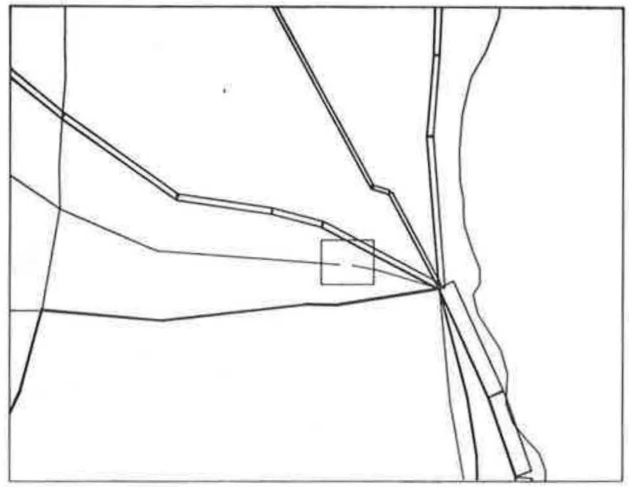


Figure 6. Geocoding of rail accidents: stage 1.

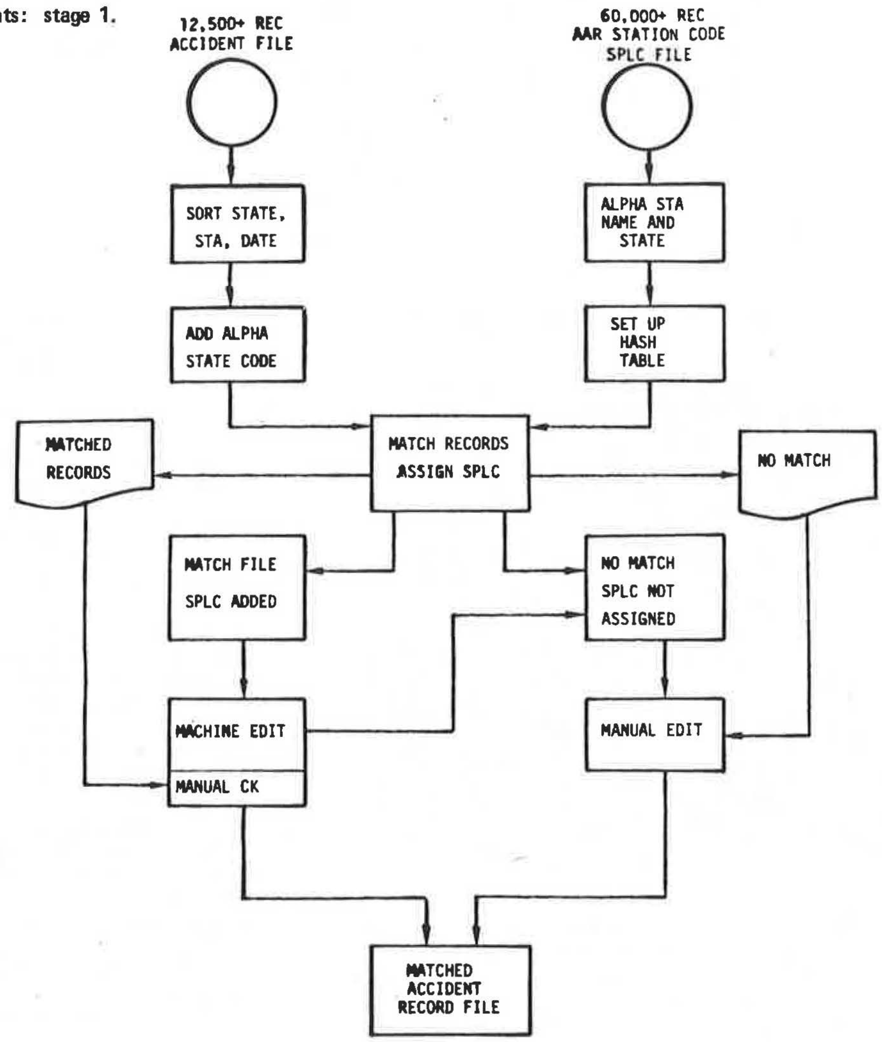


Figure 7. Geocoding of rail accidents: stage 2.

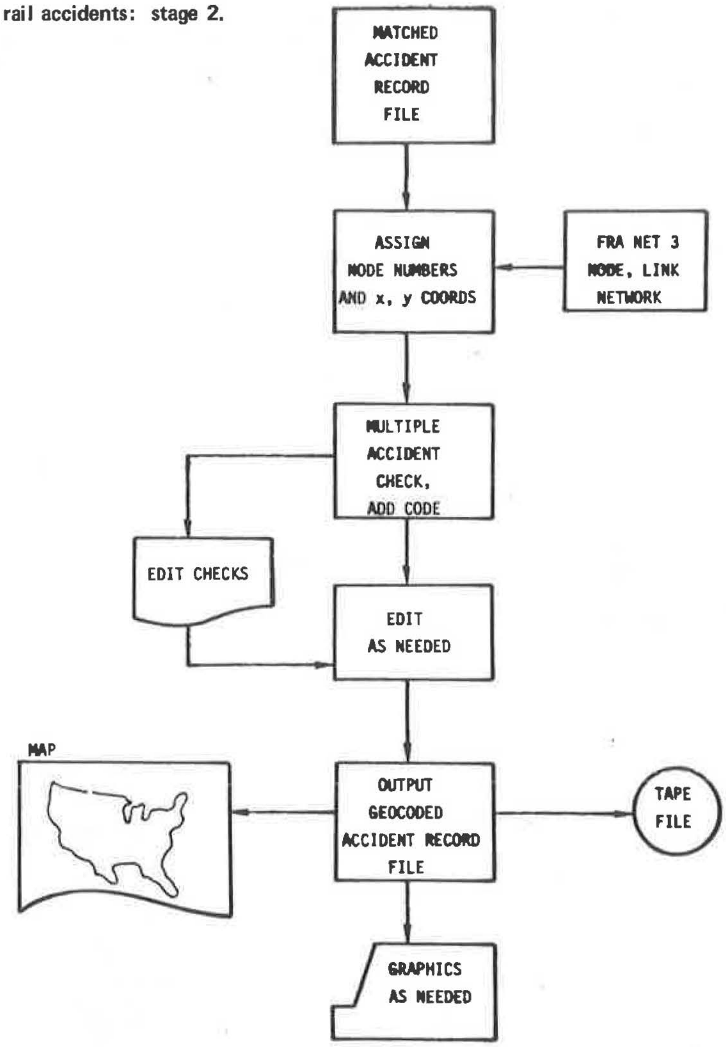
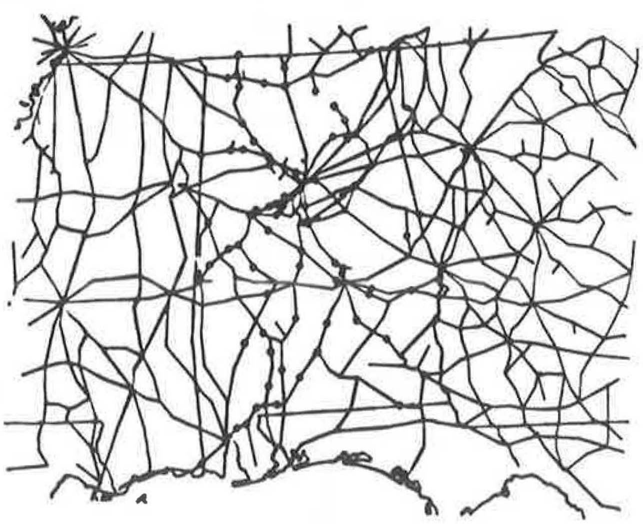


Figure 8. Alabama accident sites superimposed on FRA network links.



The situations and solutions described above concentrate on the pictorial explorations and interactive handling of problems of data integrity in geographically based, large-scale management information systems. However, the flexibility demonstrated above is useful not only for chasing after subtle errors in the data base but also for responding to challenges that were not originally planned for when the data base was designed and created.

MAPPING ACCIDENT LOCATIONS

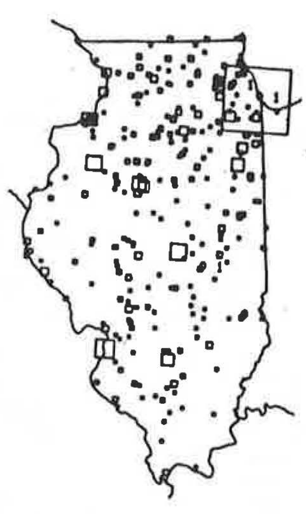
Since 1966, all class 1 and 2 railroads have been required to file monthly reports of all accidents that involve casualties and equipment or property damage above a given monetary threshold (readjusted periodically). These data are placed on computer tape and used to produce annual tabulations and summaries (9). In a program initiated by FRA to prepare more detailed analyses of these accident reports, one of the highest priorities was the identification of areas that have a higher incidence of accidents, especially accidents involving hazardous materials. To obtain a quick impression of the geographic distribution of accidents, the Reports and Analysis Division of the Office of Standards and Procedures of FRA turned to the use of interactive computer graphics to prepare maps of geocoded rail accidents. A pilot project involved geocoding and plotting reported accidents for 1976 (10).

A computer tape containing 12 555 records that represent rail equipment accident-incident reports (FRA form F6180-54) for 1976 was received from FRA. Each record contained the name of the freight station nearest the accident site. But, to locate each accident on the FRA network model, which contained the graphical coordinates needed for plotting, each accident had to be assigned a location code that corresponded with FRA identification codes for

Figure 9. U.S. railroad accidents in 1976.

Figure 10. U.S. railroad accidents in 1976: spills of hazardous materials.

Figure 11. Illinois railroad accidents in 1976.



network nodes. Fortunately, a correspondence table existed between FRA network node numbers and the six-digit standard point location codes (SPLCs) used by the American Association of Railroads (AAR) to reference freight stations (11).

A tape that contained approximately 60 000 station names and SPLCs was obtained from AAR and, by matching the station name on each accident record with those on the AAR tape, a numeric SPLC was obtained for each accident record that contained a valid station name. The SPLC was added to each record, which permitted each accident to be assigned to a point on the FRA network model. The accident records were then amended to include alphabetic state code, SPLC, FRA network node number, location coordinates, and counts of accidents and spills of hazardous materials that occurred at each network node. The entire process is shown in Figures 6 and 7.

A variety of graphical output was produced for this project. Figure 8 shows an example produced for an interim presentation. In the figure, accident sites (denoted by large dots) have been superimposed on the FRA network model links and state boundaries for Alabama. A full-size 92-cm (36-in) Calcomp plot produced for the project was done in three colors. The state boundaries were drawn with a blue technical pen. Each accident node was shown symbolically as a square drawn in black technical pen, and the side of the square was proportional to the number of accidents reported at that node. Hazardous spills were denoted similarly by a red circle, the diameter of the circle being proportional to the number of accidents involving spills.

Figure 9 shows a Tektronix photocopy of the data file plotted for the entire continental United States. A plot of hazardous accidents is shown in Figure 10. Figure 11 shows a plot of the state of Illinois, one of several state maps requested by FRA. In these plots, the area of the square is proportional to the number of accidents. A constant scale is used for all accident symbols; map scale varies to permit the largest possible image to be drawn. A circle is used to denote spills of hazardous materials, and the number of these accidents is shown to the right of the circle.

In a subsequent study for the Transportation Systems Center of DOT, the pressure for immediate solutions to the hazardous-materials accident problem required the speedy creation and analysis of a data system that correlates the flow of hazardous materials and train accidents (12). An interactive traffic assignment was run for hazardous freight to determine the number of carloads flowing on each link of the FRA network. In this assignment, traffic records from the FRA 1 percent sample of carload waybills for 1976 were selected based on the commodity codes for hazardous materials. These shipments were assigned to network links and displayed as rectangles, the width of the rectangles being proportional to the number of carloads. The direction of flow was shown by drawing the rectangle to the right side of each link. The traffic-flow data were superimposed on a plot of accident data, as shown in Figure 12. Here, accidents were disaggregated by type, and different symbols—octagons and triangles—were used to distinguish main-line from other accidents. These plots were prepared in four colors: green to indicate flow volumes, black for rail links and accident symbols, blue for state boundaries, and red for hazardous-materials accidents.

As the data were being processed for plotting, accident tabulations were calculated and printed in the legend. Variable scaling was used, and maximum symbol sizes were calculated and inserted in the legend. Thirty-two class 1 railroads were plotted, and color Xerox copies were prepared for inclusion in copies of the final report.

ANALYZING AMTRAK PASSENGER FLOWS

Another example of interactive graphic analysis of rail traffic is shown in Figure 13. In conjunction with a DOT study of the future of Amtrak, it was necessary to examine present and expected passenger volumes on each link of the Amtrak network (7). Machine-readable records of ticket sales were used to obtain station-to-station volumes on the network. A correspondence file was created to match each Amtrak station with the closest node on the FRA model. Then an "Amlink" network was created by extracting the appropriate subset of nodes from the FRA network. Station-to-station flows were assigned to the network and plotted.

Figure 12. Flow of hazardous materials superimposed on plot of accident occurrence.

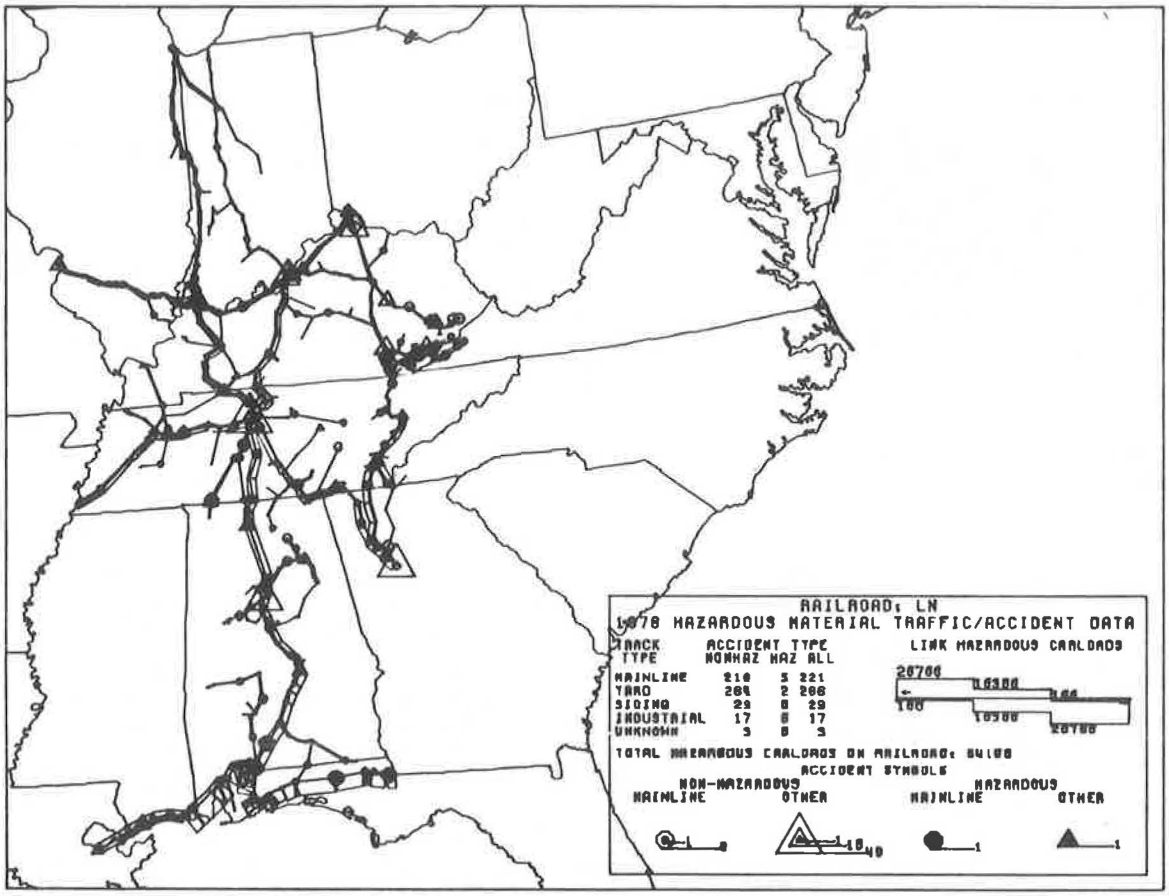
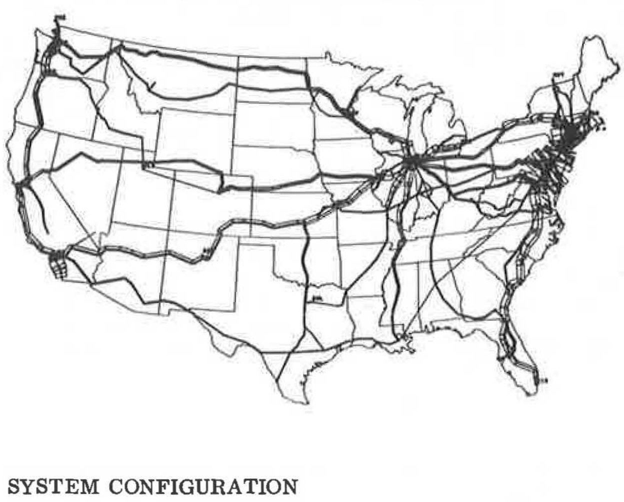


Figure 13. Passenger flow on Amtrak subsystem.



SYSTEM CONFIGURATION

The railroad analyses reported above have all been conducted by the Interactive Computer Graphics Laboratory of Princeton University. An IBM 370/158 computer, running under VM370/CMS, is used for time-sharing applications. This machine is supported by an IBM 360-91, which is used for batch operations running under the OS operating system. Both systems are interconnected so that jobs can be entered interactively and processed in batch mode if desired. The system supports approximately 20 Tektronix 4013/4015 graphic terminals and a similar number of nongraphic terminals. Two Tektronix 77x102-cm (30x40-in) digitizing tablets are available as well. Graphical output is obtained from a Calcomp 936 multicolor 92-cm (36-in) plotter, two smaller Calcomp plotters, and three Tektronix photo-processing hard-copy units. In several projects, the system was accessed remotely via data phone from a remote job-entry station at FRA in Washington, D. C. Programmers at Princeton developed software and map displays that were transmitted to Washington, where they were plotted by FRA personnel on a Calcomp 1036 plotter. A test run was also conducted from the Transportation Systems Center in Cambridge, Massachusetts, by using a Tektronix plotter.

The core of the system is VSAPL, enhanced by a graphical processor and an auxiliary processor that interfaces APL with lower-level languages like ASSEMBLER, FORTRAN, and PL1. The virtual machine environment permits the authorized user to define a virtual computer of a size of up to 16 million bytes. The main graphical processor has been implemented under APL as an auxiliary processor written in ASSEMBLER but highly transparent to the APL user. It has been designed for the efficient display of a high density of information on Tektronix 4013 and 4015 terminals in a time-sharing environment.

The mathematical power of the APL language is available for interactive data analysis. Arithmetic and logical manipulations of arrays and tools of Boolean algebra obviate many of the tasks required for the creation and manipulation of large-scale geocoded management information systems. Abstraction and aggregation of data by geographic and nongeographic attributes are easily achieved, as are analysis and display of statistical data.

CONCLUSIONS

Planning for the future of the nation's railroads is one of the most difficult and complex tasks facing the U. S. Department of Transportation. The problem is particularly difficult in that it demands a great deal of data and the results of any action will affect specific regions of the country and have obvious political repercussions. Consequently, federal rail system planners must, in a short time, test many alternatives to arrive at a feasible solution. In this planning context, interactive graphic analysis has great potential for application. The speed of the large computer coupled with the facility of APL makes it possible for the analyst to generate many solutions in a short time, and the graphic display permits him or her to grasp, almost at a glance, the geographic implications of the analysis. Finally, the power and clarity of the graphical display permit the analyst to communicate results immediately to policymakers and to the public.

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Computer Graphic Animation of UTCS-1/NETSIM Traffic Flows

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The development of a program for computer graphic animation of network traffic flows to increase the potential effectiveness of the UTCS-1/NETSIM network simulation package by visually displaying vehicle movements through street networks is described. The program is a tool that can aid traffic engineers in generating and evaluating alternative control strategies by enabling them to view network traffic in real time. It thereby provides them with additional information, such as lane-specific delays and queue buildups, that would not be readily available through the standard statistical output of UTCS-1.

As traffic flows through street networks, it experiences periods of congestion that may result from inadequate geometric design or signalization or simply excessive demand. Traffic simulation techniques are becoming important tools for the traffic engineer in investigating the impacts of various traffic control strategies. These simulation experiments can yield an enormous amount of data that could not be obtained in real life for economic or other reasons.

Among the network traffic simulation models, the Urban Traffic Control System (UTCS-1) model produced for the Federal Highway Administration (FHWA) has been the most popular. UTCS-1 has been extensively validated and is generally considered to yield reasonable results. It is excellent for evaluating signal control schemes and the effect of buses on traffic movement. The UTCS-1/NETSIM model is a fully microscopic model that collects and updates statistical network data at 1-s intervals. At the end of the simulation period, link-specific and systemwide data are printed out for use by the traffic engineer in evaluating the operational characteristics of the network. The aggregated nature of the data makes it useful in defining the existence of potential traffic problems. However, the user would be likely to get a more intuitive understanding of the conditions that gave rise to these potential problems and be more capable of isolating effective control strategies if vehicle flows were displayed visually.

The use of computer graphic techniques and computer-generated films for visual displays of traffic flow information is a relatively recent development. Parakh (1) proposed to improve the analysis of large-scale flow problems by visually displaying the output of computer simulation.

The proposed model, graphical interactive traffic simulation (GRITS), can produce local and global displays of simulated network conditions. More specifically, the program has the capacity to display, at each intersection, three-dimensional plots of stops and delays as a function of split and cycle time. Traffic densities on the network links can also be displayed. Global displays include saturation, queues, and stops on all links in the network. The simulation model used in GRITS is a deterministic "platoon-level" model.

Figure 1. Description of computer-graphic system.

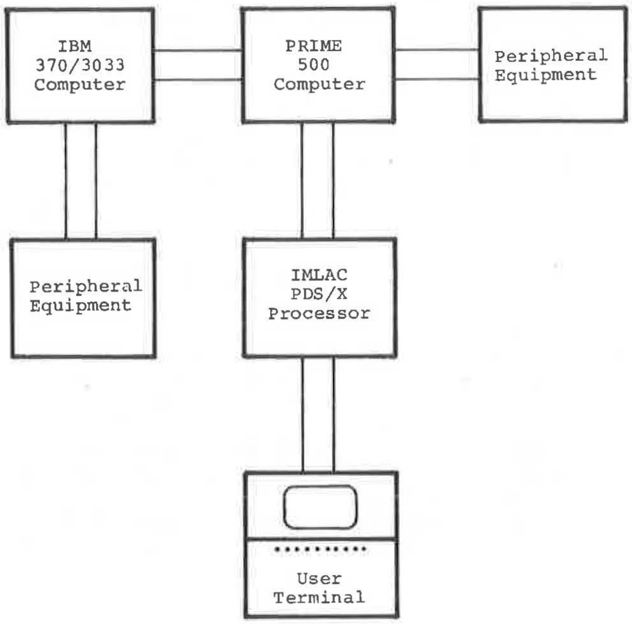
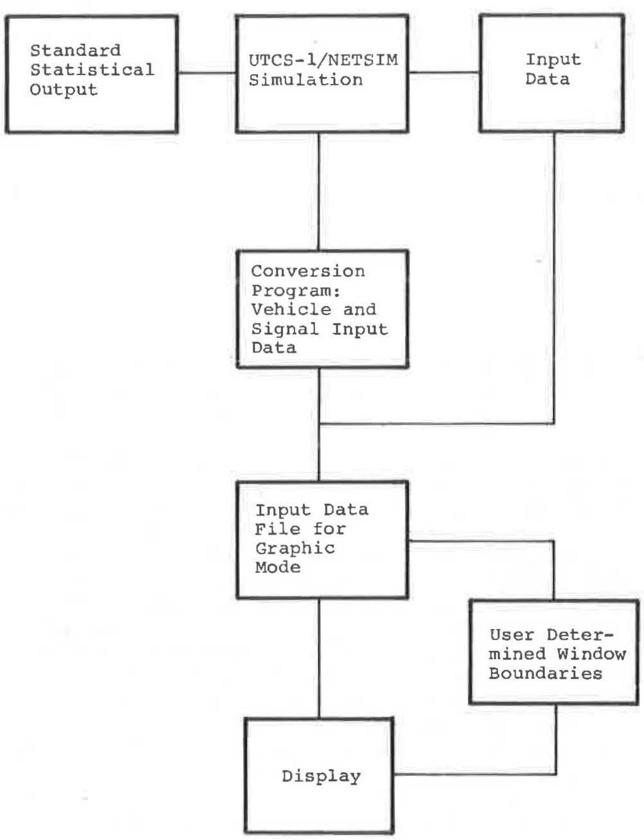


Figure 2. Operation of GRANT module.



The Stark/NBS model (2) has the capability of producing a movie of the simulation that is cathode ray tube (CRT) based. Unfortunately, the simulation model is deterministic and not very flexible in admitting input data. Moreover, it has not been validated. Along the same line, the Aerospace Corporation VPT model (2), although it contains the feature of movie presentation, is not flexible and has poor validation. Joline (3) has developed a movie presentation of the UTCS-1 but, because of the proprietary nature of the model, user documentation is not available.

Computer graphics has been extensively used in transportation planning. Rapp and others (4, 5) applied computer graphics for planning node-oriented transit systems, and Rapp and Gehner (6) proposed interactive graphics to identify the characteristics of high-performance bus rapid transit systems for riders who reside in a generalized suburban corridor and are bound for the central business district. Schneider and Porter (7) conducted a study to determine the amount of improvement that could be achieved by designing a bus rapid transit system by using interactive graphics rather than conventional methods. The results of the study indicate that computer graphics can be a cost-effective tool in design.

Other areas in which applications of computer graphics were investigated include community participation (8, 9), land plots (10), allocation of nodal services (11), and highway design (12). An updated bibliography of computer-graphic applications in transportation is included in a recent paper by Schneider (13).

These applications of computer graphics in transportation illustrate that computer graphic routines, either alone or in combination with existing packages, are potentially very cost-effective tools that can be used by the practicing transportation engineer in analyzing data, generating and evaluating alternative solutions, and presenting the results. The objective of the research reported here was to develop computer graphic displays for the animation of UTCS-1/NETSIM vehicle flows through a network and thereby improve the capability of the model by providing the user with the option to visually display vehicle movements through a network of streets and highways or any portion of a network.

SYSTEM DESCRIPTION

The interactive computer graphic facility used in this study consists of two PRIME 500 digital computers that are interconnected to the Rensselaer Polytechnic Institute (RPI) IBM 370/3033. In addition, a number of IMLAC graphic terminals and tape and disk drives and a Versatec printer-plotter are available. Many of the software programs were obtained from other sites and converted to run on the PRIME-IMLAC system; others were written at RPI. The graphic terminals run on IMIGE, an IMLAC-supplied FORTRAN graphics package. The overall system is shown in Figure 1.

COMPUTER GRAPHICS

The UTCS-1/NETSIM program is completely microscopic and updates the position of every vehicle in the network at the end of each 1-s scanning subinterval. This information is contained in the vehicle array V(M, K) in terms of the lane and the link that the vehicle occupies and its distance from the upstream intersection. Similarly, link signal data are also updated and contained in the link array LINK (L, K) as the signal code facing the link. The display of the information contained in these two arrays results in the animation of vehicle movements through the network.

Operation of the program graphic animation of network traffic (GRANT) is shown in Figure 2. Initially, the roadway network is drawn with specified coordinates for all nodes, lanes, and links. This defines the network in the (x, y) coordinate system. At the end of each scanning sub-

Figure 3. Display of test network.

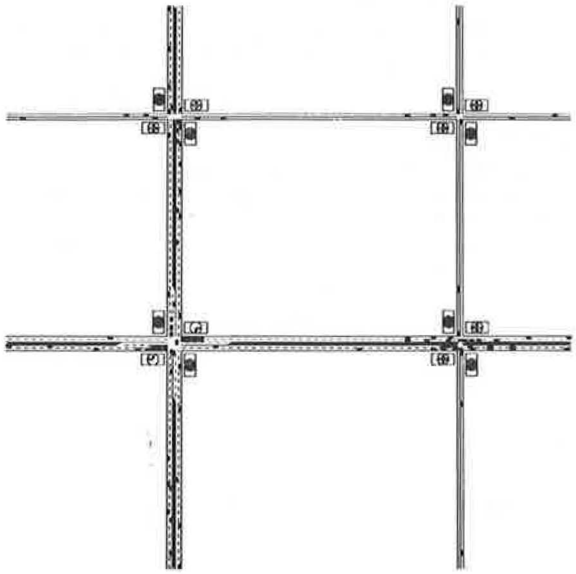
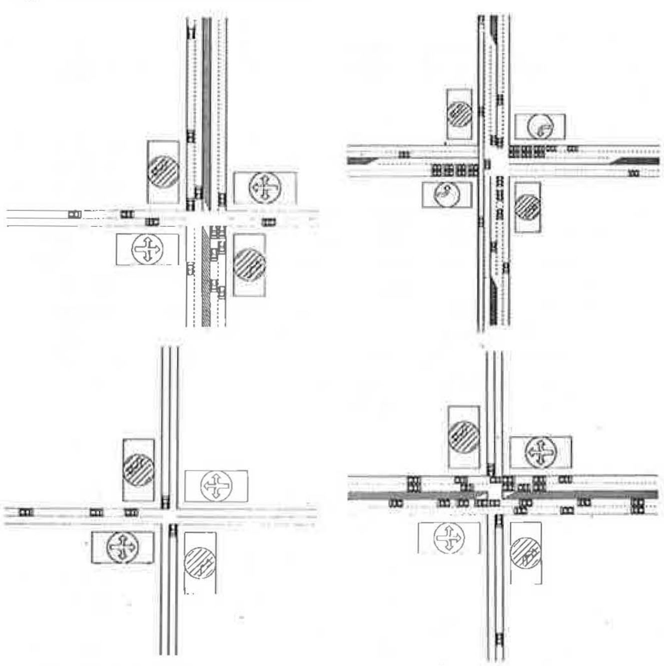


Figure 4. Intersection windows.



interval, a computer program is used to convert the link, lane, and distance data for every vehicle in the vehicle array to (x, y) coordinates in correspondence with the externally defined network coordinate system. This information and the signal code data are accumulated in a temporary file that constitutes the input data file for the graphic mode.

In the graphic mode, existing and developed FORTRAN-based software routines are used to draw the network and to draw and superimpose the vehicles and signal indications on it at 1-s intervals. This gives the impression of real-time movements of vehicles through the network. All the computer programs are written in FORTRAN IV so that they can be transferred from this system to others.

Since most networks of interest are moderate to large in size and since the size of the display is limited, GRANT has the capability to create windows or "zoom in" on any portion of the network. That capability is available on the IMLAC-PDS graphic terminals that operate in conjunction with the PRIME 500 system. The "zoom-in" effect is achieved by generating an enlarged image space that is clipped by the boundaries of the defined window. These boundaries are input interactively by the positioning of cross-hair cursors to mark the lower left and upper right corners of the window. The user can stop the display at any time, define new window boundaries, and zoom in on another portion of the network.

Figure 3 shows the CRT display of one time frame of a simple four-intersection network. Figure 4 shows the CRT displays of the enlargements of the four intersections achieved by defining windows about these intersections. Ten signal indications that correspond to those defined in UTCS-1/NETSIM are possible. Figure 4 shows these signal indications displayed for each link. Although it is not of primary importance in this research, different vehicle types, including buses and trucks, can also be displayed.

Note that the network geometry input to the UTCS-1/NETSIM program does not have to be graphically consistent—graphic consistency as used here meaning that the distance between any two vertices in the network is a euclidean distance. For graphic displays, consistency is essential. Currently, if one wishes to display the simulation of a graphically nonconsistent network, link free-flow speeds must be adjusted to reflect the differences in link lengths.

CONCLUSIONS

The GRANT module demonstrates the feasibility of graphically displaying the animation of vehicle flows through networks, as simulated by the UTCS-1/NETSIM program package. GRANT provides additional information that would not be easily obtainable through the standard statistical output of UTCS-1/NETSIM. More precisely, lane-specific delays and queue buildups can be visualized. Additional information of this type can help in generating and evaluating alternative control schemes cost-effectively. In addition, the visual display can aid in the demonstration of alternative solutions.

Further research in this area would address the problem of making the package totally interactive with respect to data input and program control. On a more macroscopic scale, it would be beneficial to display some performance measures for links and intersections so that the user would be able to predetermine which network segments should be focused on. This would act as a screening stage for further analysis. In addition, program documentation that is consistent with existing UTCS-1/NETSIM documentation remains to be developed.

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Interactive and Graphic Techniques for Computer-Aided Route Selection

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The development of the GCARS system of computer-aided highway corridor selection and its application in an environmental impact analysis in western New York State are discussed. Current versions of GCARS use an efficient minimum-path algorithm to generate route alternatives by accessing digital data bores that define engineering, socioeconomic, and environmental factors. These data bores are manipulated interactively by a companion computer system called GMAPS. The GMAPS and GCARS systems clearly show the desirability of low-cost, easy-to-operate, interactive systems for regional transportation planning studies. Graphical and statistical displays are essential, and a variety of black-and-white and color display options have been developed. Because each product has unique cost-benefit characteristics, the choice of display type must be matched to audience needs and costs of production. The use of GMAPS-GCARS in a corridor-selection study for a 160-km (100-mile) four-lane highway in western New York is described. The study shows a marked reduction in planning time at no increase in planning costs. This suggests that more widespread use of computer-aided analysis systems may result in large savings during periods of rapid inflation.

The process of highway corridor selection was revolutionized by the passage in 1969 of the National Environmental Policy Act (NEPA). Today, the "best" location for a transportation system is no longer necessarily the one that produces the greatest reduction in travel time or the one that 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 must be made on the number of factors and the relative importance of all factors. Sensitivity analyses are required.

The digital computer offers an efficient means of applying models that describe the regional environment to the task of corridor selection. This requires the integration of a wide variety of digital models, each of which defines some component of the regional environment. The success of such applications depends on many factors, the most critical of which are

1. Efficient, low-cost methods of data entry, checking, and display;
2. The ability to accept and manipulate many kinds of data;
3. Easy-to-use, preferably interactive, methods of determining which data are available and for manipulating such data; and
4. Statistical and graphical display methods to allow for rapid assimilation and assessment of data by the system user.

This paper discusses the design philosophy that underlies one such system, the Generalized Computer-Aided Route Selection (GCARS) system. GCARS has been under development for at least 10 years (1); however, the development of smaller, economical interactive computers over the past 4 or 5 years, accompanied by recent development of low-cost graphical display hardware, has greatly assisted the transition of research concepts into a practical, commercially viable system. The integration of these new hardware capabilities with appropriate software design is illustrated in this paper by a recent application of GCARS to a highway location study in New York State.

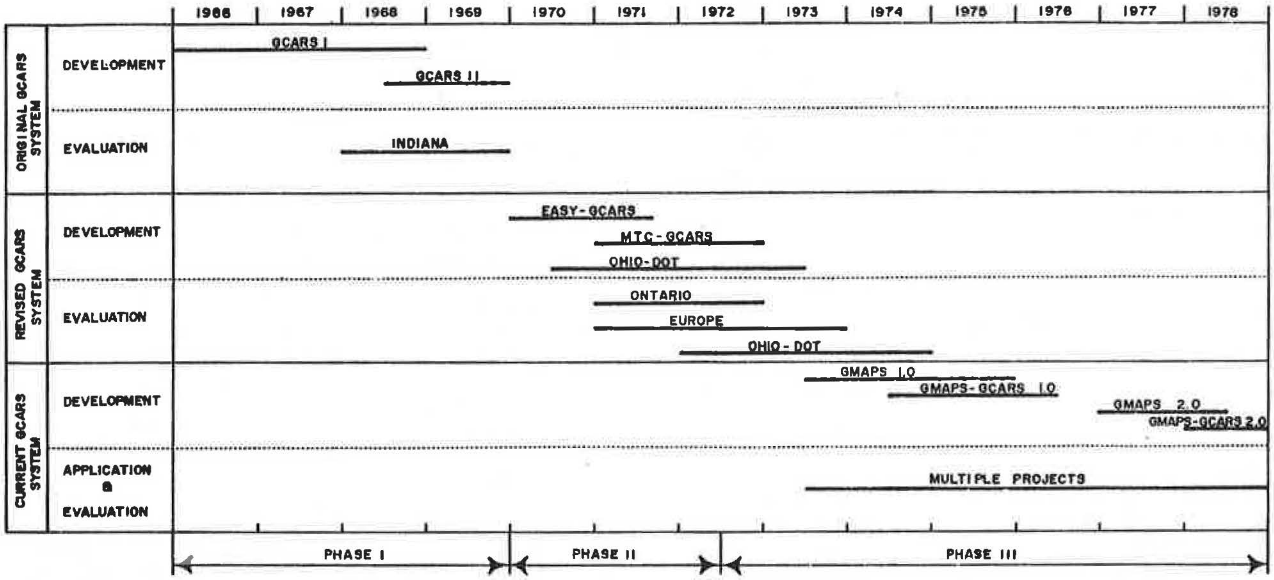
SYSTEM DESIGN GOALS

Development of the GCARS system has been guided from the beginning 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 person-machine information interchanges. This goal appeared necessary in order to allow engineers to apply their 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.
6. The system should be generally compatible 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

Figure 1. Chronology of GMAPS-GCARS system development.



goals might prevent their complete achievement. Nevertheless, they did represent, and continue to represent, an ultimate yardstick by which all computer-aided planning systems should be measured.

HISTORICAL DEVELOPMENT OF THE GCARS SYSTEM

A recent companion paper (1) traces the development of the GCARS system from its first development in 1966 to the present. Only a brief summary is included here to illustrate the effects of improvements in computer hardware. As Figure 1 shows, GCARS development can be divided into three main phases, each of which contains a development-evaluation cycle.

Phase 1: 1966-1969

During phase 1 of GCARS development, two research systems—called GCARS I and GCARS II—were developed and evaluated. GCARS I was used in a batch processing environment on Control Data Corporation (CDC) equipment. The programs stored environmental conditions as matrices no larger than 50x50 cells and located routes by performing minimum-path analysis on these matrices. The minimum-path algorithm was adapted from Martin's FORTRAN coding of the British Road Research Laboratory algorithms (2). Both GCARS I and GCARS II were able to generate about one alternative per minute of control processing unit (CPU) time on the largest-sized matrix (2500 cells) while using only moderate core storage (around 50K words on the CDC 6600).

The GCARS I design was tested at two areas (3-5). Demonstrations were subsequently given for practicing highway location engineers. In view of the favorable response, it was decided to present the GCARS system to a broader group of engineers and students and obtain their evaluations.

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 was prepared that allowed users to access the GCARS I programs and data sets via the PROCSY system. This series of programs was called GCARS II (6).

GCARS II proved to be an ideal teaching tool. After 10 or 15 min of 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: During the submission procedure, the terminal prompted the engineer with a series of questions, to which the engineer responded and so prepared a job request.

Phase 2: 1970-1973

In phase 2, the earlier versions of GCARS I were modified to work on IBM 360 systems, where they used about 165K bytes of storage. An extensive series of evaluations was made in Canada, the United States, and Europe. During this period, GCARS evolved from a purely research tool into an instructional one. This required methods by which larger numbers of persons, some of whom had little or no background in computer use, could interact with the programs.

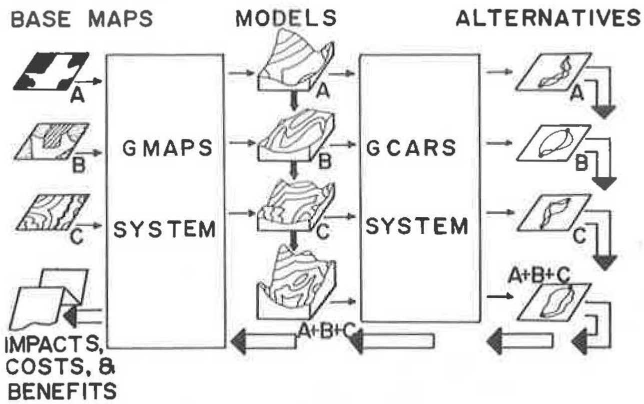
Ideally, conversational, interactive methods would be used. The advantages of such capabilities had been clearly demonstrated by GCARS II. But few conversational systems were available, and so it was decided to develop a simplified request system that could be submitted as a series of batch jobs in the regular job stream. Since the cards had to be punched by inexperienced persons, it was desirable that the cards be as simple and flexible as possible. Accordingly, a FORTRAN program called EASY—which used the NAMELIST statement available in IBM FORTRAN—was developed. Each student was supplied with a set of job-control-language cards and submission instructions.

Although it was 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 for people who had 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 London, about 95 percent of the jobs submitted ran successfully). EASY-GCARS was also used on a number of demonstration projects in Ontario (7).

Phase 3: 1973-1979

A totally new system of programs called GMAPS-GCARS, developed beginning in 1973, incorporates many changes shown to be desirable by the previous work. In these new systems, the model-building steps were separated from those of corridor selection so that the GMAPS (Generalized Map Analysis Planning System) programs were responsible for model building and a new GCARS program suite was

Figure 2. Concept of GMAPS-GCARS.



responsible for corridor selection (see Figure 2).

The GMAPS-GCARS programs are designed to use interactive terminal dialogs in time-sharing environments. Initial development was done on DEC System-10 computers, but later installations were made on CDC CYBER computers (operating under the KRONOS and NOS time-sharing systems), IBM 370/168 computers (operating under TSO), and PDP 11/34 and PDP 11/70 computers (operating under RSTS/E).

GMAPS-GCARS SYSTEM

Basic Concept

The basic concept of GCARS from its inception 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 route combines directness and "low elevations" so as to obtain the lowest total cost. Less desirable routes follow other valleys and "pass over" the intervening high-cost areas. Sometimes such alternatives are shorter than the first choice and, although they have a higher cost per unit length, may be more desirable. The various choices should thus 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 then assigned the cost of traversing it. Thus, minimum-path analysis will discover the optimal path. Ayad (8) has proposed a method of generating a series of significantly different ranked alternative choices. If the central links that form the optimal route are raised in value, their reuse 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 allows for sensitivity analyses and leads naturally into impact assessments.

Figure 2 also shows that models for several factors can be superimposed to produce models that represent any desired combination of factors. This model-building component was fairly simplistic in the original GCARS I system, but it is now a fairly large and complex task that is assigned to the GMAPS system programs (Figure 2).

Goal achievement and cost statistics are important analytic tools in comparing the alternative corridors generated by GCARS. This capability has also been enhanced in the latest GMAPS-GCARS versions. As Figure 2 shows, the production of impact, cost, and benefit statistics is performed largely by GMAPS, which uses data supplied by GCARS along with its own model data.

GMAPS Programs

The GMAPS programs were originally developed to meet the needs of environmental assessment. It was recognized that relatively sophisticated capabilities for data-base manipulation were required but that these must be understandable to persons who had little experience with computers. At the same time, the system had to be capable of comprehensive quantitative analyses, accept a variety of data, and operate economically (9).

An interactive cellular mapping system that uses composite computer mapping techniques was chosen. A modified cellular storage concept was selected because it lent itself to economical data-entry procedures that required no specialized equipment. A method of "cellular strings" was used to economically convert existing mapped data to machine-processable code (9). The GMAPS programs also accept other optional data sources, including census data tapes and LANDSAT digital imagery classifications.

All steps of the GMAPS process—data entry, checking, cataloging, manipulation, and display—are performed as a series of interactive, self-prompting operations. This makes GMAPS very attractive to use, for the following reasons:

1. The programs are self-prompting. They ask a sequence of questions to which the user responds and by which the user defines the operations and sequence of operations he or she wishes to perform.
2. The programs allow the user to verify and correct commands so that meaningless operations are eliminated.
3. The system is easily used by the layperson.
4. The time-sharing concept gives the user economical access to a high-capacity computer.

The composite computer mapping techniques incorporated into GMAPS represent a powerful extension of the traditional planning method of overlaying tonal transparencies and visually selecting optimum areas (10-12). In GMAPS, the overlaying of tonal transparencies is replaced by the algebraic combination of two or more matrices whose elements have values that correspond to the gray-tone densities. GMAPS allows both arithmetic and logical compositing procedures. Arithmetic compositing is a simple extension of tonal overlay procedures but allows much more varied analyses by 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 that reflects these conditions.

The GMAPS programs include a variety of display capabilities that reflect the diversity of user needs and the economics of the applications. At one extreme is the capability to display scaled-down maps, or selected "window areas" of maps at full scale, on the standard 80-column, 30-characters/s terminal. Such displays are obviously limited by terminal speed and size; however, they form an indispensable quick-look capability for a user who is working late at night or in an isolated location.

The standard line printer, set at 3 lines/cm (8 lines/in), is the most commonly used display device. The printer is economical because it is readily available, rapid, and capable of producing large-scale displays. This is useful for data-checking purposes. The line printer gives a 10-level (maximum) gray-tone display by using 2-level overprinting; aesthetic quality is further enhanced by adding titles in 2.5-cm (1-in) high block letters (such as those used for banner pages on most systems), legends, north arrows, and bar scales as appropriate.

GMAPS has been used to generate more sophisticated displays where specialized equipment and needs existed. Products include cathode-ray-tube (CRT) and electrostatic plotter displays, direct productions of 35-mm color slides, and hard-copy color displays by several techniques. Interface programs are required to convert the standard GMAPS data bases to the plotting standards of these specific devices.

GCARS Programs

An entirely new sequence of GCARS programs was developed to interface with the GMAPS data bases and incorporate all the suggested improvements. Because GCARS contains a substantial computation cycle, it operates in a mixed foreground-background manner. Job-request generation is performed interactively in a self-prompting format. The computations are then performed in a background mode, which frees the terminal and the operator to perform other tasks.

An entirely new minimum-path algorithm is incorporated into GCARS. This algorithm is 10-20 times more efficient than the Martin algorithm (2) originally used. The new algorithm has several other advantages: It allows movement along diagonal directions, core requirements are drastically reduced, and computational efficiency is a linear function the length of the corridor.

The results of a GCARS analysis can be displayed in a variety of ways that are selected by the operator in an interactive fashion. The options include maps of the routes—either on their own or superimposed on appropriate gray-tone cellular maps—and statistical summaries that give the user the basic path totals, lengths, and comparisons needed to make assessments. The planner is also assisted in evaluating goal achievement and cost criteria. Achievement can be measured by comparing each alternative corridor generated for some composite suite of goals with the optimal corridors produced by evaluating each goal dependently. Cost evaluations are made by overlaying the generated choices on a construction cost model.

SOUTHERN TIER EXPRESSWAY STUDY

In 1975-1976, the GMAPS-GCARS systems were used to aid in the environmental impact analysis of about 160 km (100 miles) of new four-lane highway, the Southern Tier Expressway in extreme western New York and Pennsylvania (see Figure 3). The impact assessment included a description of transportation and transportation-related problems, resulting transportation needs, specific project objectives, transportation location alternatives, and an evaluation of the potential impact 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 complete 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 3). 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 that earlier study had shown to be of greatest impact, influence, and interest with reference to the Southern Tier Expressway.

Corridor alternatives were evaluated by two methods: a computer-aided method that involved the GMAPS-GCARS programs and an independently conducted conventional transportation analysis. Data for 22 baseline maps (see Table 1) that described a variety of engineering, cultural, economic, and environmental factors were plotted on a 1:62 500-scale 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 hm^2 (7.8 acres), or a rectangle (cell) 198x158 m (650x520 ft). A total of almost 180 000 cells were required.

As Table 1 illustrates, the GMAPS process produced a series of derivative, determinant, and ultimately composite models that showed the desirability of highway corridor location based on (a) engineering feasibility, (b) improving social and economic conditions, and (c) environmental impact. These three composite models were calibrated and approved and then combined in various ratios to produce a sequence of total highway corridor feasibility models.

Figure 4 shows the corridor alternatives generated by GCARS for each of the three basic composite models and for one combination of these models. After a very large number of such analyses were run, a general pattern emerged in which five major alternatives dominated. These results were synthesized with those obtained by conventional techniques, and 12 detailed alternative corridor locations were selected by using various combinations of 31 sections.

CURRENT RESEARCH AND DEVELOPMENT ACTIVITY

The current versions of GMAPS-GCARS have evolved over a decade, but they are not static products and further developments are under way. Based on experience to date, the use of cellular interactive geoinformation systems offers an attractive mix of cost efficiency, flexibility of display, and analytic capability that is most appropriate during the early project planning stages. Current research and development activities are focused on three areas: automated data entry, expanded analytic capabilities, and color display capability.

Automated Data Entry

The need for realistic baseline data has been recognized from the beginning. Development of GMAPS greatly improved data collection and resolution capabilities, but further improvements are needed.

The use of direct television video scanning of basemaps and the subsequent analog-to-digital conversion of these signals appear to offer a breakthrough in data gathering. In a recent paper, Chu and Anuta (13) describe experiments in automatic color map digitization. Early incorporation of automatic data-entry methods into GMAPS is anticipated.

Expanded Analytic Capabilities

Work is already under way to add new analytic capabilities to GMAPS. Contouring and proximity functions are being tested, and a suite of multivariate statistical functions is being developed. These will require additional file handling and cataloging capabilities and will enhance the ability of GMAPS (and GCARS) to interact with air- and water-pollution models, socioeconomic analyses, and similar simulation models.

Color Display Capability

GMAPS has already been interfaced with two color display systems. At Los Alamos Scientific Laboratory, color 35-mm slides were produced by using a modified FR-80 film plotting device. More recently, hard-copy color dis-

Figure 3. Southern Tier Expressway study area.

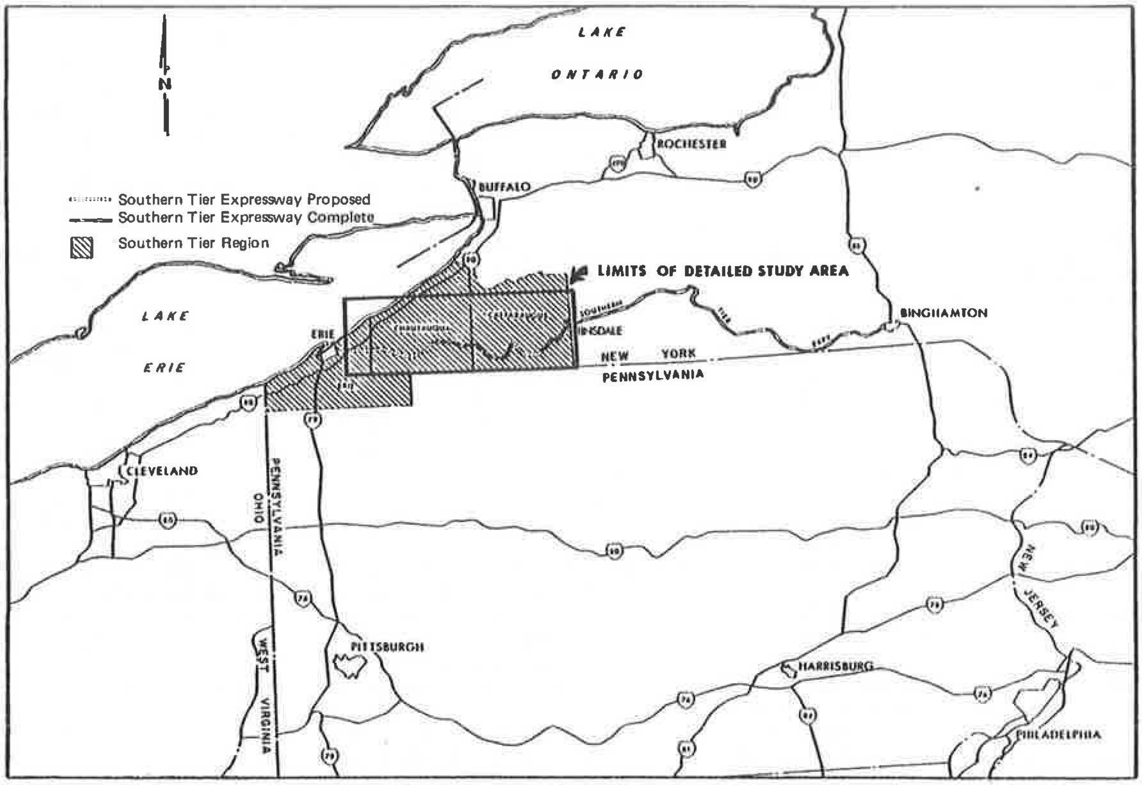


Table 1. Baseline, derivative, determinant, and composite data products for Southern Tier Expressway project.

Baseline	Derivative	Determinant	Composite
Accessibility Land use Pipelines and transmission lines Existing transportation Landforms Soil types Slope Mean annual rainfall Mean annual snowfall Water bodies	Land values Erosion potential Existing maintenance conditions Geotechnical factors Drainage potential	Cost Land acquisition Construction Maintenance	Feasibility of highway sites
Ecologically sensitive areas Groundwater yield Water bodies Recreation Land use Landforms Slope Agricultural districts Areas of highway needs Soil types Historical, archeological, and cultural sites Population density Level of service	Water quality sensitivity Erosion potential Vegetation types Scenic sensitivity Agricultural productivity Noise sensitivity Air quality sensitivity	Impact Ecological Land use Energy use Cultural and social	Environmental impact
Outmigration Unemployment Land use Average family income Recreation Population density Trip attraction Accessibility Landforms Mean annual rainfall Mean annual snowfall Level of service	Areas of economic need Institutions, recreation, and commercial areas Growth centers Areas of highway need User costs Safety	Stimulate regional economy Improve accessibility User benefits	Social and economic benefits

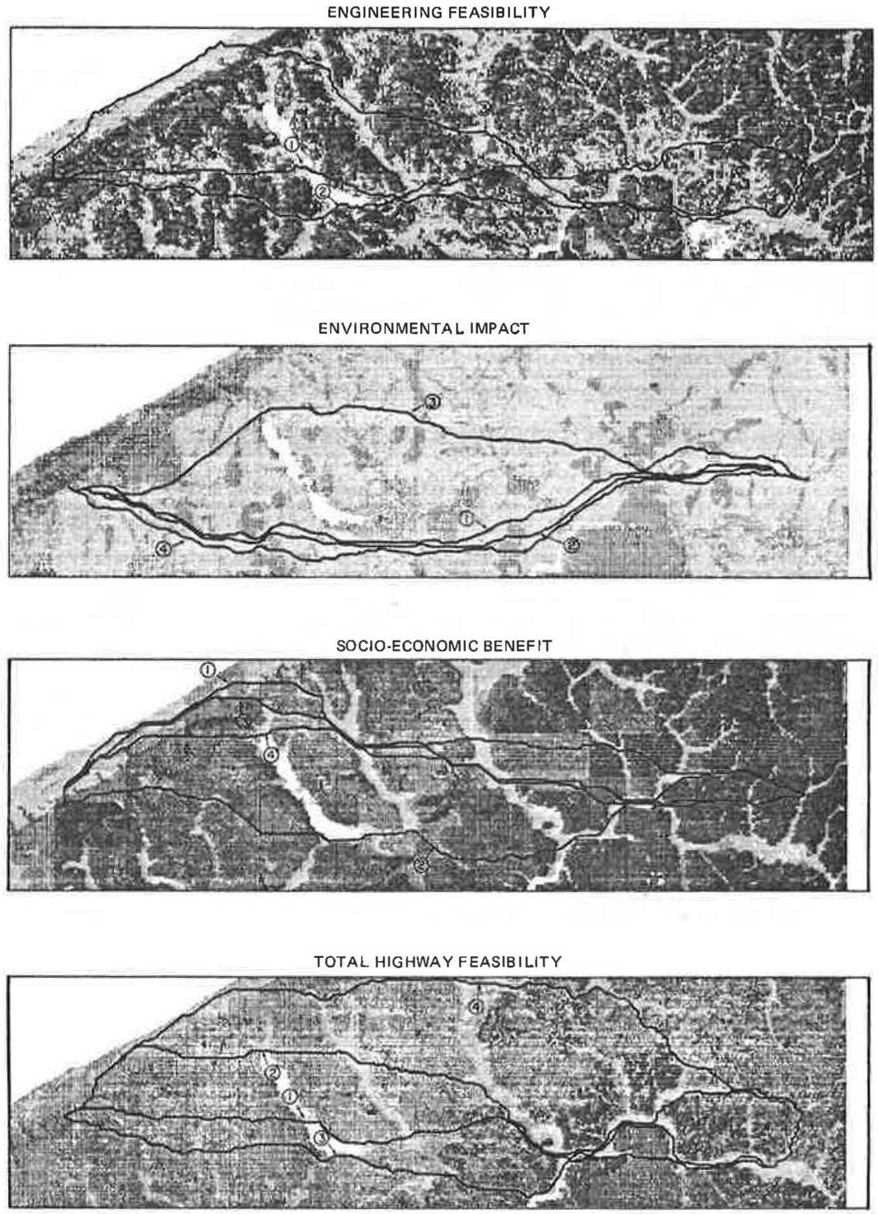


Figure 4. Four GCARS alternative corridor analyses.

plays were produced on an APPLICON color ink plotter. Interface programs are being refined that will allow the production of displays that include titles; placement of legends, north arrows, and bar scales; the plotting of entire maps or selected portions of them; and the overlaying of selected political or geographic boundaries.

CONCLUSIONS

It seems probable that computer-aided planning systems that incorporate at least some of the GMAPS-GCARS system elements will have a large role to play in future planning methodology. Computer-aided systems are particularly attractive in analyzing complex or 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, demand for new electrical transmission lines and for oil, gas, or coal slurry pipelines seems to be on the rise. The location analyses for these transportation forms can be easily handled by the GMAPS-GCARS systems.

The GMAPS-GCARS programs substantially reduced the time required for the Southern Tier Expressway study. In spite of the controversy and complexity of this project, the draft environmental impact statement (EIS) was prepared in one year rather than in the two years normally anticipated. The final EIS received final approval in just over two years from project initiation rather than in the more normal three years.

Such time savings translate into large economic savings, especially when the analyses are performed at costs lower than or equal to those of the more traditional manual methods. In the Southern Tier Expressway study, the entire GMAPS-GCARS analysis involved about \$20 000 of computer time, and each 300-m (1000-ft) wide GCARS corridor cost about \$0.30/km (\$0.50/mile) to generate. More recent versions of GMAPS cost even less to use because they can operate in as little as 25K words on a PDP-11.

The key to a successful system such as GMAPS-GCARS lies in its ability to (a) operate interactively; (b) perform analytic functions economically at a precision appropriate to the project planning level; (c) accept data rapidly and economically, possibly by way of video digitizing; and (d) display results graphically and statistically in a variety of formats.

For public presentations, color displays are most effective. They appear "familiar" to lay people and can illustrate points vividly without appearing "automated". A substantial segment of the population appears to view computer-generated products as subject to manipulation. Color display products appear to partially allay such fears.

The successful application of GMAPS-GCARS to the Southern Tier Expressway case points to the increased importance of such systems in future planning for all modes of transportation. This prediction of increased importance and acceptance is based on current trends, namely

1. The availability of good-quality, computer-processable data banks;
2. The development of "companion" computer programs to handle other aspects of transportation planning and design;
3. The increased availability of interactive computer systems;
4. The widespread installation of time-sharing computer networks supported by minicomputers; and
5. The availability of newer, cheaper, and yet more powerful units that are capable of producing color and black-and-white products suitable for projection or printing via offset printing techniques.

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Improved Highway Safety Through Interactive Graphics

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The Centralized Local Accident Surveillance System (CLASS), which is being developed by the Traffic and Safety Division of the New York State Department of Transportation to meet federal requirements and to improve highway safety for New York motorists, is described. CLASS includes information about each of the almost 600 000 accidents that occur annually on the 172 000 km (107 000 miles) of public roads in New York and is primarily geared toward meeting the needs of local safety officials, who have responsibility for 148 000 of these kilometers (92 000 miles). The major elements of CLASS are (a) an accident-site-location map produced by interactive graphics techniques and a "link-node" coding scheme, (b) a data base that contains highway information and accident data oriented to the link-node system, and (c) a software system that allows data base information to be accessed, summarized, and analyzed and permits communication between the graphic and nongraphic files. The advantage of a highway safety program based on the concept of interactive graphics is demonstrated.

The New York State Department of Transportation (NYSDOT) is actively involved in aiding local governments to carry out their safety responsibilities on the highways under their jurisdiction. This involvement begins with the provision of the accident data and analytic techniques that are necessary to identify where safety efforts should be aimed. The Centralized Local Accident Surveillance System (CLASS) will provide this local support.

CLASS is a computerized tool that provides three primary types of information to local officials: safety, highway inventory, and map. Each type of information will be discussed in more detail later in this paper. In brief, CLASS is a versatile system designed to meet local needs and provide current information.

In implementing this project, New York will be the first state to provide and analyze accident information for every public road within its boundaries. The project is also unique in that it uses direct computer interface between graphics and data files. The CLASS project, totally funded under the Section 402 Highway Safety Grant Program (Title 2, Surface Transportation Assistance Act of 1966, as amended), will provide a focal point from which a consistent, statewide highway safety improvement program can be implemented.

PROJECT BACKGROUND

Each year, almost 600 000 accidents occur along the 172 000 km (107 000 miles) of public roads in New York State; approximately 75 percent of these accidents occur on non-state-controlled facilities. For more than 10 years, accident analysis techniques have been used successfully to evaluate the 24 000-km (15 000-mile) state highway network. During that time, however, little effort has been expended on other public roads. The CLASS project was developed to fill this gap and to supply local safety officials with the necessary data to carry out their assigned duties.

To many people, Centralized Local Accident Surveillance System suggests a conflict of purpose—i.e., centralized versus local. The fear raised is the long-standing one of the "big brother" or "ivory tower" concept often associated (and many times rightly so) with government bureaucracy. More than a year was spent in dealing with this question by involving a representative sample of local safety officials in the development phase of the project. Existing local systems were reviewed to determine their strengths and weaknesses as perceived by the users. Safety groups from each county and major municipality were queried to determine the need for the proposed system as well as to identify problems foreseen in the management of the system by the state.

The justification for the approach taken and the basic interface with local safety officials can best be explained by examining the wording of the project title.

Centralization

The Highway Safety Act of 1966 requires each state to monitor accident experience on every public road to determine which highway segments warrant improvement. This process, entitled accident identification and surveillance, is also the name of Highway Safety Standard 9 of the 1966 Act. During the past 10 years, several local governments have made an effort to develop their own systems, with varying results. When a state highway accident surveillance system was successfully implemented, the value of a centralized system that would cover other public roads became evident. The factors that led to this decision included the following:

1. Decreased development costs—Analysis of large quantities of data can be handled most efficiently by using a computer, but development of computer software can be expensive. So, instead of each safety group expending the necessary resources to develop their own computer systems, centralization means that development costs occur only once and the resulting system can be used by all.
2. More complete data base—The systems that were being developed by each safety group had access only to police-reported accident data. Approximately 60 percent of all reported accidents are investigated by the police; the remaining 40 percent that are reported only by the motorists involved could not, therefore, be used in these local safety analyses. The centralized system uses the New York Department of Motor Vehicles (DMV) accident data base, which contains information about all accidents reported, regardless of the reporting source.
3. Increased computer capability—Most local governments could not justify the level of sophistication in computer capability that a centralized system can provide. In fact, many local groups could not justify any computer capability, and thus the centralized service is a real advantage to them.
4. More stable staffing conditions—Year-to-year budgeting conditions are more stable in the environment of the centralized state-operated system because of the uncertainty associated with local governments' ability to ensure continued financial support. This is especially true with respect to the accident coding process, which the state DMV is already mandated to perform.

Local Interface

Local interface comes in two forms: assistance and access. State assistance is designed to help local governments implement effective safety improvement programs (SIPs). The SIP includes all necessary functions, beginning with individual accident information and ending with implementation of effective remedial actions.

Assistance specifically relates to four areas:

1. Where to look—The primary product of CLASS is data on accident location; this is accomplished through an analytic technique called "accident surveillance", which is discussed in detail later in this paper.
2. How to look—Standard traffic engineering principles must be applied to each location identified in the first step. Short traffic engineering courses developed by NYSDOT are taught by qualified instructors at sites throughout the state. These courses cover data requirements, factors to be considered, and evaluation techniques. The primary attendees are local safety officials.
3. How to improve—Consistent accident patterns usually define the choices of remedial actions, the best being determined by a cost analysis of expected accident reduction. Accident patterns are determined by reviewing the data supplied by CLASS, and cost analysis is performed by following procedures developed by NYSDOT for use on the state highway system.
4. How to fund—The biggest problem for local officials is funding. The federal government has established several funding programs that are aimed at improving the safety of local roads but require accident data. CLASS provides the data, and the Community Assistance Section of NYSDOT helps the local government apply for the funds.

A combination of several state-sponsored programs provides assistance to local areas in implementing effective safety programs; CLASS provides the basic information without which no safety program can be effective.

Local access to information contained in or related to CLASS is the key to satisfying local needs. This access covers five primary areas:

1. Regional computer terminals—Most inquiries by local safety officials pertain to recent accident experience at a particular intersection or along a given stretch of highway. Each regional office of NYSDOT has a computer terminal from which local officials may obtain this information within 15 min.
2. Local computer terminals—Several larger counties may generate enough requests to warrant their own terminals. Local governments will have to pay for the terminal and communication costs.
3. Periodic reports—Many listing, summary, and analytic programs produce output that is too voluminous to transmit via telecommunications. These reports will be produced on a high-speed printer and transmitted by mail.
4. Updates—Updates of highway characteristics are primarily based on information from local offices. These updates can be transmitted via telecommunications but will probably be screened at NYSDOT before being entered into the data base. Updates can be either interactively entered or batch-processed into the data base. If local needs result in the identification of additional items to be included in the data base, consideration will be given such requests. The current content of the data base was greatly influenced by the local perception of needs.
5. Retrieval of accident reports—During some safety investigations, computer-generated accident reports may not provide all needed information. In that case, local safety officials can request a paper copy of the original accident report(s) submitted to the DMV.

This variety of access provides needed information, as required, and at no cost to the local community for the output.

Accident Surveillance

Accident surveillance is the monitoring and analyzing of reported accident data to determine locations that have an unexpectedly high rate of accident occurrence. Surveillance techniques can be as simple as sticking pins in a map or as complicated as the sophisticated computer analysis of CLASS. Simple techniques can only compare locations based on the number of accidents, which usually indicates only high traffic volume. Expected accident frequency, however, is different for different types of highways. By using the computer, one can make the calculations necessary to analyze accident experience more accurately.

The CLASS surveillance procedure begins by defining hundreds of different highway types and intersections by using such factors as type of geographic area, number of lanes, control of access, functional classification (travel purpose), intersection configuration, and type of traffic control. The accident data are then accumulated for each category, and mean accident rates are calculated. The actual accident experience for each segment of highway or each intersection is then compared with the appropriate mean rate based on category type by using a standard "upper control limit" statistical formula. Locations for which the actual accident rate is significantly higher than the mean rate (e. g. , three standard deviations) warrant a safety investigation to determine what remedial action should be taken.

Traffic volumes are the best exposure base (rate basis) to use in the process of accident surveillance. But, in developing a system to monitor all public roads, data on traffic volume are not always available. CLASS techniques have therefore been programmed to operate with or without information on traffic volume.

THE BASIC SYSTEM

CLASS is based on an interactive graphics system developed by M&S Computing, Inc. The system consists primarily of standard computer hardware linked together by software developed by M&S Computing. The basic components of CLASS are described below.

Hardware

The major hardware components of CLASS are three digitizing units comprised of Tektronix screens and Altek digitizing boards; a fourth interactive station, which also uses Tektronix screens; a Digital Equipment Corporation PDP 11/70 computer with 256K words of core; four 300-mb Ampex disk drives, two Kennedy 9100 tape drives, a high-speed Data Products line printer, and a Kongsberg flatbed plotter.

Software

Three operating systems are used in CLASS:

1. The RSX 11-M operating system of the PDP 11/70, which controls general systems operation, provides file control and administration, directs communications, and supports the general utility tasks available to the user;
2. The interactive graphics design system IGDS 7.2, the graphics operating system that controls all graphical tasks; and
3. The data management retrieval system (DMRS), the data base operating system that controls the definition of the data base structure and the ability to inquire and report on information contained in the data base.

Costs

The total cost of development will be about \$2 million, of which the hardware-software-maintenance contract represents \$750 000. The other \$1.25 million is primarily personal service funds required to enter the graphical and highway inventory data and to produce the outputs for the first two years of operation. These costs are about the same as the estimated costs of preparing these products by using standard cartographic procedures for the reference maps. Nevertheless, as I will explain later, the advantages of interactive graphics justified the selected approach.

Staff

Sixteen state employees are assigned to the CLASS project. This staff is divided into three primary groups, and a technical coordinator manages the project. The cartographic staff of five is responsible for the digitizing and map production functions. The data preparation staff of seven is responsible for highlighting map features to make the digitizing process more efficient and coding the data on highway characteristics. Three data-processing personnel run the computer and plotter and perform other typical data-processing functions. This level of staffing is to be maintained for the three-year development-creation phase.

SELECTION OF INTERACTIVE GRAPHICS TECHNIQUE

Interactive graphics was selected as the medium on which the CLASS project would be based because of its updating advantages, display capabilities, accurate mileage calculations, more efficient technique for coding accident location, and other applications that could be implemented by NYSDOT. The M&S Computing system was selected because of its unique graphics capabilities and its ability to "marry" a large data base and graphical files by means of computer software.

The key to a reliable system of accident analysis is accurate, current map information. The interactive graphics concept is the most efficient means of accomplishing this goal. The primary advantages of interactive graphics in the updating process are the ease with which changes can be made and the increased frequency at which changes to maps can be implemented. Because of the direct link between the graphics and the data base, highway inventory updates can be made interactively to the graphics files by using the road elements as visual keys to aid in making the correct change and then programmatically unloading the information to the data base files.

The old saying, "A picture is worth a thousand words," can certainly be applied to the use of interactive graphics in CLASS. Any item contained in the data base can be displayed graphically. The two primary applications will be in safety and cartography. When the accident surveillance programs identify "hazardous" locations, this information can be relayed to the graphics file in such a way that the computer plotter can produce a map that shows these suspicious highway segments in red and all other segments in black. This will give safety officials a clear visual perspective of their problem areas. In cartography, thematic (special-purpose) mapping is much in demand; it is also very time consuming. In CLASS, maps that show, for example, the federal-aid or functional classifications of highways can be directly produced on the computer plotter by interfacing these elements in the data base with their respective elements in the graphics.

Aid to local communities is often based on the road mileage under their jurisdiction. Since the CLASS road network is an accurate digital representation of the NYSDOT base map series, the graphical files can be used to determine mileage without having to drive each highway or measure maps.

Added justification for using interactive graphics was obtained by investigating the accident location coding process performed by the DMV. Two advantages were found to exist: the efficiency of the process and the reduced rate of error. Because the interactive graphics approach main-

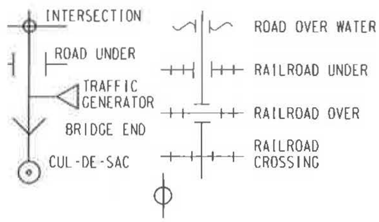


Figure 1. Accident coding of nodes

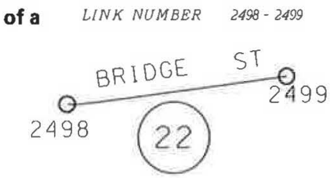


Figure 2. Description of a link.

Table 1. Interim accident summary.

Link-Node	Total Accidents	Severity: Fatal	Injury	Property Damage Only	Non-reportable	Number of Vehicles: 1	2	≥3	Accident Type: Fixed Object	Pedestrian	Wet Conditions	Nighttime
12	1	0	1	0	0	0	1	0	0	0	0	0
13	2	0	2	0	0	1	1	0	0	1	1	0
13-8	2	0	0	2	0	0	1	1	0	0	0	0
8	5	0	5	0	0	2	3	0	0	2	0	3
8-14	3	0	1	2	0	0	2	1	0	0	0	0
14	1	0	1	0	0	1	0	0	0	1	0	1
14-15	6	0	2	4	0	0	3	3	0	0	1	3
15	1	0	1	0	0	1	0	0	1	0	0	1

Figure 3. Verbal description listing.

Region 6 County 1 Mohegan Municipality 88 Village of Doeville Run Date 10/21/77

Link/Node Location = 14 - 15

Injury , Thu 2/19/76 03 PM, Weather-Rain, Road-Straight/Grade/Wet , No Traf Control, Lite-Oth 02 Veh, 0 Killed
Collide W/Mot Veh Overtake, On Road, 07 Injured

Veh: 01, Going Straight ,Go-E, Hit Bldg/Wall ,Front, Factor-Brakes Def ,Other (Human), ,Pub-Prop,Viol
Veh: 02, Left Turn ,Go-E, Hit Utility Pole ,L-Door, Factor-Tire Def ,Pavement Slpr. ,Viol

Case No. 6194125

tains the maps required to locate each accident as graphical files, the actual location process can be accomplished by "tagging" the appropriate graphical element for each accident. This process makes the interactive graphics approach more efficient than any alternate approach because it eliminates the need to repeatedly code and keypunch the location identifier. The second advantage—the reduction in error—is related to the elimination of these two additional steps. NYSDOT experience with state highway accident data coded by using manual techniques indicated that almost 10 percent of accident location codes were wrong because of mistakes made during these two steps. The automatic location tagging procedure will virtually eliminate these types of errors.

A final justification for using interactive graphics in CLASS is that other NYSDOT activities could ultimately benefit from this capability. Examples of such activities are (a) the automated county base map series, (b) the interactive redesign of intersections for improved safety and traffic flow, (c) network traffic assignments for planning functions, (d) other network inventories (e.g., railroad), and (e) site location needs of other state and local agencies.

SYSTEM ELEMENTS

Structure

The major elements of CLASS are a highway-site-location map, a data base that contains highway data and associated accident information, and a retrieval system that is designed to manipulate the data base to produce needed output reports. The site location map is used by the DMV to locate accidents and by NYSDOT as a basis for coding data on highway characteristics.

The basic highway-site-location technique used in CLASS is called "link-node." A node is a point of intersection along the highway; each type of node is graphically illustrated by a unique symbol called a "cell" in the interactive graphics operating system. Types of nodes and the symbols used are shown in Figure 1. (The symbol shown at the bottom center of the figure is used to represent a group of nodes to which accidents cannot be coded: points at which a highway and a boundary or a highway and a map neatline cross, a change in highway characteristics, a mileage break to keep highway segments from becoming too long, and a dead end.)

A link is the portion of highway between two nodes. Each node is assigned a number in such a way that there are no duplicate node numbers within a municipality. The link number is simply the low-high combination of the two node numbers that define the ends of the link. An example is shown in Figure 2.

A data base will be established for each of New York's 62 counties. The 172 000 km (107 000 miles) of highway will be divided into about 750 000 links, which will result in an average link length of 0.25 km (0.15 mile). For each link, more than 25 characteristics will be contained in the data base. To define this number of links, more than 500 000 nodes (each with 10 characteristics) will also be encoded to the data base. Three years of accident data (i.e., almost 2 million accidents, each with 30 characteristics) will also be retained in the data base, which includes the following:

1. Interim accident summary—The interim accident summary provides a link-by-link, node-by-node summary of accident data for a specified time period, such as three months. An example is given in Table 1.
2. Priority investigation location—The priority investigation location listing is the key to an effective SIP. The analytic technique used to create this output determines an expected accident rate for several hundred types of roads and intersections and then determines which specific road segments and intersections experience an accident rate

Table 2. Street characteristics.

Main Street at	Node	Number of Lanes	Functional Class	Area Type	Section Length (km)	Parking
East Pearl/West Pearl	12	2	Minor arterial	Urban	0.10	Both sides
Jefferson	13	2	Minor arterial	Urban	0.10	Both sides
Madison	8	2	Local	Rural	0.18	One side
East Fassett/West Fassett	14	2	Local	Rural	0.18	One side or restricted

Note: 1 km = 0.62 mile.
All highway characteristics maintained could not be displayed in the available space. Others are, for example, federal-aid class, pavement width, and pavement type.

Figure 4. Creation procedure.

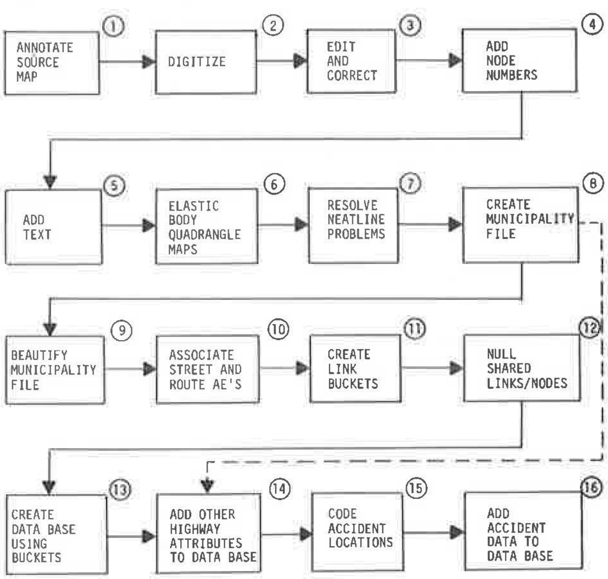
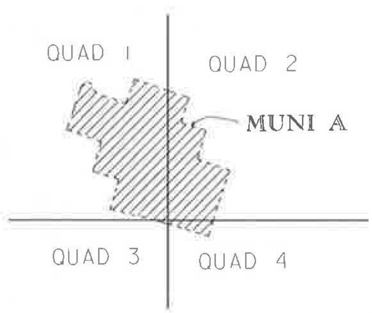


Figure 5. Elastic-body process.



significantly higher than the expected rate. Each listing includes a display of important accident data and accident rates.

3. Verbal description listing—The verbal description listing (see Figure 3) describes in abbreviated terms each accident that occurred at the given location and identifies the situations and possible causes. These listings are available to local officials through remotely located alphanumeric computer terminals that can provide quick answers to specific questions.

Highway Inventory

Information about highway characteristics is essential to an effective accident surveillance system and subsequent roadway analysis, facilitates the proper management of the highway network, and aids in fulfilling state and federal data requirements. The link-node system provides a simple means to collect and maintain required data about highway characteristics in a form that directly corresponds to accident data.

Several listings and summaries of this highway information are available in CLASS. Table 2 gives one example.

An aspect of the DMRS is a user-oriented report generator language. If none of the 19 preprogrammed outputs provides the analysis required by a local safety official, a special program can be designed and written. This service would probably be performed by CLASS personnel, but local officials who wished to do so could learn the language and write their own programs. Voluminous reports would still have to be produced on the high-speed printer and sent to the user by mail.

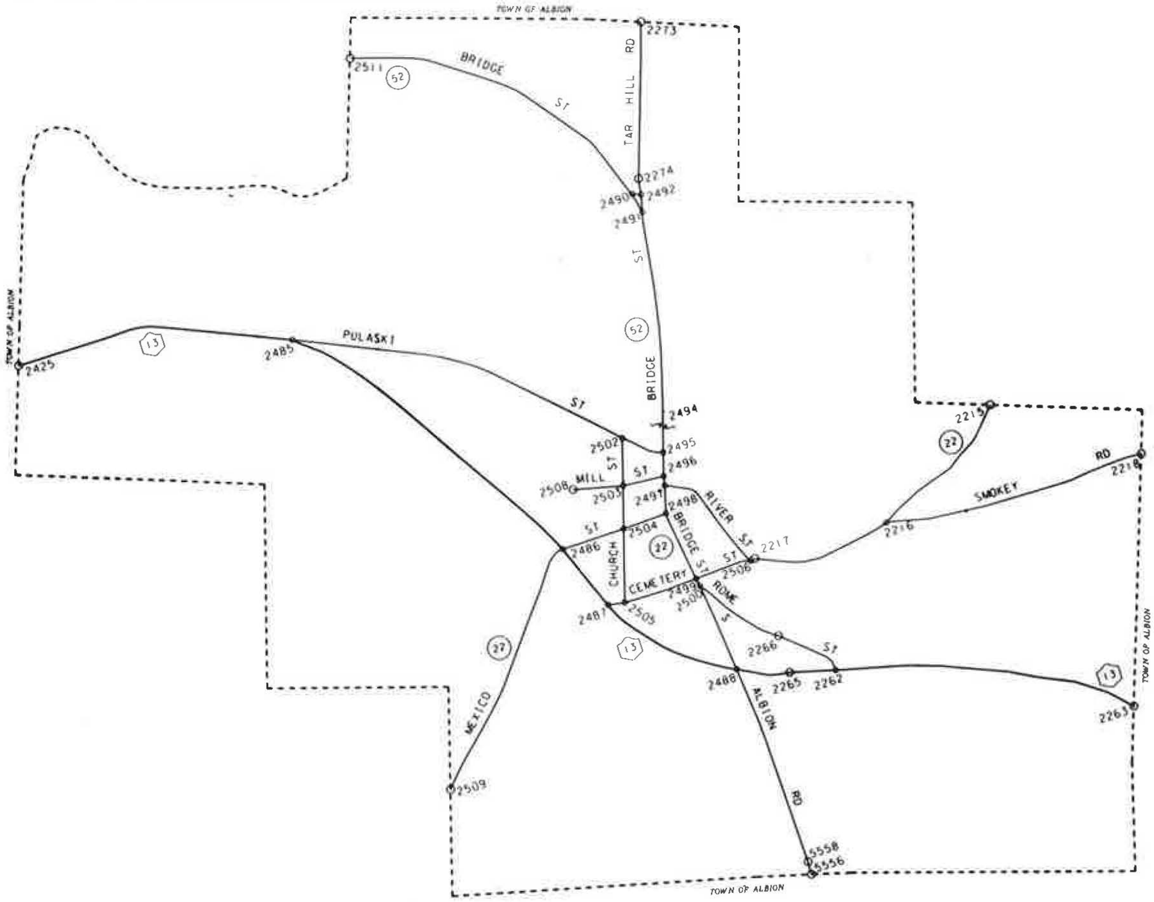
CREATION PROCEDURE

Three primary files are generated during the creation process: a graphical file that precisely replicates the road and boundary alignments of the original NYSDOT source map, a graphical file that contains information on a single municipality (i.e., a city, town, or village), and a data base file that contains the data on highway characteristics and historical accident data. These three files are integrally related to ensure that every roadway element exists and can be uniquely identified on each of the three files.

Figure 4 shows the steps required to create the three separate yet integrally related files. The steps (referenced by number in the figure) are as follows:

1. Annotate source map—Key map items are highlighted in color on the source documents, and confusing map features are clarified to make the digitizing process more efficient.
2. Digitize—Basic map elements, including control monuments, boundaries, exact highway alignments for all public roads, major shorelines, and location of all nodes, are digitized. The different types of data are each stored separately on one of 63 available levels.
3. Edit and correct—Plotted digitized maps are then edited for accuracy and completeness to ensure that the single-line plotted highway alignment falls entirely within the double-line representation of the highway on the source base map.
4. Add node numbers—Each node is programmatically given a four- or five-digit number, which is then placed on the graphical file with a given orientation to the node.
5. Add text—Street names and route markers are added to the graphical file.
6. Elastic-body quadrangle maps—The irregularly shaped municipality maps are "clipped" from the rectangular quadrangle maps after they have been merged (see Figure 5).
7. Resolve neatline problems—Even after the elastic-body process, locations along the neatline, where the two ends of a highway are supposed to come together, still may not align perfectly, so that further adjustment is required.
8. Create municipality file—The individual municipalities are "clipped" from the merged elastic-body file. Figure 6 shows a municipality.

Figure 6. Map of municipality (village of Altmar).



9. Beautify muni file—Several additional map features applicable only to the municipality maps are added at this time.

10. Associate street and route associated elements—An associated element (AE) is the procedure used to add textual intelligence, such as street name, to a graphical element, such as a line.

11. Create link "buckets"—Transfer of data from the graphical file to the data base file and vice versa is accomplished by using a technique called buckets. A bucket is a nongraphical element within a graphical file that has direct association with a graphical element. The key highway characteristics (attributes) are contained within the link buckets. Node buckets also exist and are established by the automatic node numbering program (step 4 above). The link-bucket creation establishes the buckets for each link and then uses the various AEs and other data base intelligence (e.g., levels) placed in the graphical file throughout this process to encode the data in the buckets.

12. Null shared links and nodes—Some political boundaries go down the middle of roads (links) and through intersections (nodes). These links and nodes belong to only one municipality but must be shown on both. This process establishes the correct municipality assignment.

13. Create data base by using buckets—Data contained in the buckets are simply transferred to the appropriate location within the data base file.

14. Add other highway attributes to data base—Other highway characteristics are manually coded, keypunched, and entered into the data base through batch processing.

15. Code accident locations—The DMV uses municipality files to location-code all accidents that occur in New York State.

16. Add accident data to data base—The accident data received from the DMV are batch-processed into the data base.

This creation procedure is both long and complex, but the resulting products are powerful, versatile data bases and multipurpose graphics files.

CONCLUSIONS

Improved highway safety requires accurate, manageable, and easily analyzed accident data. The link-node location system in CLASS provides a simple and accurate means of identifying accident locations. The interactive graphics system provides accurate, easily updated maps for use in the process of accident location.

The data base manager system provides for the storage of data on highway characteristics and accident data as well as analyzing the relation between these two elements. It can thus be concluded that the many different aspects of CLASS jointly provide the information local safety officials require to properly perform their duties.

The versatility of CLASS and the interactive graphics system on which its development was based also provide numerous "spin-off" products to NYSDOT that otherwise could not be realized.

ACKNOWLEDGMENT

I wish to thank M&S Computing, Inc., of Huntsville, Alabama, for permission to describe their interactive graphics system as it relates to the CLASS project. IGDS and DMRS are standard M&S products. The concepts and capabilities of CLASS were designed by NYSDOT staff. The descriptions in this paper are mine.