Transportation Applications of Computer Mapping in New Mexico

LuANN WANDSNIDER, LAURENCE M. SPEAR, STEVEN FLINT, and ROBERT U. ANDERSON

ABSTRACT

Geographic information systems are devices for processing data with a geographic component and have been hailed as an adroit solution to the manager's dilemma of high demand for quality information and low supply of human resources with which to meet the demand. One such system, the Geographic Road Network Data Base developed by the Division of Government Research at the University of New Mexico, is described. The capability of the system to present transportation information, such as the incidence of vehicular accidents and the status of roads, is demonstrated by a series of maps generated by the system. Finally, the future role of the system in other transportation applications is briefly discussed.

The definitions of "information" include "1: the communication or reception of knowledge or intelligence, 2a: knowledge obtained from investigation, study, or instruction, 2c: facts, data" (1). The same source defines "data" as "factual information (as measurements or statistics) used as a basis for reasoning, discussion, or calculation." Throughout this paper, the term "information" will be used to refer only to knowledge or intelligence. "Data" will refer to an aggregate of isolated facts like measurements or objective observations.

This is a critical, although perhaps pedantic, distinction that cannot be overstated. Computers, with their incredible storage capacities and lightning-fast access times, have permitted the collection and storage of tremendous amounts of data. Especially in the domain of transportation, data about roadway characteristics, accident occurrences, and citation incidents accumulate at a frightening pace, but direct access to entire libraries of data does not mean that anything more is known about a given phenomenon. Instead, it means that the possibility of knowing, the potential for manipulating these facts to produce information, is high.

How then, is information to be extracted from data? The ultimate answer to this question lies in the domains of the philosophy of science and the chemistry of the human brain. For more proximate purposes, it can be observed that new and useful information appears to result from the meaningful juxtaposition of facts. For example, knowing only that many automobile accidents appear to occur in the same place during the course of a year is useful information that suggests that that particular piece of road should be inspected for failure or poor marking.

Herein a specific kind of data and information is considered: that with a geographic component, which most transportation phenomena have. To set the stage for a discussion of the Geographic Road Network Data Base (GRNDB), a geographic information system designed and built by the Division of Government Research, how geographic information systems turn data into information will be briefly reviewed. The GRNDB is then introduced and its capabilities and limitations are examined. Several applications of this system to transportation problems are reviewed. This paper concludes with a brief prospectus on future applications of the GRNDB system to produce new information of use to transportation planners.

The use of geographic information systems in transportation and planning is still relatively new. Indeed, it is difficult to find widely published accounts of the development and operation of geographic information systems in the transportation domain. It is hoped that a discussion of the GRNDB will aid others in their own design and application of geographic information systems, and inquiries from those interested in the detailed workings of the system are invited.

GEOGRAPHIC INFORMATION SYSTEMS

Planners and decision makers today are caught between the rock of limited funds and the hard place of increasingly vehement demands for informed and well-made decisions. With reduced monetary resources, planners in federal, state, and municipal arenas must efficiently seek out pertinent and accurate information. They must then use this information so that solutions to problems can be quickly identified and cogently described. Alternative solutions and the consequences of implementing a given solution must be explored. Yet, with the data explosion of the last decade, extracting the information required for good decision making from these data becomes a formidable task. Given growing concern for fiscally responsible decisions, the task of designing visionary plans and making informed decisions becomes almost overwhelming.

To extricate themselves from this potentially debilitating situation, decision makers have developed a tool that allows them to manipulate large amounts of detailed data for problem solving. The cost of such a tool is large but not so large as the same sort of operation performed by human beings, who are expensive and, more important, inaccurate and incapable of complex multidimensional data analyses. This tool is the geographic information system (GIS).

"An information system is a chain of steps that leads from observation and collection of data through analysis to use in some decision-making process. . . . If the data being handled by the system are geographic data (i.e., they have a spatial component) . . ., and the techniques being used are spatial data handling techniques, then the system concerned is referred to as a 'geographic information system'" (2). Completing a tax form is, according to this definition, an information system. Compiling data for a state road network map for tourists is an example of a geographic information system, the end product of which may be an atlas of road information. The concept of a geographic information system has come to include more than the manual data juggling of the type just mentioned. Computers, imperative for both data management and analysis, play a critical role in the functioning of modern geographic information systems.

Calkins and Tomlinson (2), Knapp and Rider (3), and others have identified the evolutionary phases of an information system. These include (a) data gathering, encoding, and inputting; (b) data storage and management; (c) data manipulation and analysis; and (d) description and presentation of new information derived through analysis of these data and effected through statistics and graphics. Each of these will be discussed in greater detail when the GRNDB is described. At this juncture, suffice it to say that the final products of a functioning geographic information system, the summary numbers and pictures, can be used to communicate information about the actual or projected status of some phenomenon.

Geographic information systems have served in several different capacities in the transportation domain. Two gross kinds of uses can be identified: (a) simple information presentation (i.e., presentation of incidence data in its geographic context) and (b) presentation of analytic results, which involves more data processing before display. The first of these functions is rarely, if ever, reported, perhaps because it is so obvious and so mundane. Nevertheless, efficient compilation and display of information are always desirable. Simple graphics, for example, can be used to persuade a legislative body to allocate funds for a specific purpose, to make the public aware of a certain condition, or to draw the attention of decision makers to an unwanted situation. For example, the Kansas City, Kansas, Police Department implemented a geographic information system that allowed them to generate each month a map showing the locations of various serious crimes and accidents (4). That is, the data on "type of crime" and "location of crime" were juxtaposed and presented in a single format. On inspection of these maps, police resources were then allocated so that protection was maximized. Another simple but elegant application of this Kansas City Police Department system involved graphically demonstrating to one concerned neighborhood that its crime rate was not significantly higher than that of other neighborhoods.

More commonly recounted are the applications of geographic information systems to situations in which multidimensional analyses are performed. These are situations in which many strata of geographical data are "stacked" one atop the other. The human mind can only assimilate and analyze three to five dimensions of raw data. To compare, comprehend, and extract the essence of such a mosaic of data, the computer is necessary. Dickey and Leiner (5), for example, used TOPAZ, a commercially available automated geographic information system, to depict several scenarios in suburban Washington, D.C., which would ensue given various planning decisions. Some of the "layers" of information they considered were travel time to and from nearby cities, pollution that would result from development, and other travel costs. The scenarios were then rated according to their benefits and liabilities allowing Prince William County planners to reach an informed decision.

Another geographic information system application to transportation problems concerns the planning and design of roads. The state of Texas Highway Department has developed a system that integrates field data on bed characteristics of potential roads (6). Road "candidates" actually can be constructed on a terminal screen and cost assessments can be made. These estimates are then used to decide the location of a new road.

Other examples of the application of geographic information systems to problem solving in transportation are numerous (see, for example, the publications of the Harvard University Laboratory for Computer Graphics, Michigan Department of State Highways and Transportation, and recent issues of Transportation Research Records). This presentation of the capabilities of the GRNDB should be considered a report on yet another system, one designed to meet the specific needs of New Mexico clients.

In each of the examples briefly described, the glowing results of the application of a geographic information system were given. Only hinted at was the tremendous investment in data and software resources that must support any useful information system. It should be clear that a geographic information system is more than just a device for drawing "neat" (but sometimes low-quality) pictures. It is a tool that compiles pertinent data and arranges them so that the human mind can discern relationships among data. Whether these relationships are meaningful or not is up to the interpreter. These are the kernels of information of use to the decision maker.

GEOGRAPHIC ROAD NETWORK DATA BASE OF NEW MEXICO

The Division of Government Research is part of the Institute for Applied Research Services, the public service arm of the University of New Mexico. It was founded in 1945 to provide technical support for researchers interested in social questions. Since 1975, the division has created new, useful information from the large, automated data bases that federal, state, and local governments keep. As part of this mission, the New Mexico Traffic Safety Bureau contracted with the Division of Government Research in 1982 to design and produce a computerized geographic information system for New Mexico that would efficiently manage, analyze, and present roadway-related information (7). The system was built by 1983 and has since been successfully used by a diverse New Mexico clientele, including the Traffic Safety Bureau, the New Mexico State Highway Department, the State Police, and the New Mexico Secretary of State.

The GRNDB system can be described as having four major components, corresponding roughly to those system components identified by Cooke (8) for geographic information systems in general: (a) the geographic data base and compatible ancillary data bases containing the phenomenon to be mapped, (b) reliable and well-supported hardware, (c) the software that manages and manipulates both data bases and produces maps presenting information, and (d) expert personnel who built (and are continuing to build) both the data bases and the software. As mentioned earlier, the geographic data base evolves through collecting, verifying, encoding, and storing in an accessible form geographic information. For GRNDB, the geographic framework of the data base consists of large files that equate real-life names of features (like roads and cities) with variables to facilitate their mapping by the software. In addition to names like Albuquerque and Interstate 40, these files contain variables like a unique identification for each feature, corresponding strings of coordinates, and other classificatory variables including feature class, which differentiates between roads; political boundaries; cities; and "windows" (the white space remaining on a map in which labels may be placed). These data files were constructed by preparing mylar overlays of the different features from the 1980 1:500,000 U.S. Geological Survey Base Map of New Mexico and other sources. The features were then digitized from the mylars and these map (x-y) coordinates, in centimeters, were carefully cross-referenced with the real-life road coordinate system of system, route, mile point, and spur developed by the State Highway Department. This means that the GRNDB need not have digitized x-y coordinates for mapping accident or citation locations. Instead the GRNDB can translate easily from a coordinate system people can readily understand, road name and mile log location on that road, to a coordinate system, x and y, which the mapping software requires. At this time, the Division of Government Research is repeating this process of geographic data encoding and inputting using 1:100,000 base maps, which will allow the production of maps with higher resolution.

A discussion of the organization of the geographic data base of the GRNDB is complex enough to be the subject of another presentation. Herein is presented a cursory description that should be of use to those already familiar with the organization of complex data bases. In general, the data base was designed to exhibit both hierarchical and relational capabilities. This is accomplished through the construction of files that are related by specific variables like DIGID and FEATNO. DIGID refers to a unique identifier assigned to each city or road segment at the time of digitization and provides a reference for the actual sequence of mapping coordinates for each feature. FEATNO (feature number) describes the type of feature and uniquely identifies the feature. Thus one file, the BOUNDARY file, consists of all of the DIGIDs and FEATNOs that describe county and state boundaries. Its shadow file consists of associated x-y coordinates. Actual x-y coordinates for mapping the boundaries of a county, for example, are pulled out of the BOUNDARY shadow file by specifying the appropriate DIGIDs or FEATNOs for that county. Similar files exist for each of the feature classes of roads, cities, and windows; and movement between each file is enabled by the existence of common variables like DIGID and FEATNO. The Statistical Analysis System (SAS), a high-powered, well-supported, and portable software package, is used to maintain these files and to translate among them.

The supplemental data base files contain information about the character and locations of accidents, citations, population, and so forth. These data bases have been built by various government agencies over the years as part of their automated record-keeping systems and are supplied to the Division of Government Research by clients. They are made compatible with the extant system and can be merged with the basic cartographic data base. For example, downed aircraft, for which location is known by longitude and latitude, can be mapped through first transforming the longitude and latitude coordinates to base map centimeters using public domain software developed by USGS. An accident, which is located by the reporting police with respect to highway name and milepost, is mapped through a more convoluted process. An accident location is reported by its position with respect to mileposts placed on roadways. When the accident report is encoded, a highway number and mile point are interpreted for the accident location. This highway number and mile point location are first translated by the GRNDB to a more exact and more consistent road coordinate system of SYSTEM (Interstate, federal aid primary, federal-aid secondary, etc.), ROUTE, SPUR, and MILELOG. Because the GRNDB geographic data base already contains the base map x-y counterpart that is specific for nodes in the SYSTEM-ROUTE-SPUR-MILELOG coordinate system, it is a simple matter to interpolate between the nodes and translate to the x-y location of the accident. SAS is used both to organize and to translate between the geographic and supplemental data bases.

There is a variety of tried and true computing systems that could support a geographic information system of the type described here. The high volume of data that is processed each day, however, necessitates a large and reliable machine. Fortunately, the University of New Mexico Computing Center maintains a large "workhorse," an IBM 3081D. The large data base and software of GRNDB reside here and are easily accessed by the 10 programmers and data managers of the Division of Government Research. GRNDB maps can be previewed on an Apple II+ emulating a Tektronix 4010. Hard copies are produced on a Calcomp 1051 four-pen drum plotter maintained by the University of New Mexico.

The software of an information system aids in the initial construction of the data base, and it also allows data to be analyzed for trends or organized for the easy presentation of observed trends. The GRNDB software, as it happens, follows recommendations made by Stenzel (_9_) in his review and prospectus of computer technology applications to traffic record systems. Stenzel observes that hardware costs over the years have diminished and anticipates that this trend will continue. Meanwhile, software costs have remained stable or have increased as they track the wages of the people who develop the software. On the basis of these observations, Stenzel suggests that cities continue to manually keep records if the size is not prohibitive, buy hardware to fit the software that suits their needs, or adapt a functioning system. When designing the geographic information system for the Traffic Safety Bureau, the Division of Government Research opted for the latter.

The GRNDB software was written using several well-supported and well-documented languages and packages. SAS was used to organize and manipulate the data base files and is now used to perform the many analyses requested by clients. To generate maps, which present the analytic results, the division chose a graphics package that was device independent. DISSPLA, a graphics package written in FORTRAN, became available at the University of New Mexico while the GRNDB system was being designed. To interface the SAS data bases with the DISSPLA cartographic software, another VS FORTRAN code was developed by Division of Government Research programmers (S. Flint, Name Placement for GRNDB Mapping, Division of Government Research, unpublished manuscript).

The last component of the GRNDB system, the human component, is often overlooked but is critical for the continued smooth operation of an evolving system. Collins et al. (_10_) note that as a geographic information system "ages" and becomes more complete, the flexibility of the system decreases. That is, the geographic information system becomes task specific. This tendency toward built-in limitation can be avoided somewhat by implementing a geographic information system designed to be flexible. The GRNDB system must be flexible because it is to be used by many disparate clients whose commonality is that the events they are responsible for monitoring occur within the state of New Mexico. This flexibility of the GRNDB system lies not only in its software but also in the expertise of the managers who wield the software and who can readily adapt it to meet the different needs of clients. Thus, on any given day, the GRNDB may be used to produce a county map showing voting precinct boundaries, a map of the state showing incidence of alcohol-involved accidents, and a map of several adjoining counties depicting the State Highway Department's 5-year plan of road maintenance.

All geographic information systems, to be useful, must have some of the capabilities described here for the GRNDB. The bane of computer-generated maps until just recently has been their lamentable quality. The GRNDB system, however, can produce publication-quality maps. Indeed, clients have inquired on several occasions about who was responsible for the fine line work. All lettering, bordering, and shading are performed by machine as directed by the GRNDB system. At the same time, the system is capable of making color separations so that, should the mass production of a map be necessary, it can be done economically by printing. The GRNDB can generate a map of a single county, several contiguous counties, or the entire state at a variety of scales and dimensions. Classes of roads and cities can be masked or displayed using color, symbol type, line width, and symbol size to depict the different qualities of the features.

The state of the art in computer mapping holds that place names and other labels must be manually situated on a map (8). The GRNDB system, however, automatically places labels (S. Flint, unpublished manuscript) and, moreover, place names can be selectively included according to the characteristics of the place such as its population or political status. This capability results in the timely production of publication-quality maps that need no "doctoring" by a cartographer.

Cooke (8) states that software to take and display incidence data, accident locations, has yet to be developed. Because the majority of the data that come to the Division of Government Research is in the form of route-mile log, it was imperative to be able to transfer such point locations along a road system to the mapping coordinate system. As already discussed, this was accomplished by taking care to know the real-life locations of the digitized road segments and developing software to translate between the two different coordinate systems.

The GRNDB system is well documented and easy to use; the users have only to select the characteristics they wish their map to have. As do all geographic information systems, the GRNDB system produces results that are as accurate as the data base. Further, it is fast; the time it takes to generate a map depends on how many transformations the data must be subjected to, but actual drawing time is minimal. Thus time normally spent refining the graphic presentation of information can be spent on producing more information. Finally, as stated previously, it is flexible enough to allow "what if?" questions to be entertained by any of its several supplemental data bases. This flexibility also permits it to evolve; new system features are added monthly.

The GRNDB system at present has several limitations related to its youth and to resource limitations. For example, it is only able to map rural phenomena; the scale and complexity of mapping many urban centers have yet to be tackled. Further, the ability to translate between the route-mile log coordinate system and the cartographic x-y coordinate system is limited to state and federal roadways. Thus accidents or citations that occur on county roads, for example, cannot be located and mapped by the system; this is a deficiency currently being addressed. At present, the county is the smallest unit that can be displayed easily by the GRNDB system; an individual with an intimate knowledge of the GRNDB can have individual roads displayed, but this is not a common application. Finally, the display device limitations somewhat restrict the form and quality of cartographic output. For example, maps with a maximum of four colors can be produced on the Calcomp 1051, whereas cost alone restricts the number of colors used on a map produced by standard printing methods. Also, the resolution of the print quality of maps generated by the Division of Government Research is somewhat grosser than what can be achieved via photographic and other reproduction methods. One last limitation of pen-plotter devices in general is that colors, perhaps used to communicate different information, cannot be overlaid without a muddle of confusing brown resulting. More traditional map production uses colors of different intensities; this permits discernible colors to lie one atop the other.

USES AND APPLICATIONS OF THE GRNDB SYSTEM

The GRNDB system has been operating since December 1982. It has served the Division of Government Research well in helping to meet the needs of clients. Two general uses, simple information presentation and presentation of analytic results, were identified previously. In this section, several applications of the GRNDB system are examined.

Simple Information Presentation

The presentation of locations of traffic-related point data is an easily understood form of information and is useful in many situations. One of these uses is to graphically demonstrate that a large-scale problem exists and then elicit help to correct the problem. In 1983 Mothers Against Drunk Drivers (MADD) used a map of New Mexico depicting the incidence of automobile accidents in which alcohol was involved to attract new members and organize new chapters in New Mexico. Figure 1 shows the locations of driving while intoxicated (DWI) accidents in Valencia County. By having tangible evidence of the extent of the DWI problem, MADD was able to convince legislators that new laws with stricter consequences for drunken driving were needed. To compile and display this information, the GRNDB had only to select those DWI accidents that occurred in Valencia County during 1983, convert the route-milepost location to the SYSTEM-ROUTE-SPUR-MILELOG coordinate system, then convert this coordinate to the x-y coordinate system compatible with the mapping software, calculate the coordinates of the symbol used to indicate the occurrence of such an accident, and send these coordinates along with the coordinates of roads, political boundaries, and city symbols and names to the plotter. This map was produced in about 3 hr and represents a concise, dramatic, and easily assimilated summary of the DWI problem in Valencia County.

In another instance, a map of New Mexico depicting the road rehabilitation schedule was generated for the New Mexico State Highway Department. The production of such a map requires more "data crunching" in that road rehabilitation in two dimensions, time and space, must first be identified and then properly mapped using the width of the space between lines paralleling road segments to show time. Figure 2 shows the 5-year construction plan for Guadalupe County. This map was used by that department to show the legislature that more funding was required for the upkeep of New Mexico roads. Again, such a map is a more effective means of communicating information about the maintenance schedule than reading off a list of road segments and the date of their sched-

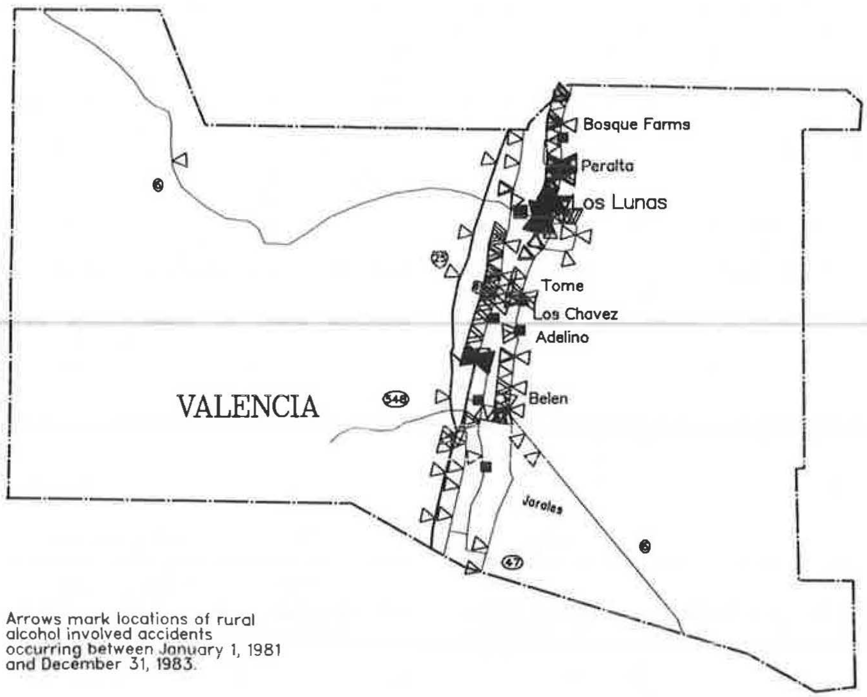


FIGURE 1 Locations of vehicular accidents involving alcohol in Valencia County, New Mexico.

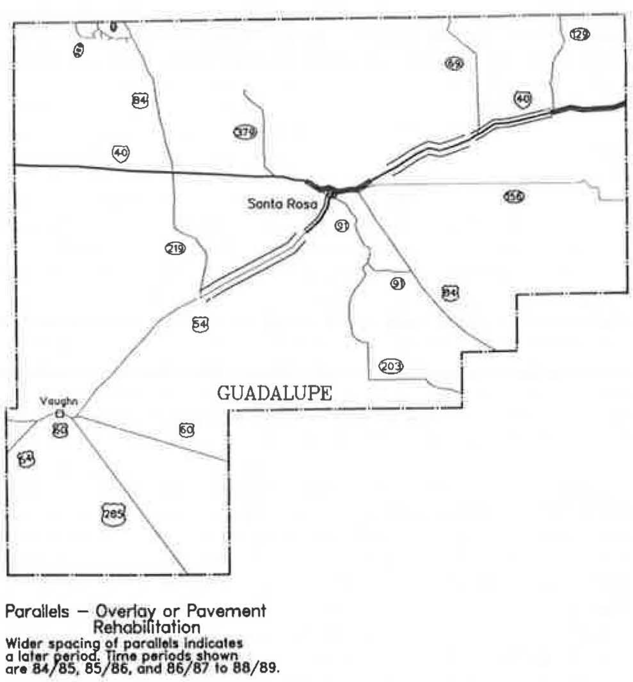


FIGURE 2 New Mexico State Highway Department 5-year construction plan showing when segments of highway have been or are scheduled to be rehabilitated in Guadalupe County.

uled maintenance. This map was produced in less than 5 hr.

One last example of the use of the GRNDB system for presenting simple information concerns the high rate of rural pedestrian accidents in two New Mexico counties. As shown in Figure 3, McKinley and San Juan Counties in northwestern New Mexico respectively have pedestrian accident rates of 11.25 and 7.88 (per million vehicle-miles), among the highest in the state and the country. Focusing on these counties (Figure 4), it can be seen that pedestrian-involved accidents happen all along the major thoroughfares in these counties with a somewhat greater occurrence near the cities of Gallup, Shiprock, and Farmington (latter two not shown). This map was used by the Traffic Safety Bureau to successfully obtain support from the National Highway Traffic Safety Administration for an investigative study into the causes of these high accident rates. These maps were produced in 4 hr and again show the information value of simply presenting a phenomena within its geographic context.

PRESENTATION OF ANALYTIC RESULTS

The GRNDB system is capable of more powerful data manipulations than those described, which involved simple operations to organize the data for presentation. This is demonstrated in Figure 5, which shows the juxtaposition of two related phenomena, DWI accidents and DWI citations made by the State Police in Luna County. This map was used by the State Police to adjust their enforcement practices to coincide with accident patterns. Because accidents and citations are reported to two different agencies using two different recording systems, the data manipulations to produce this map are somewhat more complicated. Approximately 6 hr were used to transform each data set into a form compatible with the mapping system and then produce this summary map. To produce such a map manually the same amount of time might be used but the resulting graphical summary would be less accurate.

The last example is experimental and involves more high-level analysis. Limited resources must be managed so that they serve the maximum number of people. This statement is especially true for emergency rescue and ambulance resources in rural areas. How should the emergency medical services (EMS) agency best allocate these limited resources? To answer this question, the present status of emer-

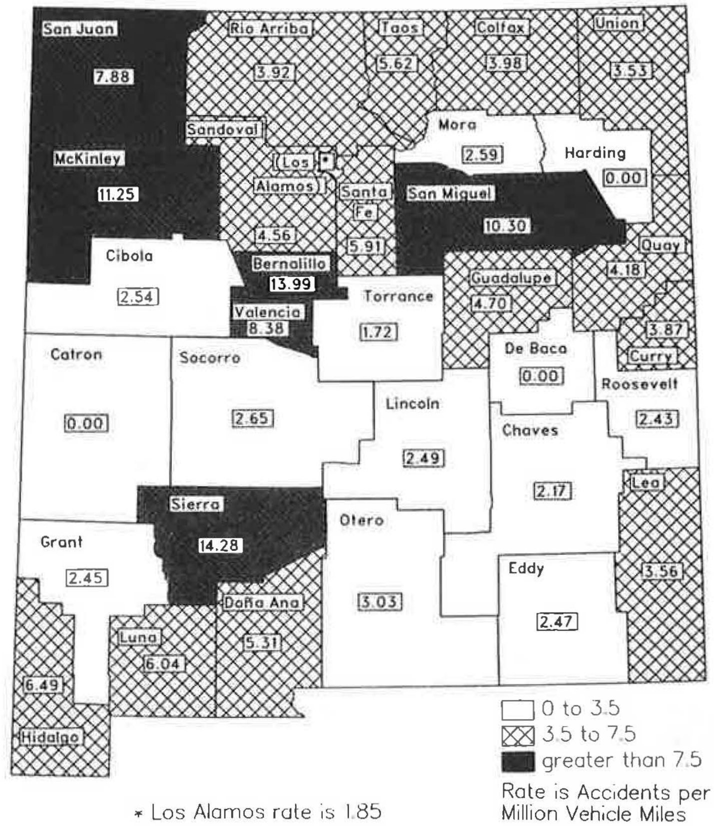


FIGURE 3 Map showing the distribution of rural pedestrian accident rates by county for the state of New Mexico.

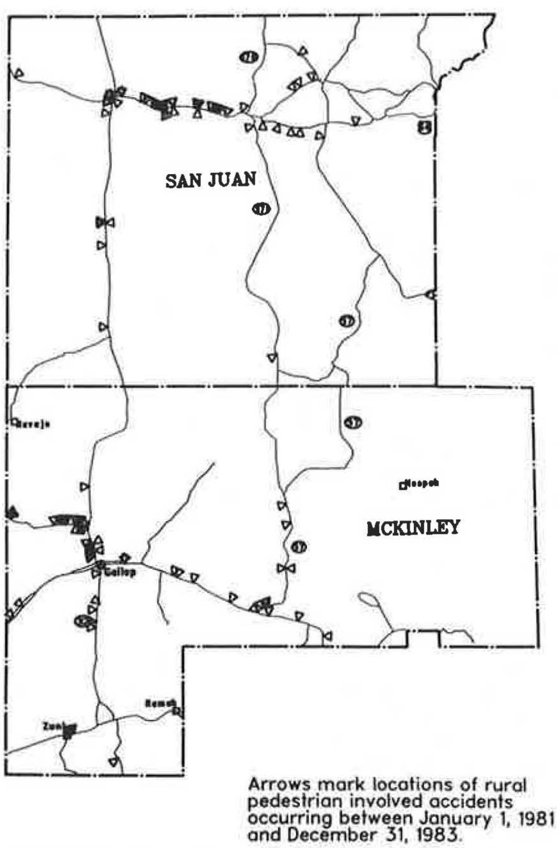


FIGURE 4 Map of San Juan and McKinley Counties showing the distribution of rural pedestrian accidents.

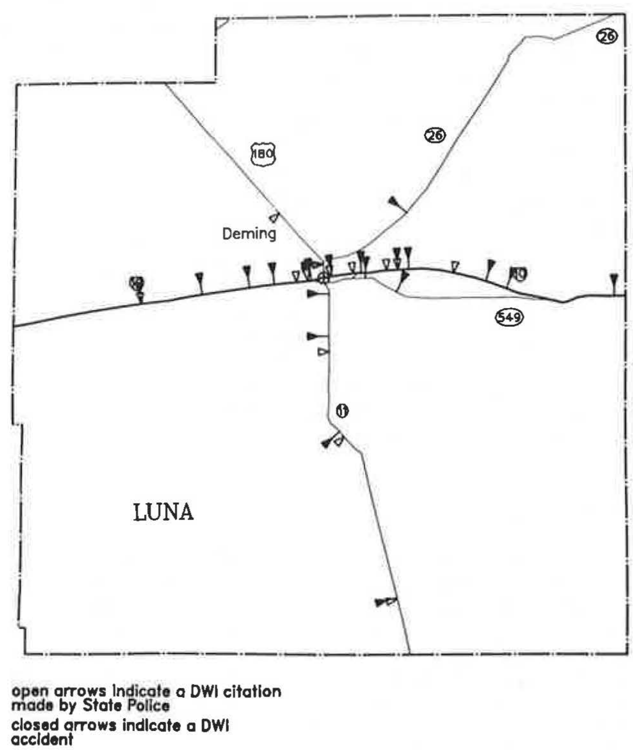
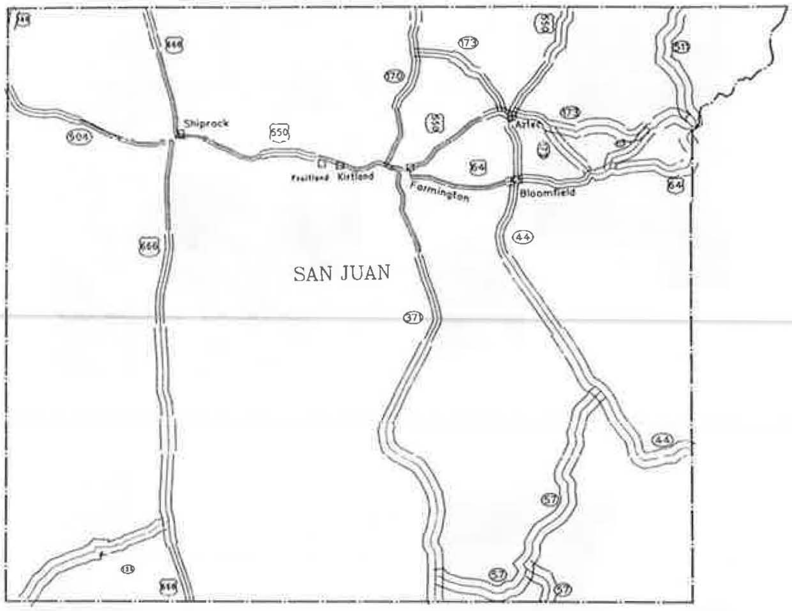


FIGURE 5 Map of Luna County showing the locations of DWI accidents and DWI citations (issued by the State Police).



Width of line indicates response time:

Thin line -- less than 10 minutes
Thickest line -- greater than 30 minutes
(line width increments of 10 minutes)

FIGURE 6 Map of San Juan County showing the present status of emergency medical services.

gency medical service in San Juan County was examined first. Figure 6 is a map of ambulance response times at different places within the county and was produced in about 15 hr. As one proceeds away from the towns of Farmington, Shiprock, Cuba, and Tohatchi (the latter two are not shown), where ambulances are kept and where clinics are found, emergency medical response time increases. Network analysis, to determine the best location for additional medical services, could be undertaken given information of the sort presented here and software currently being developed at the Division of Government Research. Or, because there is no town or city in the central portion of the county that could host another clinic, perhaps the best way to reduce the high emergency medical response times would be to retain a helicopter equipped with at least minimal medical facilities. At this point, another map of airborne emergency medical response times could be developed and a complementary network analysis performed. Possible solutions to the problem of delayed response times, however, must be evaluated in light of the need for medical service in this area, which has not been done here. A "medical need" map would provide another stratum of information to be considered in the redesign of an emergency medical response program for this area.

PROSPECTUS

The GRNDB system, developed by the Division of Government Research, is a functioning geographic information system that has produced useful, new information for several New Mexico agencies. It is anticipated that future uses of the system will be of the kind exemplified in the last application discussed, wherein planning questions are addressed. Because the system is user friendly, people versed in questions of transportation planning who do not have an extensive computer background can use the system as an applied research tool. It will also continue to serve as a simple information summary and reporting device for the many agencies in New Mexico that are accumulating bountiful data but require information about their respective constituencies.

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