NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
SYNTHESIS OF HIGHWAY PRACTICE 133

INTEGRATED HIGHWAY INFORMATION SYSTEMS

TRANSPORTATION RESEARCH BOARD
National Research Council

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DWIGHT W. BRIGGS
COMSIS

BENJAMIN V. CHATFIELD
Chatfield Associates, Inc.

Topic Panel

G. ROBERT ADAMS, *Michigan Department of Transportation*
NORMAN BAKER, *Iowa Department of Transportation*
DAVID BLAKE, *Utah Department of Transportation*
TOMMIE F. HOWELL, *Texas State Department of Highways and Public Transportation*
JAMES A. SCOTT, *Transportation Research Board*
WILLIAM T. BAKER, *Federal Highway Administration* (Liaison)
ROLF R. SCHMITT, *Federal Highway Administration* (Liaison)

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

The Transportation Research Board of the National Research Council was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as: it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state, and local governmental agencies, universities, and industry; its relationship to the National Research Council is an assurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and its Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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NOTICE

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration of the U.S. Department of Transportation.

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The Transportation Research Board evolved in 1974 from the Highway Research Board, which was established in 1920. The TRB incorporates all former HRB activities and also performs additional functions under a broader scope involving all modes of transportation and the interactions of transportation with society.

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire highway community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

By Staff
Transportation Research Board

This synthesis will be of interest to designers, traffic engineers, planners, and others concerned with the collection and use of highway data. Information is presented on current practices of states in correlating or linking highway-related data maintained in various types of independent computer files.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated, and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project, carried out by the Transportation Research Board as the research agency, has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

As computer technology has enabled data collection and storage to grow, data files have been developed independently in various units within highway agencies. This report of the Transportation Research Board describes the integrated highway information systems used by states to link independent data files so that the agency as a whole (as well as the individual units) will benefit from the ability to see and compare information from the various files.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the Board analyzed available information assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the researcher in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

CONTENTS

ACKNOWLEDGMENTS

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James A. Scott, Transportation Planner, Transportation Research Board, assisted the NCHRP Project 20-5 Staff and the Topic Panel.

Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance were most helpful.

INTEGRATED HIGHWAY INFORMATION SYSTEMS

SUMMARY

The transition of emphasis in our Nation's highway program from construction of new facilities on new locations to the reconstruction and preservation of existing facilities has brought with it the demand for reliable, relevant, and economical data. Ideally, these data are to be available at a moment's notice to answer management inquiries on policy-related questions, to meet the ever increasing data demands of federal and state highway programs, and to assist in future efforts to preserve the highway system now in place. At a session of the 1986 Annual Meeting of the Transportation Research Board, the chief administrative officers of state transportation agencies listed information systems (including data and the compatibility of data bases) as one of three principal issues currently facing them.

An *integrated highway information system* typically contains computerized files of geometric, traffic, accident, roadway features, and other data related to the planning, design, construction, maintenance, and operation of a highway system. The primary links among these files are the locations of points on, or segments of, the roads in each system. Other links, such as railroad-highway crossing numbers or vehicle registration numbers, may be used.

Fortunately, in this day of fast-changing technology, many improvements in data collection, processing, storage, access, and analysis techniques are occurring to assist those responsible for highway data. Computer hardware and software have now evolved to the point where integration of large data sets can be handled with some ease. Many highway agencies have already made valuable use of this new technology, linking many and varied highway-related data sets together. Other agencies are poised to follow, given some encouragement concerning the benefits of the process.

Although the forms of information systems and the types of benefits vary among agencies, this investigation has found that successful integrated highway information systems have the following characteristics:

- Coordination among agency personnel and organizational units to reduce duplicate and inconsistent data acquisition and inappropriate data use.
- Flexible data entry at the source of the data rather than at some centralized location.
- Timely, usable output information based on availability of all highway data for a particular highway location.
- Capability to expand the data system to incorporate additional data categories, if necessary.
- Employment of state-of-the-art, user-friendly computer hardware, software, and automatic plotting capabilities with built-in expandability to allow for future enhancements.

The biggest problem in the development of an integrated highway information system is not technology, but people. Although coordination of agency personnel is a very positive attribute, the lack of such can stifle any effort to achieve the far-reaching advantages of such a system. It takes cooperation and coordination within an organization over a period of years to obtain the desired results. The full support of key management officials is necessary to develop and operate such a system.

The accomplishments of the several organizations referenced in this synthesis are well deserved and not without a history of dedication and hard work. Their accomplishments should enable the reader to focus on the important issues involved. It is the objective of this synthesis to promote integrated highway information system development by highlighting the benefits to be obtained from such a system, by describing some of the efforts (past and current) undertaken in this field, and by outlining the conditions under which development of such systems is most likely to be successful.

CHAPTER ONE

INTRODUCTION

DEFINITION

An integrated highway information system is a system (a) for collection and storage of highway-related data in such a way that data from different sources that apply to the same point on, or section of, a highway can be correlated or linked; and (b) for putting those data into the hands of those who can make use of them. The system may also provide for the production and distribution of routine reports.

The collection of highway-related data involves a wide variety of activities: traffic counting, sign inventories, skid resistance measurements, photologging, accident investigation, recording of construction and maintenance projects and funding, right-of-way surveys, inventories of signs and roadside obstacles, bridge inspection, rail-highway crossing inventories, speed monitoring, pavement condition surveys, geometric design inventories, and other data-collection and maintenance activities. In the past, these activities were often uncoordinated within highway organizations and across organizational boundaries. Collected data were typically stored in paper files or in single-purpose computer files accessible only to a few people. Because of the lack of coordination, or of a narrow concept of data use and application, data collected for one purpose were rarely usable for others. If two users needed the same data, or very similar data, the data were often collected twice.

The key to an integrated highway information system is the inclusion, in any data-collection activity, of data elements that can be used as links to other files or collections of data. Such links permit the correlation of data from two or more sources. Examples of links are highway route numbers, bridge numbers, rail-highway crossing numbers, motor vehicle registration numbers, location references, and other variables that can be used on a stand-alone basis or in conjunction with each other to form an identifier for a unique section of highway. In highway agencies, the location reference is the single most important link among data files.

A simple integrated system might, for example, include a file of roadway widths and a separate file of traffic volumes, each of which contains compatible location reference data. Inclusion of the location reference link significantly increases the information content of these files. Without the link, the files contain no information about the relationship between volume and width, a relationship of considerable importance to a highway organization.

Integration of data from separate data-collection activities may be handled in different ways. Data may be stored in separate files, as in the case of the width and volume data in the example above, or may be combined in a single file. The choice depends on considerations of storage efficiency and the convenience of those who maintain or use the data.

In the simplified example above, the product of integration was a single relationship between two data elements, the correlation of width and volume. Few data files are so simple. Integration generally makes it possible to study many relationships among two or more data elements. As an integrated system grows, the cost of providing the linkage is rapidly offset by the value of the increase in information that the system provides.

In practice, integration of data can be relatively complex. It is not always efficient or convenient, for example, for everyone to use the same location reference system when collecting data. It may be best for a traffic-counting team at an intersection to identify the intersecting highways by name, whereas a survey crew recording sight-distance restrictions might use mileage from the county line. This is not a problem if the systems that are used are compatible with each other or with a third system so that location data can be translated from one system to another. However, use of more than one location reference system may increase the complexity and cost of integrated data maintenance.

BACKGROUND

Twenty-five years ago, before computers were in general use for purposes other than financial accounting, relatively few opportunities existed to satisfy the need for integrated systems. Without the means to process large volumes of data, the linkage that makes such processing possible was much less important. Many stories from the early 1960s tell of hours spent sorting punched cards for research studies, and the problems that occurred when the cards absorbed too much moisture on rainy days or when a stack of cards was dropped. Under 1960 conditions, it often took days to do what now can be done in seconds on a microcomputer (*1*).

It was obvious in 1960 that the capacity to process large volumes of data was increasing rapidly, and that the cost was dropping. As a result, pressure to integrate data files began to grow. In the highway field, the pressure came largely from two directions. First, the benefits of integration were recognized by highway planners. Large volumes of data concerning the characteristics and operation of the nation's highway systems are used in forecasting future needs. Efforts to promote integrated records systems during the 1960s laid the groundwork for much that has been done since. Second, the rapid rise in traffic deaths in the United States during the early 1960s made it evident that a better understanding of what was happening on the highways was needed if substantial improvements were to be made. U.S. House of Representatives Report No. 1700, written in support of the Highway Safety Act of 1966, addressed the need for integration of data files in the following words (pp. 10–11):

> ... the most definitive, objective, and specialized accident investigation of which we are capable will be useless unless its results can be fed into a record system, correlated with other relevant data, and made to serve some purpose other than mere accumulation.
>
> This is not to suggest, however, that we are not in need of more accumulation; we are. Few States collect adequate accident statistics; the Federal Government collects practically none at all.
>
> This information ... can be useful for education, licensing, traffic engineering, highway design and maintenance, vehicle inspection, traffic surveillance, and virtually every other aspect of highway safety.
>
> ... the accident record system is the one aspect of the total State program that the committee believes can and should be developed and at work by the end of 1967.
>
> This will require data equipment, and people trained to operate the equipment. It will require personnel competent in accident investigation and reporting. This kind of capital investment and personnel will be expensive, at least initially, and it will involve all of the agencies responsible for all agencies of highway safety. No other part of the State program is as basic to ultimate success, nor as demanding of complete cooperation at every jurisdictional level. That is another reason why it is undoubtedly the element in which we should invest the most time and the most money in 1967.

The Highway Safety Act of 1966 required that each state, to qualify for federal safety funds, have a highway safety program including provisions for an effective record system of accidents (including injuries and deaths resulting therefrom) and for surveillance of traffic for detection and correction of high-accident locations. No state had developed a system like that contemplated in Report No. 1700 by the end of 1967, but in the late 1960s many states began to set up statewide integrated traffic records systems and to develop the location reference systems that were needed to link some of the key components of the traffic records systems. This work was supported by federal-aid planning and safety funds, as well as state and local government funds.

Data systems dealing with highway inventory and travel also accelerated their evolution from independent manual systems into integrated computerized systems during this period. In the 1960s, much of the information concerning existing facilities was kept on straight-line diagrams, route logs or in other paper-oriented formats. Summaries of this information were annually reported to the federal government by each state highway agency using a set of complicated paper tables requiring much innovation and personnel to complete. At the same time, periodic special studies for the purpose of acquiring data to determine highway needs and performance were also developed by the federal government, requiring much of the same type of highway inventory data on a sample basis and in an entirely different format. Gradually, throughout the 1970s, these independent data were first computerized and then merged. Merging took place not only in the data content, but in the organizational structure of most supplying agencies as well.

Development of integrated state files had progressed to a point by the late 1970s where it was feasible to replace many isolated federal reporting requirements with a Highway Performance Monitoring System (HPMS) administered by the Federal Highway Administration (FHWA). Work is continuing on integration of data systems to support highway program management. Progress in the safety area, however, has not satisfied the U.S. Congress. In 1984 Congress authorized grants to the states for development or improvement of comprehensive computerized safety record-keeping systems "designed to correlate data regarding traffic accidents, drivers, motor vehicles, and roadways" (P.L. 98-363, July 17, 1984). These funds are being used to accelerate the traffic records development efforts that have been under way for almost 20 years.

Because of the intimate ties between integrated highway information systems and comprehensive computerized safety record-keeping systems, there has been considerable confusion and concern about duplication of effort. "Comprehensive computerized safety record-keeping systems" is a new name for what has been known for a number of years as "statewide integrated traffic records systems" or, more simply, as "traffic records systems." Integrated highway information systems are designed to support programs for planning, construction, maintenance, and operation of highway systems. Safety is one of the primary concerns in the operation of such programs. Comprehensive computerized safety record-keeping systems are designed to support state safety programs. These safety programs encompass not only improvements of the highway, but of vehicles and human behavior. Safety record-keeping systems include a number of data files that may be of little interest to highway system administrators, such as driver license records, vehicle inspection records, emergency medical service records, financial responsibility data, driver education records, etc. On the other hand, safety program administrators may not be concerned with files in an integrated highway information system that have little or no relation to safety. But in each state, a number of data files (notably traffic accident files, highway inventory files, travel files, rail-highway crossing inventory and accident files, etc.) are included in both the integrated highway information system and the comprehensive computerized safety record-keeping system. Thus, either system could be viewed as an extension of the other system; there is no intent that the two systems be independent. (Eventually, both may be regarded as subsystems of a more comprehensive state system.) What this means is that when a data file is created or modified, its relationship to both systems must be considered.

The differences between integrated highway information systems (IHIS) and comprehensive computerized safety record-keeping systems (CCSRS) may reflect the interests of system users more than the characteristics of the systems themselves. An integrated system is illustrated in Figure 1. Those who are interested primarily in the files to the left in Figure 1 are likely to call the integrated system with which they are working an IHIS. Those whose interests are focused on the files to the right in Figure 1 are more likely to label the system a CCSRS or a statewide integrated traffic records system (SWITRS). Any of these names may be used for the system illustrated.

OBJECTIVES OF SYNTHESIS

Highway agencies have been a fertile breeding ground for independent data-collection activities and the data files that result from them. It has often been easier for organizational

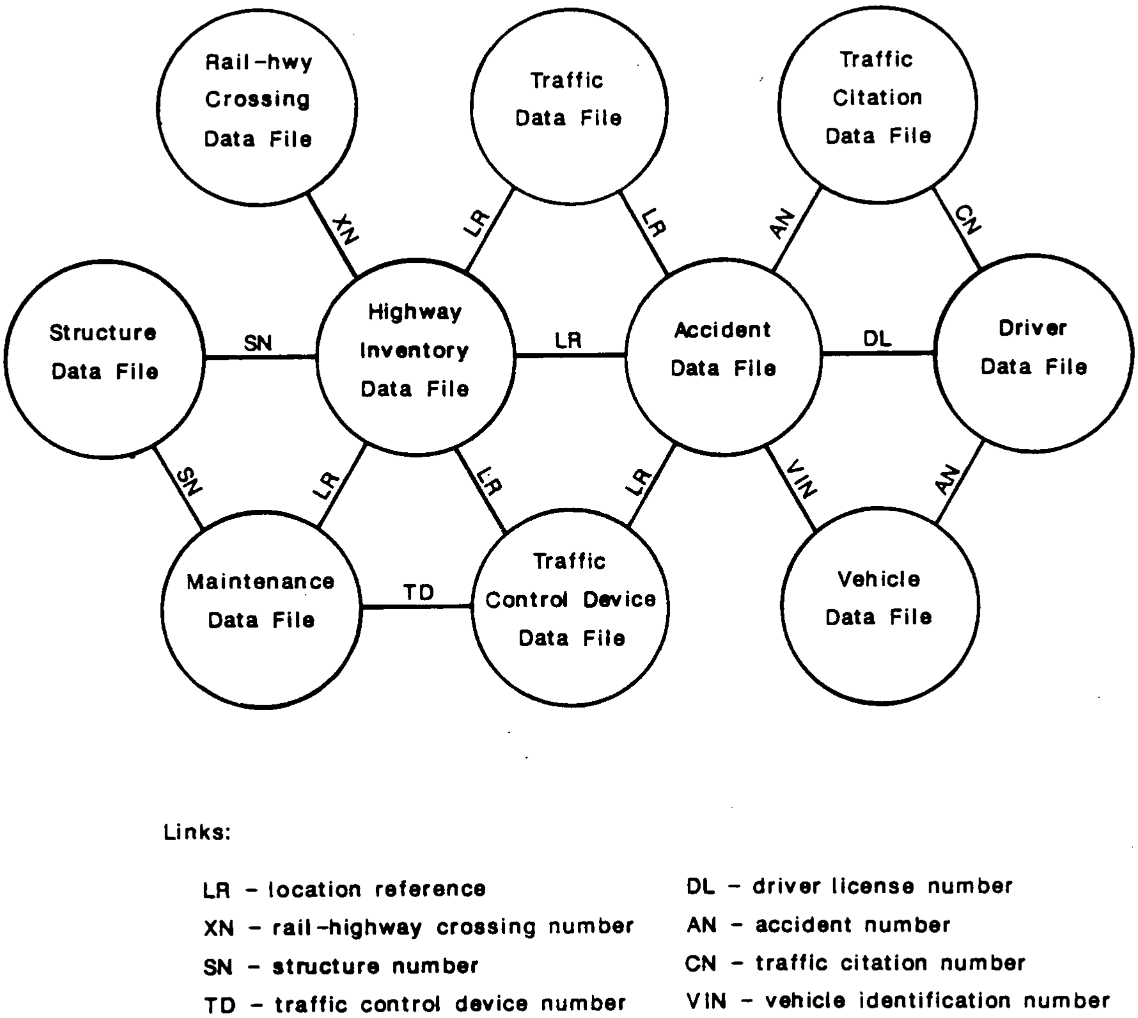

FIGURE 1 Components of an integrated highway information system. The files toward the right are those typically associated with a comprehensive computerized safety record-keeping system. Addition of other files makes an integrated system.

units to independently develop the information systems they need to operate their programs, without coordinating their efforts with data-related activity in other organizational units. In some cases, this has been the most reasonable approach to take—duplication of effort has been more apparent than real. There is no question that coordination requires resources and often involves compromises with respect to data specification, editing, and maintenance. But as systems grow and the cost of data collection rises, independent data-collection and data-storage activities become expensive luxuries. Integrated systems permit broader use of collected data, which increases data value.

The objectives of this synthesis are to describe what some highway agencies are doing to incorporate existing independent data-collection activities in their integrated highway information systems, to identify some of the benefits of integrated systems, and to point out examples of the institutional and technical problems. These problems have been overcome by some highway agencies in the development of successful integrated systems. For other agencies, they continue to retard the optimum development and use of integrated systems. The contents of this synthesis are designed to contribute to a better understanding of the advantages of data integration and to encourage broader implementation of the process by highway agencies.

Information for this synthesis was obtained from a number of highway agencies; however, it must be acknowledged that many more organizations are making effective use of integrated data.

GLOSSARY

Comprehensive Computerized Safety Record-keeping System (CCSRS) A "statewide integrated traffic records system." The term "comprehensive computerized safety record-keeping system" was introduced in a 1984 amendment of federal highway law (23 USC 402(k)). The 1984 law specifies that the system be "designed to correlate data regarding traffic accidents, drivers, motor vehicles, and roadways" (*2*).

highway location reference A data element or set of data elements, such as a distance and direction from a known point, that identifies a specific point on a highway.

highway location reference method The technique used in the field or office to identify a specific point (location) on a highway (*3,* p. 4).

highway location reference system The set of procedures for recording the location of specific points along a highway. The system incorporates one or more highway location reference methods together with procedures for storing, maintaining, and retrieving location information about points or segments on the highway (*3,* p. 4).

integrated highway information system (IHIS) A system for collection and storage of highway-related information, typically managed at the state level by the planning staff of a highway or transportation department. The system is integrated in the sense that data elements included as links in data records permit correlation of data from various files. Files may be merged in a central computerized data base for ease of maintenance and access.

link (1) A highway location reference, vehicle identification or registration number, bridge number, railway-highway crossing number, or other data element that may be used to correlate data from two or more data files describing objects (e.g., vehicles, segments of highway) or events (e.g., maintenance activity, traffic accidents, traffic flow for a designated time period).

link (2) A connection between two nodes in the link-node type of location reference method. A node represents an intersection, a change in highway direction, or other critical location along a highway. Each node is given a unique node number. The link represents a unique highway segment and is identified by the numbers of the nodes at each end of the link.

linkage The use of a link (as in the first definition above) to correlate data from two or more files.

Statewide Integrated Traffic Records System (SWITRS) A data system developed by a state in compliance with requirements of Section 402 of Title 23, United States Code (23 CFR 402), and Highway Safety Program Standard Number 10, Section 1204.4 of Title 23, Code of Federal Regulations (23 CFR 1204.4), administered by the National Highway Traffic Safety Administration. Standard Number 10 provides that the system, which may consist of compatible subsystems, includes "information regarding drivers, vehicles, and highways" that "shall be compatible for purposes of analysis and correlation." (See **comprehensive computerized safety recordkeeping system.**)

TIGER The Topologically Integrated Geographic Encoding and Referencing System, which is being completed by the U.S. Geological Survey and the U.S. Bureau of the Census to aid in taking the 1990 Census of Population and Housing. TIGER will provide computerized files nationwide that can be used to identify, locate, and map all roads, railroads, rivers, political boundaries, and other features that can be digitized from maps at a scale of 1:100,000.

CHAPTER TWO

BENEFITS OF INTEGRATED DATA

MAXIMUM USE OF COLLECTED DATA

As the nation's highway program evolves into a period where maximum benefits to the public must be provided from the existing facilities, accurate measurement and evaluation of highway operation, performance, cost/benefit relationships, and trends become imperative. These depend on reliable data. Because good data are far from inexpensive, it makes economic sense for highway agencies to try to obtain as much information as possible with their data-gathering dollars.

The trend away from the emphasis on building new highway facilities has increased the need for detailed evaluation of existing facilities. It has, at the same time, allowed data related to those facilities, and organized by location along those facilities, to become much more stable and, therefore, easier to maintain and process. Organization of data by highway location makes good sense, is central to any analysis of a transportation system, and provides the capability of answering one of the highway administrator's fundamental questions: What is happening in this particular section or at this particular point along the highway system? In organizing data by highway location, users can be assured that they are obtaining a more complete picture of the characteristics of a particular point or section.

The ability to look at each of the various types of data that are available for a particular segment of, or point along, a highway is extremely useful to those responsible for designing, maintaining, modifying, or evaluating the highway system. The use of data that, of necessity, formerly had to stand by themselves suddenly is greatly broadened in scope as other data for the same highway location are considered. For example, accident data by themselves provide some measure of number and severity of accidents occurring on a given highway segment. When traffic data are processed and used as a measure of exposure together with accident data, accident rates (i.e., fatalities or accidents per vehicle-mile) can be developed to provide a measure for comparison with other roadway sections throughout the jurisdiction. With the proper data, these exposure rates can be classified by time of day or by day of week. Further, with access to inventory data for the highway segment, some judgments can be made in regard to the relationship of accident rates and, say, divided versus undivided highways or artificially lighted highways versus unlighted highways at night. With the high cost of data collection, it is imperative that the use of each data item be maximized. The integration of data by location goes a long way to accomplish this.

In the United States today, there is a rapid expansion in the availability of geographically based data. Most likely, this is being driven by the desire to depict these data graphically, but, whatever the reason, it cannot help but enhance the cause of highway-data integration. This is true because usable additional information is becoming available that does not have to be collected by the highway organization and that can, if properly used, enhance the benefits of location-specific highway data. Of particular interest are such items as political boundaries; census data including population, housing, and journey-to-work information; and hydrologic and terrain features. Data such as these, in conjunction with those related specifically to the highway, can provide an even broader picture of the complex highway situation that is currently unfolding. The Topologically Integrated Geographic Encoding and Referencing (TIGER) System being developed by the Bureau of the Census is particularly important because it could provide a key element in highway location reference systems that can be used to correlate data across state lines and to correlate highway data with other transportation and nontransportation data. A brief discussion of the system is included in Chapter 5.

Today's advanced computer technology, in the areas of both hardware and software, offers the capability of interacting with available data in a fast and efficient manner. At the same time, highway agency policy and decision makers are demanding quick and accurate answers to their questions regarding the attributes and performance of the facilities within their purview. Integrated highway data allow computer technology to serve the needs of highway officials. With the proper data and an effective method of data retrieval, the range of issues that can be quickly addressed is almost unlimited. The Transportation Planning Procedures Section of the Michigan DOT, which has integrated data from a number of files, has used these data for more than 1,700 applications in the past 8 years.

Currently available computer graphics and automatic plotters can often reduce even the most complex data to a picture that is easily understandable. For example, Figure 2 shows a plot of rural pedestrian accidents in two counties in New Mexico (*4*). Highway networks, segments, and intersections lend themselves to graphic displays that can reveal patterns and trends not easily discernable from a stack of computer printout. The use of various colors or of band widths along representations of highway segments is now common in displaying traffic volume, accident rate, and other highway performance patterns. Pen and electrostatic plotters, coupled with on-line and interactive software provide the user with the tools to produce impressive, informative and resourceful computer graphics products.

Of some additional importance is the fact that increased use is being made of highway networks, particularly on a national basis. An example of this is Oak Ridge National Laboratory's recent development, sponsored by the U.S. Army Forces Com-

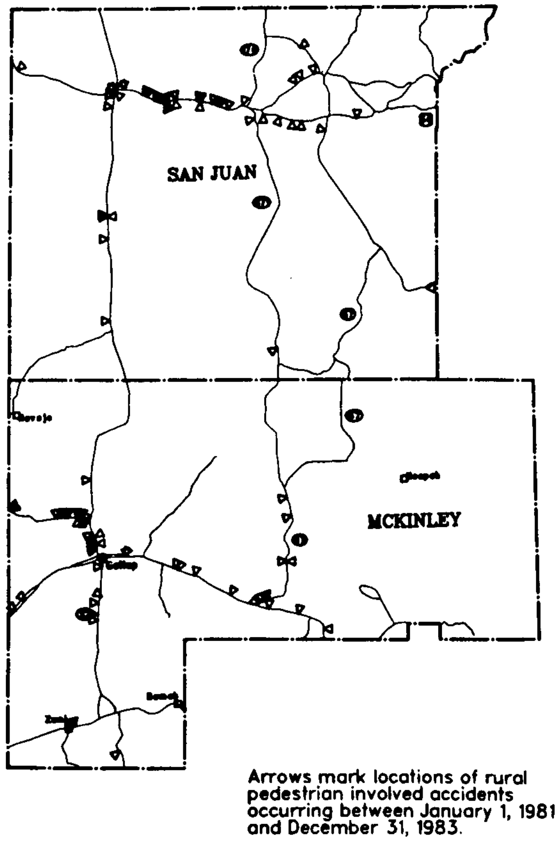

FIGURE 2 Map of San Juan and McKinley Counties, New Mexico, showing the distribution of rural pedestrian accidents (*4*).

mand, of a routing and scheduling model for military convoys. Although the level of efforts such as this is clearly directed at national systems approximating the level of the Interstate system, it is advantageous to be able to verify and correlate the data involved in such efforts. One obvious nonmilitary application of the Oak Ridge work relates to the routing of hazardous materials.

Additional benefits occur because of the above-mentioned environments. New technology allows the entering of data into an integrated system at its source location rather than through an inflexible arrangement at a centralized location. The environment for future system expandability is generally created—advanced hardware and software providing additional help for the user can be added as it becomes available. New categories of data elements can be easily included as they become essential for program evaluation or other purposes not envisioned at the time of initial system design.

Despite all that has already been accomplished, the door for future innovative results in the above-described areas is wide open as technology and data linkages expand.

AVOIDANCE OF DUPLICATION

Highway data bases have typically been developed to meet needs within the various organizational units of each highway agency. In most cases, there was no centralized unit to oversee what each data-collection effort was accomplishing. Various data bases were created because of requirements of the federal government or of a particular state program. The lack of coordination of an agency's highway data has at times led to certain of the data elements being collected, processed, and maintained in more than one system. Because different means may have been used to collect and process the data, minor differences in the available versions of what are substantially the same data have resulted, making the data incompatible. Once a dataset has been established, it has, historically, been extremely difficult to modify it or to combine it with existing datasets of other units within the organization. Possession of data and responsibility for their maintenance represent power that few like to relinquish. An effort to evaluate and incorporate all of the available highway data in an integrated system has proved, in many states, to be of immeasurable worth in dealing with the problem of duplication.

In any discussion of duplication in data systems, it should be emphasized that not all such duplication is wasteful. Some duplication or redundancy in data collection and processing is often valuable for verifying data quality by comparing duplicate datasets. However, much of the duplication found among existing systems serves no useful purpose. Moreover, efforts to coordinate data collection should result in more consistent definitions and thus in more consistent and higher quality data collection and analysis.

Duplication of effort takes place on an interagency basis as well as within agencies. Cooperation among highway agencies and traffic law enforcement agencies or among state and local agencies that can profitably share data can substantially increase the benefits of integrated systems. Such cooperation can be found in many states.

The costs of manual collection and processing of data have soared in recent years, while the costs of computer storage and processing have dropped steadily. Efficient operation of information systems increasingly requires that unnecessarily redundant manual operations be eliminated. Integration of data files provides many opportunities to eliminate duplication of effort and to obtain maximum production from a given data system.

NEW HORIZONS

One of the least understood benefits of integrated highway information systems is that, in addition to performing current operations more efficiently, these systems allow the use of data in ways that were formerly possible only in theory. Because of the large volume of computations and sorting operations in some applications, implementation was not economically feasible when the work had to be performed manually or even with punched card data processing technology. Relationships among highway geometrics, traffic control devices, traffic operations, accidents, and maintenance problems, for example, can be monitored more closely than ever before with integrated information systems, enabling highway agencies to determine where problems are developing and to plan more timely and effective remedies.

In recent years, sovereign immunity from tort liability in the highway area has been sharply diminished. For example, the number of annual new tort claims in California has tripled in the last 12 to 15 years (*5*). The above-mentioned data relationships give highway agencies the capability of accessing any and all available information regarding a specific highway location. Thus an agency could have geometric and performance data for a particular section of highway to disprove an accusation that an accident occurring at that location was caused by, say, inadequate shoulder width.

MICHIGAN'S EXPERIENCE

The most direct benefit from developing an integrated highway information system is increased productivity. Increased productivity was the primary reason behind the development of Michigan's Statewide Transportation Modeling System of which the Highway Planning Information System is a major element.

Webster's New World Dictionary defines productivity as producing something "abundantly and effectively" in relation to goods or services. These characteristics can be judged using three measures. The first deals with just the sheer number of times a service has been supplied. The second is the cost of the service as compared to other supply sources. The third is the variety of users requesting the service. Variety is extremely important to any state considering the development of an extensive statewide highway planning information process, because this is where the true interdepartmental "multiple" benefits are generated.

In regard to productivity, since the statewide highway planning information system has been in operation in Michigan, requests have been filled for many different organizations in a variety of subjects. The number of applications relative to the organizations that have requested applications or developmental work is summarized as follows:

Organization	Number of Applications
Regional Planning—State	182
Bureau of Transportation Planning Administration	62
Model Planning Division	132
Socioeconomic Analysis	206
System Development	137
Legislative Administration	156
National Committees	42
General Data Base	265
Regional Planning—County	45
Interdepartmental	220
Misc.	110

More than 150 additional applications have been completed where the same product was used unchanged a second time, thereby doubling the benefits received by the state. The same applications can also be summarized by the type of product:

Product	Number of Applications
Place Classification	14
Social Impact Analysis	66
Economic Impact Analysis	102
Fiscal Analysis	171
Legislative Analysis	192
Travel Impact Analysis	272
Aviation Market Analysis	37
Administration Systems	83
Travel Demand	186
Highway Functional Class	37
Rail Freight	38
Trucking	27
Model Development	26
Needs Application and Cost	51
Highway Network Inventory	63
Bus Pass Alts	8
Rail Pass Alts	21
Carpool Modeling	15
Energy Planning	13
Strategic Planning	102
Regional/Systems Planning	63
Program Prioritization	28
Hazardous Waste	19
State Transportation Plan	43

When including recent requests, the applications amount to more than 1,700. This is the direct result of the development of a statewide transportation modeling system that utilizes a highway planning information system as its base.

The second measure of productivity is the cost of each product. Michigan's system development costs are estimated as being roughly $11,800 per major information file, $13,300 per major analytical system, and $570 per system application. These costs do not include overhead, nor do they include the costs for data collection, which any agency would incur if it chooses to start from scratch. In Michigan, data-collection costs are relatively small because a vast majority of the information was collected for other purposes and then reorganized to be used in the highway planning information system inventory. The above costs demonstrate that an application-oriented statewide transportation modeling system is extremely cost-effective.

The final measure of productivity is the variety of users, as this is the true base from which multiple benefits are derived. It is also a very good indicator of product utility. The following is a summary of Michigan's application experience by type of user:

18 Sections in the Bureau of Transportation Planning
6 Division Administrators
8 Modes (Highway, Rail, Air, etc.)
4 Bureaus in the Department of Transportation
32 States
18 Universities
9 Nations
1 Legislator
1 Director
1 Commission
4 National Organizations
12 State Planning Regions
15 Departments

After evaluating Michigan's experience related to the utilization of a highway planning information system, it becomes apparent that the development and application of such a process can have an extensive impact on productivity of a state department of transportation and its immediate clients both inside and outside the department.

CHAPTER THREE

ORGANIZATIONAL CONSIDERATIONS

OBSTACLES

The advantages of an integrated highway information system have been widely recognized for a quarter century or more. At a session for chief administrative officers (CAOs) of state transportation agencies at the 1986 Annual Meeting of the Transportation Research Board, information systems (data and the compatibility of data bases) was one of three principal current issues raised by the CAOs. Why aren't more data files integrated? Although technical problems may have prevented integration in some cases, many opportunities have been missed because individuals or organizations concerned with data management or use did not work together. Some of this failure to cooperate and coordinate is inadvertent, but much of it is quite deliberate. A few of the obstacles to integration are described below.

1. The most frequently mentioned organizational obstacle to integration of files is management concern that cooperation with another administrative unit will lead to a loss of authority or funds to that unit. Especially when funds are limited, competition among units may block creation of integrated systems. Although this competition is sometimes evident at high levels in state governments, much of it takes place at relatively low levels where managers believe they have personal investments in data files.
2. Management officials, who could direct coordination among units under their control, sometimes do not realize there is a problem or understand its implications when these units fail to integrate their files.
3. When an organization is highly compartmentalized, units may operate data files exclusively to meet their own needs. The benefits of proposed file integration may go primarily to units that have no responsibility for the management of the data files and contribute no resources for data collection or file maintenance. If their own unit does not benefit from integration, file managers have little incentive to integrate their files with others. This is especially true if file managers are competing directly for budget and staff with the units that benefit from integration.
4. If an organization requires certain data to carry out its functions, it has a strong incentive to develop an independent data system rather than rely on integration of data managed by others. What happens, for example, if an outside data source stops collecting data or changes it in a manner that reduces its usefulness? In such cases, the user's decision generally depends on the costs of the alternatives. The user may be a highway department that needs traffic accident data, for example, but cannot afford to duplicate police accident reporting systems.
5. In many cases, modification of files is necessary to permit integration. A common example in highway organizations is the need to adopt compatible location references. Although such a modification may be beneficial in the long run to the unit responsible for the data or to another unit, it often involves extra cost and staff time for the unit that must change its file. In a period of limited resources, reluctance of file managers to make such changes is understandable. Support for the modification must come from higher levels.
6. Some opposition to integrated highway information systems comes from managers who fear that facts restrict freedom of management action. The most evident aspect of this is reluctance to create integrated data files that might be the source of information permitting outsiders to evaluate agency programs. This fear is particularly strong in areas where there are tort liability considerations. Privacy and freedom-of-information laws also tend to increase opposition to file integration.

COORDINATION

By definition, management of the data files to be included in an integrated highway information system must be coordinated. If file managers go their own ways without regard to the impact of their decisions on relationships among files, there is no assurance that files can be integrated or, once integrated, that they will stay that way.

Among the types of action that require coordination are:

- establishment of a new continuing or periodic data-collection activity
- termination of a continuing or periodic data-collection activity
- changes of data element definitions in existing files
- addition or deletion of data elements in existing files
- changes in schedules for collection or processing of data
- changes in procedures and costs of accessing data

Coordination of one-time data collection for special studies is less critical than coordination of continuing or periodic activity but may increase the value of the data collected.

At a 1985 American Society of Civil Engineers conference on interdisciplinary communication among professionals concerned with traffic safety, the participants found that (*6*):

> ... a key element for successful ... information systems ... within a state or other organization is an individual or group with responsibility for establishing database administration policy and coordinating data collection, processing and access. This

> presupposes strong management support. Without such support, individual elements of an organization are likely to establish and maintain uncoordinated and duplicative information systems which are of unnecessarily limited usefulness.
>
> The need for central coordination of information systems is closely related to the demand for links between various data files. . . . Almost all disciplines [represented at the conference] cited linkage as a top priority. . . .

A great deal of coordination among file managers is voluntary. Most file managers recognize that there are often mutual benefits from file integration. But the good will of file managers is not enough to sustain an integrated system. Coordination is not always easy or inexpensive. If file managers are concerned primarily with the most cost-effective operation of their unit alone, they have little incentive to invest in changes for the benefit of users in other organizational units. Coordination also takes time. Determination of the needs of users, and negotiation of compromises among users with conflicting needs, may delay creation or modification of files for extended periods. For these reasons, coordination of data files should not be at the option of file managers; there must be management support from above and strong incentives to comply with established policies and procedures.

One approach to coordinated management of an integrated highway information system is to transfer responsibility for all data files to a centralized unit. This may be effective on a small scale, but the quality of data and usefulness of data files is likely to deteriorate when those who know the data best—those who collect and use it—have little influence over or information about data processing decisions.

As a general rule, it is best for a data file to be under the control of the organizational unit that needs the data most. This decentralized approach increases the need for continued management attention to coordination. A coordinator or coordinating committee should be appointed to ensure consideration of the needs of all users, along with data collection and management issues, when files are integrated or when integrated files are modified. The coordinator or coordinating committee should have authority to resolve conflicts among data providers and users or, if not given that authority, they should have the support of management officials with that authority.

In a recent demonstration project, the Utah Department of Transportation (UDOT) (*7*) expanded its integrated highway information system by adding structure, pavement condition, and railroad crossing files to previously linked traffic, accident, and geographic data files. Coordination for this project was provided successfully by the following four-level committee structure.

Executive Committee:
- Members: Director and other top UDOT officials
- Function: Establish policy, provide general direction and emphasize high-level commitment

Steering Committee:
- Members: Managers of UDOT divisions who provide or use data
- Function: Provide staff direction and recommend action by the Executive Committee

Coordinating Committee:
- Members: Staff from UDOT divisions who provide or use data
- Function: Oversee data system development

Technical Committee:
- Members: Representatives of major potential users
- Function: Identify data needs and recommend formats for routine output reports

In many states, highway departments are coordinating effectively with state police agencies to integrate traffic accident files with traffic volume and highway inventory files. Highway and police agencies work together particularly to ensure that the location of each accident is reported accurately. One of the better known location reference systems, the Michigan Accident Location Index (MALI), is the product of coordination between the Department of State Police and the Department of Transportation. In the State of Washington, the Department of Transportation codes the location of all accidents on state highways before accident data are computerized by the Washington State Patrol, thus ensuring that the accident data file can be integrated with a variety of highway data files. Similar arrangements are in effect in other states for the mutual benefit of the coordinating agencies.

The Michigan Department of Transportation (MDOT) has, over the years, created many independent data files. In 1984, a multidisciplinary Data Base Task Force identified more than 50 separate data files holding from less than 100 to more than 300,000 records for each year (*8*). The Task Force noted that:

> There is a substantial amount of duplication of effort in data collection and storage. Oftentimes, the same data is collected and stored in separate data files by more than one functioning area. This fragmentation of data systems breeds many inefficiencies, including: (1) Inconsistent methodologies being used; (2) Conflicting reports being published; (3) Available data is unused because reference system data cannot be interfaced; (4) Data that is costly to collect may be largely unused; (5) Management decisions and priority rankings are often based on insufficient, inconsistent and/or outdated data.

Some independent system development was still occurring in 1984. The Task Force reported that the problem was too large to be solved by one individual or operating unit, but no centralized technical monitoring group had authority to optimize the development and use of computerized data systems.

Coordination is clearly essential if data systems are to be integrated.

IDENTIFICATION OF DATA NEEDS

Data needs fall generally into two classes. Some data are needed to carry out ongoing programs; other data are needed to support management decisions on policy issues. An example of the first type—program support data—might be the highway bridge inventory data collected in support of the federal-aid highway bridge replacement and rehabilitation program. States need these data to qualify for federal-aid funds (23 USC 144). Examples of program support data in other contexts are the applicant name and address on applications for driver licenses or bank accounts and hours of work on payroll records. The second type of data—decision support data—might be illustrated by vehicle-mile and ton-mile data for various types of tractor-trailer combinations classified by number of trailers, width, length, trailer body type, road type or other characteristics. State and federal officials could use these data to support changes in designated truck routes or in size-and-weight regulations. Other examples of decision-support data might be the weather data on traffic accident reports and responses to questions in political polls.

Program-support data are necessary in the sense that they must be provided for a program to operate effectively. Decision-support data are optional in the sense that management or policy decisions will be made whether data are available or not. The two types of data are not mutually exclusive and, in practice, much of the data used to support decisions is program-support data because it is difficult to prove that acquisition of data to be used exclusively for decision support is justified.

Program-support data needs tend to be relatively easy to identify, and the reason for collection is generally apparent. On the other hand, potential users of decision-support data files rarely know precisely what they "need." There may be exceptions, as when the needs are presented in detail in legislation, but for most uses needs are quite flexible. Collection of data is usually limited by its cost, so that users frequently have to live with fewer data than they would like to have. Many potential users of decision-support data have little interest in data collection and processing or in development of plans for future data analysis. It is very difficult to get them to seriously consider the applications of data that might not be available, from a data file under development, for three years or more. In a 1978–1979 study of safety-related information needs in the Federal Highway Administration (FHWA), many needs were identified by representatives from operating units (*9*). When these units were contacted after completion of the study to develop plans to meet some of the highest priority needs, their top priority needs, in many cases, had changed and sometimes disappeared altogether. Much of the change was the result of personnel turnover, emergence of new issues, or declining interest in previously identified issues. Even when needs had not changed, some units were unable to define their data needs precisely enough to design collection forms.

Collection of decision-support data on a continuing basis through established systems, as opposed to limited ad hoc efforts, is a long-term process. It is often three years or more between the decision to collect the data and their availability for a specific use. In such a situation, it is very difficult to determine beforehand what the value of data will be. Data are often used to support policy decisions related to issues that had not been anticipated when data collection began. Although it is generally agreed that the quality of decisions is related to the availability of good data, there is no reliable way to forecast the type and quantity of data that will be most useful in the future. Such a forecast necessarily depends largely on the judgment of those who control data-collection decisions.

Despite the difficulty of forecasting future needs for decision-support data, the high cost of data collection makes it necessary to predict what the future needs might be and to determine which of those needs should be met. To ensure support of data-collection activity during the period before data are available and in use, potential users must be convinced that the data will meet their needs. The most effective way to obtain this user support is to give users the opportunity to influence data-collection decisions. States normally provide this opportunity through formal or informal solicitation of comments or suggestions from those who are concerned. When major changes in data systems are involved, interagency or interdepartmental committees are often established to ensure that the interests of all major collectors and users receive appropriate attention.

The Utah coordination committee structure described in the preceding section includes a technical committee representing major potential users with responsibility for identifying data needs. Although the existence of such a committee does not guarantee that all data needs will be anticipated, it does increase the likelihood that data will be available when they are needed. Similar committees have been appointed, and have achieved varying degrees of success, in many states over the past 20 years or more.

ACCESS TO DATA

Access to data depends largely on whether the custodian of the data can and will let others use it and whether potential users have the technical skills to take advantage of the opportunity.

There are a number of reasons why the manager of a data file might restrict access to the data in it. Some of these reasons have legal ramifications, such as privacy, security, and tort liability considerations. Others are technical, such as the aversion to releasing incomplete or incompletely edited records or the fear that users might alter the data file. In many cases file managers have been reluctant to release data to those who were likely to misinterpret it. On the other hand, freedom-of-information laws and regulations may make it necessary to allow access to all data in files except for those that are explicitly restricted. When a computer file contains both restricted and unrestricted data, access can be provided selectively to individual elements in the file or the unrestricted data can be copied to a separate file for use by persons who are not authorized to use the restricted data.

When any computerized data are made available to users, precautions should be taken to ensure that users cannot make unauthorized data entries on master files. Whether such changes are inadvertent or well intentioned but erroneous, they could markedly reduce the value of a file or destroy it. Users do find problems in data files; procedures should be established for reporting these problems to file managers so that appropriate action may be taken.

For unrestricted data, it is often to the advantage of file managers to encourage use of the data by simplifying access to it. Broader use of the data increases its value and also increases the likelihood that flaws in a data file will be identified and corrected.

File managers should consider user capabilities when providing access to data. If potential users are skilled programmers, it may be enough to give them copies of the file on magnetic tape or on floppy disks. Alternatively, skilled users could be allowed to read or copy the master file. For less skilled users, file managers can provide technical assistance, including programming services, or install software that reduces the need for computer skills. The former, providing programming assistance, has been common in many organizations for many years. It is a high-cost solution most appropriate for routine applications. Rarely is it easy or economical for a potential user with a one-time question to get a prompt answer through this type of service. As a result of long delays and the difficulty of describing their needs to an intermediary, many potential users of data do not bother to try.

Microcomputers have changed user expectations. Large-volume markets for software have led to the generation of a wide variety of "user-friendly" software. The user-friendly approach has carried over to mainframe software. With a minimum of training, potential users can now access data on mainframes or microcomputers and perform a wide variety of operations on the data without working through a human intermediary. Users are able to receive answers promptly without exposing their lack of knowledge about computer operations.

File managers must also change. It was not unusual a few years ago for file managers to control use of the data and to keep much of the information about data definitions and idiosyncracies in their heads. With the number of users greatly increased, such control of data is seldom possible or advantageous. However, file managers still have a responsibility to limit misuse of the data by making detailed definitions and other information about data characteristics readily available to users. This responsibility may mean a substantial increase in the work load of a file management staff as the number of users grows.

CHAPTER FOUR

COMPUTER HARDWARE AND SOFTWARE

HARDWARE

As computers have improved in versatility, in efficiency, in availability, and in range of sizes, so too has their usefulness in providing a wide range of capability to serve the needs of integrated highway data applications. Because of the massive amounts of data available or contemplated for the highways in a particular jurisdiction, mainframe computers are being used extensively to process applicable data. This equipment is able to access mass data storage media such as magnetic tapes, disk volumes, or other such hardware. Mainframe computer systems are accessible over telephone lines by cathode-ray-tube (CRT) or other types of portable or permanent terminals, making mainframe data processing from remote locations extremely convenient and easy. Mainframe computing costs have decreased to the point where large quantities of data can be processed efficiently at reasonable cost.

The advent of minicomputers and microcomputers into the data processing picture has brought with it the capability of down-loading data onto storage media connected to the smaller computers.

Sophisticated work stations (through the use of such features as dual-screen capability) can display, for example, color plots of the data being considered together with numerical data summaries or listings. Available for use with these workstations, or with any terminal or computer, for that matter, are electrostatic or color pen plotters, as well as hard copy units for printing data processing results.

The recent proliferation of personal microcomputers has created an atmosphere of demand for more and more applications for these machines. The subject of integrated highway data has been prominently addressed in this regard. The broad availability of these machines is an indisputable advantage. However, many states have found that the large amounts of data necessarily involved in integrated highway data have somewhat limited broad interactive data applications on personal computers. Although several states have been successful in using these smaller computers to process highway data, special discernment and care have been necessary in selecting the data to be addressed to ensure their representativeness and utility in representing the overall highway picture. These personal computers, portable or otherwise, can, of course, be used as terminals that provide access to mainframe computers. Selected data from the mainframe can be easily transferred to the microcomputer storage media for stand-alone use on the small machine. The recent introduction of high-speed 32-bit microprocessors in personal computers, the availability of large capacity magnetic disks, and the massive storage capacity of optical disks will increase the speed and computing capacity of personal computers, thus expanding the limits of their use in working with data applications.

Of major importance in today's hardware environment is the interface between mainframe and microcomputer, which provides a flexibility in both equipment and data processing that was not attainable just a few years ago. The use of microcomputers as terminals in communicating with mainframe computers can result in broad net works of hardware tied together with direct data lines or, through modems, with telephone lines. This can make highway data available at the touch of a key to users within a highway agency. Thus, even widely scattered field organizations can both input and use applicable data to enhance their operations.

Tied in with this type of activity is the ability to select and move subsets of large data bases resident on the mainframe computer to the microcomputer for processing with the broad range of software now available on those machines. Editing, updating, summarization, analysis, and even sophisticated plotting activities can now be conducted on microcomputers, giving users complete control of the data most applicable to carrying out their responsibilities.

As an illustration of what can be accomplished with the mainframe/microcomputer relationship, a recent development by FHWA is informative. For the Interstate highway system, some 56 of the 75 highway performance monitoring system (HPMS) data elements have been moved from the mainframe to the microcomputer. Microcomputer software has been developed to allow queries on individual variables such as lane-miles, pavement condition, number of travel lanes, or type of shoulder. Combinations of these variables can be used so that, for example, the number of miles and lane-miles of Interstate highway with asphalt pavement in rural areas can be summarized by state. Using digitized coordinates for the Interstate system that were developed by Oak Ridge National Laboratories, plots for broad areas of the Interstate or for specific sections are possible, picturing the locations of specific roadway or travel attributes. Once the down-loading of Interstate HPMS data from the mainframe is complete, the remainder of the processing is handled entirely with the microcomputer.

A discussion of applicable hardware for integrated highway data should not conclude without a mention of "smart" data-collection vehicles. This equipment (by means of on-board minicomputers) collects, records, and references by location such highway-inventory-related data as horizontal and vertical curvature and pavement roughness. Some of the equipment available for this purpose is described in the FHWA Demonstration Project No. 72 (*10*) and in NCHRP Synthesis 126 (*11*).

SOFTWARE

Although hardware is an essential part of any data system, it cannot work by itself. Reliable and useful software must be in place to make the available hardware perform at its maximum potential. Of primary interest in any discussion of software is the question of whether commercially available ("canned") programs are being used or whether users are coding their own programs to meet the needs of the application being addressed.

Because of the wide dissimilarity of data formats among the agencies responsible for working with integrated data, most of the software is written by or for the particular state (or other agency) and is tailored to the data. Although software development times are often long, programs designed and coded to meet a specific need may be cost-effective in the long run. In some rare cases hardware suppliers may supply tailored software as a selling feature of a system. Processing efficiency usually suffers when generalized routines are used, but these can produce summaries, graphics, listings and other standard outputs helpful to a particular state's monitoring of its highway system.

Many states are looking at and some are experimenting with or using commercial data base management systems (DBMS). Very simply, these provide software control of the data from various data files incorporated in the integrated system. The DBMS handles storage and retrieval of data and usually provides three attributes: integrity (protection of data files from hardware and software malfunctions), privacy (protection of data against unauthorized access or modification), and data independence (ability to make structural changes in the data files with minimum change to application software). Generally each data element is identified by a unique name; the user works with the data elements rather than data files, and the DBMS handles the accessing of the proper data files. A DBMS usually provides canned routines that provide for easy access to and manipulation of the data in the system. In many cases, the DBMS also allows easy interface with fourth-generation programming languages to provide flexible queries, report writing, editing and graphics capabilities.

The Utah Department of Transportation has tested two data base management systems that provide access to linked files in its integrated highway information system. One was installed on the state computer system and another was used on a commercial system. The two software packages were used side by side and both provided the required service.

Utah reports that its DBMS offers a valuable feature well beyond its ability to produce pre-programmed reports—its capability to create reports on a one-time or individual basis with data drawn from up to three linked files (*7*). Such reports can be created by technicians with minimal training. Both Washington and Utah use an advanced programming language to produce custom reports (*7, 12*).

CHAPTER FIVE

CONTENTS, ORGANIZATION, AND LINKAGE OF INTEGRATED HIGHWAY INFORMATION SYSTEMS

Integrated highway information systems are being developed by all state highway departments and by many local agencies responsible for construction, maintenance, and operation of highways. Although the scope and rate of this development varies widely from one organization to another, current integrated systems have many characteristics in common. A number of the data files found in many integrated highway information systems are described in the first section of this chapter.

Provisions for access to data in integrated systems is changing. In the past, data were accessible only to those with a relatively high level of computer skills. A potential user of the data had to either acquire these skills or work through a specialist. The advent of "user-friendly" software has changed this situation considerably. Integrated systems in some states are now being designed so that users with little or no special training can retrieve and manipulate data. The design of integrated systems is discussed in the second section of this chapter.

The key to integration of data files is the linkage among them. In an integrated highway information system, the primary links are location references. In the last section of this chapter, location references and other links are described.

DATA BASE CONTENTS

Roadway Inventory Data

A basic ingredient of any state's data relating to its highways is an inventory containing the physical and geometric attributes of at least those segments of highway located on the state highway system. Handwritten inventory sheets and either straight-line representations of roadway logs or other diagrams have been used to store essential data containing such information as the number and width of travel lanes on the roadway.

In the last several years, most states have made a large effort to replace, or at least supplement, their manual, paper-oriented inventory files with more sophisticated computer files, resulting in highly structured data storage. In addition, data collection methods have progressed with the incorporation of automated data procedures and the resultant improved accuracy and reliability of data.

Roadway inventory files have been among the first files converted to computerized formats. Many states have credited the FHWA with providing the impetus for this because of the implementation of the Highway Performance Monitoring System (HPMS) and its forerunner, the Mileage Facilities Reporting System (MFRS), in the middle and late 1970s. There is no doubt that FHWA's move to annual inventory data reporting in a computerized format greatly influenced the states' development of computerized inventory data procedures.

The following list contains various kinds of data commonly included in many state and local highway inventory files. Although it is not a list of the kinds of data included in any one particular data file, it does represent the type of highway facility information needed to administer a highway system.

functional class
federal-aid system
state system
route type
signed route number
inventory route number
governmental control
domain
toll considerations
special route (such as truck route)
length
number of through lanes
type of surface
type of pavement section
access control
lane or traveled way width
approach width (in urban areas)
shoulder type
shoulder width
median type
median width
right-of-way width
horizontal curve information
vertical grade information
sight distance information
speed limit
use of artificial lighting
capacity information
traffic control device information
parking information
drainage information
terrain
interchange and intersection information

The Ohio Department of Transportation maintains its inventory data on several different files. The primary inventory file contains data relative to each of the facilities on its state highway system. In addition, it has a local road inventory file containing data on county and township roads, as well as a municipal street inventory file that carries data on facilities in the various municipalities of the state. Ohio selects data from these various inventory files for inclusion in its annual HPMS file for submittal to FHWA.

The Washington State Department of Transportation (WSDOT) is implementing a roadway file as the first major component of its Transportation Information and Planning Support System (TRIPS), an integrated highway information system currently being developed to make WSDOT data more accessible to users. The roadway file component was placed in operation in September 1987. The data include horizontal and vertical alignment, width, pavement type and condition, signals, intersection and interchange information, various jurisdictional boundaries, indexes to video logs, and links to separate bridge and rail-highway crossing files. Traffic data will be incorporated into the system in 1988 and 1989. The safety data phase will follow the traffic data phase.

The Iowa DOT maintains a summary of roadway inventory data for state primary routes in a Base Record Inventory, which includes traffic and accident data as well as geometric, sufficiency, and administrative data.

Idaho's Milepost and Coded Segment System (MACS) provides a uniform method for cross-referencing various categories of data relating to roads within the state. Data linkage is accomplished by means of a road or ramp segment code, milepost, and time (the date the data came into existence). Roadway features are referenced by the beginning and ending mileposts on a particular ramp or segment. Four categories of file make up the system:

- Control Files describing political boundaries, physical location, and actual road mileage.
- Road System Files describing attributes of roads. Files currently exist for federal-aid routes and for the state highway system.
- Roadway Data Files describing the various characteristics of roads. Functional Classification and Roadway Jurisdiction Files are part of the initial system.
- Data Files containing data used to translate codes into names for reporting purposes.

Idaho's Roadway Environmental Data Base (REDB) consists of two sets of files: MACS files and Roadway Segment (ROSE) files. The ROSE files are a user system that directly accesses the MACS files and other ROSE files (such as Traffic Volume) to produce various reports.

Traffic Data

States have long sought to improve procedures for assigning accurate, up-to-date traffic data to specific links on their highway systems. Computerized traffic data files separate from or included as part of inventory data have been implemented successfully by most states. Not only does the necessity of providing such data force the acquisition of detailed, accurate traffic figures, but the resultant files provide the basis for the calculation of travel data at the various levels needed for such purposes as provision of exposure data for determination of accident rates (for comparison with rates on other segments of the highway system for safety analysis purposes) and trends analyses. Some traffic data files may contain a minimum of data for a particular year, perhaps only the average annual daily traffic (AADT). More sophisticated data files may include:

- percent of trucks in the traffic flow
- traffic data for several separate years
- traffic data by time of day
- traffic data by day of week
- traffic data by month of year
- traffic data by component of vehicle population
  - automobiles
  - vans
  - light trucks
  - heavy trucks
- traffic data by through-traffic lane
- vehicle weight and axle configuration

Automated and simplified data-collection methods such as automatic vehicle identification systems (AVIs), weigh-in-motion procedures, and remote sensing techniques are resulting in the availability of more information with less manual effort. Data systems must be capable of making optimum use of these expanded, more accurate data.

The ability to tie traffic data to a specific highway location and thus to applicable inventory and accident data is invaluable to governmental agencies assessing activity on particular segments of highway under their jurisdiction.

Because of the many uses of traffic data, this type of data file is often among the first to be incorporated into an integrated highway information system. Many states have linked traffic data with highway inventory data and traffic accident data. In Utah, for example, earlier development of computerized linkage among traffic volume, roadway inventory, and accident files provided the core for recent development of its integrated highway information system. The Washington State DOT, in developing its TRIPS system, is beginning to integrate traffic data as the second major component of the system.

Traffic Accident Data

All states collect reports of motor vehicle traffic accidents. These reports are usually submitted by police or by drivers involved in accidents to state motor vehicle departments or police agencies. Reports by investigating officers are customarily used to create the basic computerized file of traffic accident data. In some states, driver reports are also included in the accident data base, particularly for those accidents not investigated by the police. Collection of some accident data is mandated by federal statute, and many states have stringent requirements for their own safety purposes.

The National Safety Council reports that approximately 18 million motor vehicle accidents, involving about 35 million vehicles, occurred in the United States in 1986 (*13*). Of these, there were about 42,000 fatal motor vehicle accidents in which almost 48,000 people died. Of the total number of accidents, about 2 million nonfatal injury accidents—in which about 3 million persons are injured—are reported each year (*14*). None of these figures are precise. Although most fatal accidents are reported, it is likely that fewer than three-quarters of the nonfatal-injury accidents and fewer than half of reportable property-damage accidents get into traffic accident data files. Nonetheless, the above figures give a general idea of the order of magnitude of accident data collection. Based on the distribution of fatal accidents, one might estimate that about half of the traffic accidents in the United States occur in 10 of the more populous states.

The traffic accident data file is an important part of any integrated highway information system. In state systems that focus on traffic safety, such as statewide integrated traffic records systems or comprehensive computerized safety record-keeping systems, the accident data file is regarded as the core of the system (*2*, pp. 3–4). (The relationship between integrated highway information systems and the safety-related integrated systems was discussed in Chapter 1.)

Most data in traffic accident data files come from police accident reports. Each state has its own report form. Although most accidents are reported on these state forms, some cities use their own forms. Despite the large number of forms in use, however, there are many similarities. As a result of efforts that began almost fifty years ago, most forms use terminology based on the "Manual on Classification of Motor Vehicle Traffic Accidents," a national standard maintained by the National Safety Council and approved by the American National Standards Institute. The current edition is identified as ANSI D16.1-1983. In the early 1970s an effort was made to standardize all components of traffic records systems. This effort, sponsored by the American Association of Motor Vehicle Administrators, led to the publication of a "Data Element Dictionary for Traffic Records Systems" in 1979. This standard was also approved by the American National Standards Institute and is identified as ANSI D20.1-1979.

The Data Element Dictionary contains listings for major data files. Its listing for an accident data file (p. 226) may be summarized as follows:

accident number
date and time
location
source of report
severity
blood alcohol concentration
contributing circumstances
direction of travel
driver identification and description
vehicle occupant identification and description
pedestrian identification and description
vehicle identification and description
roadway description
road surface condition
speed
harmful events—type and location
deaths and injuries
property damage
vehicle maneuvers
pedestrian action
use of safety devices (e.g. seat belts, child safety seats)
lighting
visibility
weather

Of these data elements, location, driver identification, and vehicle identification are often used as links to other data files. Where the location reported by police is not in the same form as the location reference in the integrated highway information system, a number of approaches are used to complete the link.

In Washington, the traffic accident data file is maintained by the Washington State Patrol (WSP). Before WSP enters the accident data into its computerized file, it forwards reports of accidents to the Washington State Department of Transportation (WSDOT) or to the counties for manual coding of location. The location references entered by WSDOT for accidents on the state highway system are those used in TRIPS. When WSDOT returns the reports with the location information to WSP, the accident data are entered into the WSP computerized file. Copies of the WSP file are furnished periodically to WSDOT, which reformats the data for use in its integrated highway information system. WSDOT stores the data for each accident in a 470-character record but uses a 122-character subset for much of its analysis. Of about 130,000 reported traffic accidents each year in Washington, about a quarter are on the 7,000-mile state highway system.

Michigan has used its Michigan Accident Location Index (MALI) system since 1976. MALI, which is administered by the Michigan Department of State Police, was developed and is maintained with cooperation and assistance from the Michigan Department of Transportation (MDOT) and FHWA. With MALI, police use distance and direction from intersections to report accident locations. These are entered directly into the computer, where they are translated into unique MALI location codes. For accidents on the state highway system, MALI codes may be translated automatically to the control section numbers and distances that are the primary location references in MDOT's integrated highway information system (*15*, pp. 29–32; *16*, p. 5).

Because of budget limitations at all levels of government in the past few years, many services have been cut. One result of this has been a reduction in police investigation of accidents, most notably those involving only property damage (*17*). One obvious consequence of this reduction in reporting is that the identification of high-accident locations is more difficult where traffic volumes are low.

The Iowa Department of Transportation maintains an accident statistics file created from accident reports submitted by police and drivers. From this, an Accident Location and Analysis System (ALAS) file is created. ALAS provides high-accident location listings, accident summaries at specific locations, and listings of accidents based on selected accident characteristics. Link-node locations, coded in the central office, have been added to the accident data files since 1977. Unique node numbers have been added to identify interchanges and complex highway intersections. A route-milepoint location system was used for the Iowa DOT Base Record Inventory, the core of the integrated highway information system. To provide linkage between the accident data and other files, an ALAS-Base Record Interface file has been created to permit translation from one location reference system to the other. Beginning with 1983 data, files of accidents on state primary routes and on federal-aid primary, secondary and urban system highways are linked with other files in the integrated highway information system (*18*). Strip maps have been developed for Interstate and major four-lane primary expressways to display ALAS data. A high priority location program selects intersections or highway sections, ranking them by number of accidents, value loss, or severity. A generalized request program lists accidents by intersection or highway section or by accident characteristics.

Kansas' State Accident/Geometric (SAGE) System links selected data elements, such as accident location and type, from its Basic Accident Record (BAR) file with highway geometric, bridge, railroad crossing, traffic, vehicle classification, surface condition, and bridge condition data from the State Highway Control Section Data Collection and Analysis System (CANSYS) data base. In working with historic accident data, Kansas has encountered a situation common to many states. It has found it impossible to link previous year accident data with its existing CANSYS data because the current highway geometric, bridge, and other data were not necessarily reflective of the conditions in existence when the accident occurred. Kansas uses an on-line proprietary program maintenance and development system to create reports from SAGE. The system translates menu selections by the user into batch jobs, allowing great flexibility in the design of output reports without the user having to learn the extensive nuances of the system.

Maintenance Data and Pavement Data

Major highway system physical categories or maintenance elements have been defined as follows (*19,* pp. 3, 4):

- traveled-way, flexible
- traveled-way, rigid
- shoulders and approaches
- roadside
- drainage
- structures
- traffic control and service facilities
- snow and ice removal

Various maintenance activities, addressed to caring for each of the above elements, are continually undertaken by organizations responsible for highways. Examples of such activities are:

- manual pavement patching
- structure repair
- culvert pipe installation
- grass mowing on medians and shoulders
- surface treatment of through lanes

Many highway organizations have developed location-specific maintenance data files in order to document beginning and ending locations of such operations and, in so doing, to exercise improved control over these activities.

The ability to relate maintenance data to inventory and finance system data is invaluable in evaluating past maintenance procedures and in planning future maintenance operations for the various highways under an agency's jurisdiction. Dates and schedules for maintenance inspections and performance can be output from files such as these.

The Pennsylvania Department of Transportation (PennDOT) is planning a highway maintenance system (MORIS) as an integral part of its Roadway Management System (RMS), now under development. Maine intends to store data concerning culverts, guardrail, and road shoulders on its maintenance dataset. Dates and schedules for maintenance inspections and performance can be kept on maintenance files.

With the current emphasis on pavement management, a number of states are dedicating a separate file to the storage of location-specific data on the structure and condition of the roadway pavement. With pavement costs representing something on the order of half of the total cost of providing highway facilities, it makes economic sense to closely control the costs of providing pavements. Although some states include these data in their inventory data file, many have set up separate files to facilitate updating by separate units within the highway agency (e.g., materials and research). Utah DOT's Highway Information System contains a Pavement Condition File that not only contains detailed data on pavement structure and condition, but allows for the prioritization of various highway sections based on pavement condition considerations. Such datasets can, in concert with the remainder of an integrated highway data system, provide more accurate predictions of pavement loadings for design purposes, determinations of a pavement's spent life as compared to its design life, and economical designs of proposed pavement overlays.

Finance Data and Project History Data

Many states are considering the development of finance data systems that would be linked by location to existing or proposed highway facilities. The systems vary, but the methodology is such that capital improvement, maintenance, and other highway funds can be assigned to the particular portions of highway which they benefit. This provides a means of determining benefits received for costs incurred and adds an additional dimension to the usefulness of inventory, condition, and traffic data. PennDOT is including a new Financial Management Information System (FMIS) in its RMS to interface with about 11 other systems now under development.

A number of states have developed project history files that precisely identify previous construction projects that have resulted in the existing highway facilities. Such data as type of project, completion date, and project location and limits are incorporated into this file, as are such reference data as may be necessary to access construction plans or other documentation pertaining to the facility as built. Although the development of such files has been of low priority in most states, appropriate implementation can provide valuable input for scheduling and prioritizing proposed capital improvements.

The Michigan DOT monitors all construction projects, from preliminary stages to completion, through its Project Planning File (PPF). Well over 20,000 current and historic projects are now in the PPF, which includes financial as well as technical data. The PPF could evolve into the key management system in the Michigan DOT. Automatic data transfer among the PPF and other files would substantially reduce costs and data entry errors associated with manual updating (*20*).

Railroad Grade Crossing Data

The Highway Safety Act of 1973, which calls for provision of federal-aid funds to the states for improvement of rail-highway crossings, requires the states to "conduct and systematically maintain a survey of all highways to identify those railroad crossings which may require separation, relocation, or protective devices . . ." [P.L. 93-87, Sec. 203]. Each state, in cooperation with the Association of American Railroads, the Federal Railroad Administration, and the Federal Highway Administration, has numbered and inventoried its rail-highway crossings. A standard national format was adopted for the computerized file containing this inventory data. The file may be linked to other files with the rail-highway crossing number or with the highway location reference. In some states this link is provided by including the crossing number in the highway inventory file.

In a number of states, efforts to keep traffic volumes, traffic control device data, and other data in the railroad grade crossing file current have fallen behind because of the cost of manual updating. Integration of the railroad grade crossing file with highway traffic volume and inventory files can significantly reduce the cost of file maintenance.

The Rail and Water Division of the Iowa DOT has recently updated its railroad grade-crossing inventory file and has automated its program management and rail-highway accident files. The new program management file contains records on more than 350 active projects from project agreement stage to final audit. The accident file contains data from police and Federal Railroad Administration data files. The Rail and Water Division staff reports that automation has improved its operations considerably, largely because the data files can be maintained with less effort and because information can be quickly retrieved.

Structure Data

In 1970, the U. S. Secretary of Transportation was directed to work with the states to inventory and evaluate the serviceability, safety, and essentiality of all highway bridges on public roads [P.L. 91-605, Sec. 204; 23 U.S.C. 144]. A bridge inspection manual was issued by the American Association of State Highway Officials (AASHO) in 1970 and a computerized file of information submitted by the states is maintained by FHWA. A unique number identifies each structure. Any state may link its file to its integrated highway information system in much the same way that the rail-highway crossing inventory is linked.

To qualify for federal-aid funds for bridge repair and replacement and to provide support for Congressional action to establish the level of funding for the bridge program, it is important that states maintain their structure files on a current basis. Integration of structure files with other state files can improve both the timeliness and economy of file maintenance by reducing duplication of manual data entry and editing.

Photolog

Photologging and videologging technology is progressing at a rapid rate, and is a key to effectively storing a massive amount of highway data. A photolog (or videolog) is a series of pictures of a highway taken from a moving vehicle, usually at intervals of 0.01 or 0.02 mile (0.016 or 0.032 km) (*21*). Location, date, and other information may be recorded on the film or tape when each picture is taken. Photologs/videologs provide a record that is useful for a number of applications by highway agencies. The most obvious benefit is the reduction of the need for field trips to view sites reported to have operational, maintenance, or other problems or to collect information for other purposes. Most states update their photo/video files on a three- to five-year cycle. Recent improvements in video techniques and storage media have led to the use of videologging as an alternative to photologging in some agencies.

Photologs are not computerized data files and thus are not themselves part of an integrated highway information system. The same holds true for videologs, currently, but technological advances may lead to automated extraction of data from photologs and videologs in the near future. A recently completed Oak Ridge National Laboratory project may be helpful in expanding the use of photologs (or videologs) to provide dimensions for certain highway geometric data. Also, indexes to photologs and videologs are now being incorporated in some integrated highway information systems. The Washington Department of Transportation will include such an index of its videolog in its TRIPS system.

In Michigan, the photolog system has been in use since 1973. It is currently updated on a two-year cycle and is used for a wide variety of applications including evaluation of traffic control devices, pavement or roadway condition, and roadside development. It has been useful in litigation involving claims related to accidents. The photolog system is tied to the control section location reference system that is used in the Michigan DOT integrated highway information system, with each section of photolog usually covering one control section in both directions (*15*, p. 33). Photolog mileages are used to verify the location of features within control sections.

The Connecticut Department of Transportation has combined photo and video technology by recording its library of photolog films on laser videodiscs (*22*). Connecticut has filmed its 4,000-mile state highway system and 600-mile railway system in both directions at intervals of 0.01 mile. This photolog is recorded on about 920,000 frames of 35-mm color film—660 reels of film. The laser videodiscs on which the photolog is being stored are 4-gigabyte write-once storage media resembling 12-in. phonograph records. Each side of a disc can hold up to 54,000 frames, and the 660-reel library is now stored on 15 discs. A laser videodisc player connected to a microcomputer can retrieve any one of the 54,000 frames on a side of a disc in less than 3 seconds and display the picture on a high-resolution color monitor. Although the initial cost of a disc is relatively high, the discs can be duplicated for less than $25 so that copies can be provided economically for use in field offices. One of the major uses for the photolog in Connecticut, which updates its photolog annually, is inspection of pavement condition.

Other Data

There are a number of data files other than those described above that may be included in an integrated highway information system. For example, Maine has a separate data file to locate boundaries of 55-mile-per-hour speed limits on highways within the state. Utah is planning to add a traffic control device and sign inventory to its integrated system. Ohio maintains files of supplementary data on such information as highway sections with excessive curves, excessive grades, junctions, angles, overlaps with other highways, areas of sight distance less than specified lengths, or of any other special conditions to be flagged.

Because many states are taking advantage of existing hardware and software capabilities to plot data automatically, datasets to reference X- and Y-coordinates of points along highway networks are being created to allow applicable highway data to be shown on representations of the actual highway facilities.

DATA BASE ORGANIZATION AND SIZE

All of the types of data previously discussed have one thing in common— they each relate to a location along a highway, whether it is a single point or a section of highway defined by specific beginning and ending locations. It would be inefficient indeed to develop a single record containing all types of data related to a single location. Rather, it is advantageous from a data utility and efficiency standpoint to develop a separate specialized dataset for each particular type of data. This dataset contains only records for those sections of highway to which the data apply. For example, there may be no accident data (and therefore no accident records) for a one-mile section of highway on which there are three bridges (and therefore three bridge records) as well as homogeneous travel and inventory information that each begin and end at different points along the one-mile section.

In most states, beginning and ending location fields (or, for point data, a single location field) are included in the data record to provide a reference for indexing the data to other data and to the exact highway location.

Each dataset, then, includes information on a related set of data elements for a given level of highway facilities within the area of jurisdiction. For example, data related to accidents might be available on a single dataset for all state highways throughout the state or perhaps on a separate dataset for each of the counties within the state. Accident data for highways off of the state system, if available, might be included in the same dataset or might be organized into one or more additional datasets. Datasets may be sorted by the variables most applicable for performing the tasks to be accomplished. To utilize these same datasets in conjunction with other datasets containing related but separate data, it is the usual procedure to sort the applicable files by the beginning location field so that the data of interest can be tied together by this field common to each dataset.

As an example of dataset characteristics, Table 1 outlines the number of elements, the number of records, and record length currently included by Maine in their various datasets.

In Maine, link records contain data on the various segments of highway throughout the state, and node records reference intersections or other locations used to denote changes in physical direction of highway segments.

For comparison purposes, attributes of some of the datasets used by Ohio and linked to each other with a county-route-milepoint location reference are given in Table 2. Under Ohio's system of location reference (and those of all agencies using the route-milepoint system, or modification thereof), separate link and node records are not necessary. A single inventory record under the route-milepoint type of reference system usually contains all of the data carried by Maine on both their link and node records, although intersection data are sometimes placed on a separate dataset.

Ohio and many other states prepare inventory data in the HPMS format developed by the FHWA for annual submittal. This format is 348 characters in length and contains 70 data elements. In addition (where applicable), structure, railroad grade crossing, improvement, and accident data are appended as necessary to form a variable length record.

It is important to realize that the data currently being used in integrated data systems by most governmental agencies are usually in formats designed when the data were being used exclusively on a stand-alone basis. There are not many examples of complete data systems being designed to fit together, with integration of data as a primary consideration. Rather, location fields of existing dataset formats have been adapted as necessary to allow various datasets to be tied together. Some of the larger states such as Texas, Pennsylvania, and New York are undertaking broad studies to investigate and redesign the whole system of highway-oriented data. Not only will this provide for evaluation of all data elements being collected and stored in the overall data system, but it will allow for maximum efficiency of data access and use by various organizational units within the state.

Pennsylvania's Roadway Management System (RMS) will be the culmination of several years of planning and development.

TABLE 1

CHARACTERISTICS OF INTEGRATED DATASETS—MAINE

Dataset Name	Number of Elements	Number of Records	Record Length (Bytes)
Link	40	61,417	275
Node	9	49,391	70
Accident	34	90,000	165
Railroad crossing	13	1,252	100
Bridge	130	4,167	600

TABLE 2

CHARACTERISTICS OF INTEGRATED DATASETS—OHIO

Record Name	Number of Elements	Number of Records	Record Length (Bytes)
Traffic accidents	119	342,000	225
State road inventory	53	19,400	130
County and township road inventory	41	162,800	110
Municipal road inventory	29	100,350	110
Structure	72	42,000	480
Railroad crossing inventory	131	7,600	525
Skid data	39	30,000	120
Pavement condition	34	4,600	120
Roughness	11	35,000	30

It is designed to be the primary management system that controls inquiry, updating, and reporting of all roadway-related data within PennDOT. Included is a broad range of highway inventory data. Included in the system's benefits is greater flexibility in the use of available data, allowing the state to better plan for the future. The data will be improved, as all redundancies will be eliminated. Outputs making use of the data will be vastly improved. For example, an automated straight-line diagram (SLD) (a graphic representation of a specified portion of the roadway) is envisioned as the focal point for easily displaying selected roadway information contained in several data bases.

New York State is in the process of designing an integrated dataset to overcome the following problems associated with the processing of their multitude of existing datasets:

- Lack of access by clients and users in the Main Office and in the field.
- Unavailability of timely information, particularly from the field.
- Highly centralized and inefficient data entry rather than data entered at the source.
- High data maintenance cost—low productivity.
- Inconsistencies in the same data item across different files, leading to errors, confusion and cloudiness of policy.
- Inflexibility with respect to modernizing and expanding (i.e., adding either data elements or new subject areas).

Compounding the situation is the fact that at least five separate highway location referencing systems are now used within the state. Also, data are unavailable to all but the most expert of computer analysts. The multitude of computer operating environments being used for various applications also add complexity to the problem. The state hopes to overcome these problems by designing and implementing an integrated Highway Data Base, which will closely integrate system needs with data and application assessments for the New York State Department of Transportation as a whole. Work is progressing on engaging a contractor to undertake responsibility for design and implementation of the integrated system. On the other hand, integrated data systems now in use in most states have evolved from a recognition by the various organizational elements within the state highway and safety agencies of the advantages that would accrue from the ability to work with data from more than one existing dataset. In these instances development has been gradual, but recognition of new capabilities to be gained has tended to accelerate the process as data integration progresses.

Some time ago in the Washington State DOT (WSDOT), the Assistant Secretary of Planning, Research, and Public Transportation (PR&PT) recognized the need for a better information system and instituted long-range planning for system development and staff training. Much of the data collection and maintenance in WSDOT is handled by the Transportation Data Office (TDO) of PR&PT. TDO, in cooperation with consultants, completed a system plan in 1984, that called for establishment of TRIPS (Transportation Information and Planning Support), a data base administered by TDO. Its principal components (and their implementation dates) are road inventory (1986), traffic (1987), and accidents (1988). TRIPS will cover only the 7,000-mile state road system under WSDOT control; Washington State has about 86,000 miles of public roads. Having provided the means to link separate data files together, it is important for an organization to define the desired purpose of its integrated data system. In general, two broad types of systems now exist:

1. The informational system type where selected data from an organization's available data resources are pulled into a centralized system in an attempt to provide the means of supplying information to the organization and to the public on an as-needed basis. Generally a specialized computer-oriented staff dedicated to this task is in place solely to satisfy information requests. Responsibility for the prime data rests outside of this special staff. The supply of information is based entirely on selected data brought into secondary data files. Michigan's Statewide Transportation Modeling System is a prime example of this approach.
2. The operational type of system where all contents of the types of files discussed above are available to the user. Data maintenance may be accomplished by a centralized organization or by the operating organization responsible for the data. Coordination of prime data is key, and data availability to the organization as a whole has proven to be extremely beneficial, generating many new data uses.

Some states, such as Alaska, are taking advantage of both types of approaches in developing their integrated systems. In designing and implementing its Highway Analysis System (HAS), Alaska is making use of the recommendations of a nine-member Technical Committee for the design and implementation of the system. Among the data being incorporated are traffic and truck data, roadway inventory and condition data (including that for structures), accident data, project history data, and cartographic data. In the future, incorporation of financial data is planned. Two basic steps are being used in the system design:

- Analyzing data and systems requirements and
- Creating prototype of the proposed system.

DATA BASE LINKAGE

Location Reference Systems

Highway location reference systems are field and office procedures that include a method for identifying and recording a specific location on a highway. Elements common to all such methods are identification of a point with a known location, measurement of the distance from that known point, and observation of the direction of measurement. The use of location references to link data files is not new, but the increase in computer use since 1960 has made this methodology much more important. Adoption of procedures for identification and surveillance of high accident locations, a component of state traffic safety programs created in keeping with the Highway Safety Act of 1966, substantially increased emphasis on development of location reference systems. Federal-aid safety and planning funds have been used for this purpose in all states.

Highway location reference systems incorporate many location methods. In a 1984 report, the Michigan Department of Transportation identified 38 reference systems, each with its own reference method, being used in that state (*15*). These are

```
COORDINATE SYSTEMS
     Congressional Survey (Township/Range/Section)
     State Plane Coordinates (Lambert)
     UTM (Universal Transverse Mercator) Plane Coordinates
     Latitude-Longitude
     Grid Coordinate System

AREA IDENTIFIER SYSTEMS
     Transportation Planning Place Code
     Planning Zone Numbers
     FIPS (Federal Information Processing Standards) Place
        Codes
     3C Urbanized Areas
     MALI (Michigan Accident Location Index) Local Government
        Codes
     Federal-aid Urban Boundaries
     Department of Transportation District Numbers
     Department of Transportation County Numbers
     Department of Transportation Planning Region Numbers
     Modal Planning City Numbers
     Local Government Place Codes
     U. S. Census Place Codes (Tracts, Blocks)

SEGMENTAL LOCATION SYSTEMS (LENGTH)
     Department of Transportation Control Sections
     MALI (Michigan Accident Location Index) Milepoints
     Photolog Milepoints
     Modal Planning Segments
     A-Node/B-Node Network Links
     Sufficiency Rating System Numbers
     Job Numbers
     Highway Performance Monitoring System
     Needs Study Project Numbers
     Maintenance Route Numbers
     Stationing (Route Surveys)
     Southeast Michigan Council of Governments Road
        References
     Pavement Management System
     Michigan Automated Roadway Survey (MARS)

POINT LOCATION SYSTEMS
     Photolog Ramp Sequence Number
     Intersection Spot Number
     Survey Monument Numbering System
     Freeway Lighting Pole Identifier
     Structure Identification Number
     Traffic Counting Station Number
     National Railway Inventory Number
```

FIGURE 3 Reference systems in use in Michigan (1984).

outlined in Figure 3. Of those listed, the coordinate systems and the segmental location systems incorporate location methods that would normally be classed as highway location reference methods.

The list in Figure 3 was compiled as part of a 1984 study to determine what location method should be adopted as the standard for use by the Michigan Department of Transportation and cooperating agencies—notably the Michigan Department of State Police. The method recommended as a standard was a control section/milepoint method. Current control section numbers will be used on the state trunkline system along with Michigan Accident Location Index (MALI) milepoints. MALI "physical road" (PR) numbers will serve as control section numbers off the state trunkline system. Some improvements will be made. Perhaps the major modification will be the assignment of control section numbers to each roadway of a divided highway to allow more precise recording of data where roadways in opposite directions are widely separated or of different lengths. In the past, Interstate highways and other divided highways have had a single control number for both directions of travel (*15*).

Michigan recognizes that new technology may provide more efficient location reference methods in the future, but considers that the control section/milepoint method is not only most useful at this time but will provide a good base for conversion to methods developed in the future (*8*).

In general, one of two types of reference method is used by governmental agencies to provide ties to specific locations along highways. These are the route-milepoint and link-node methods. The first, route-milepoint or some modification thereof (*3*), uses a unique route number assigned to a continuous section of highway through all or part of a state. The number may coincide with the route number shown on signs along the highway and with that included on maps published to provide directions to travelers, or it may be some other number used strictly for inventory data purposes. Usually special maps are available to equate this inventory number to existing highway facilities. The route number may be unique within the whole state or only within each county or other area subdivision within the state. On each route, a zero mileage point is chosen, and the mileage measured along the route from that point forms the unique location along the particular route. Generally, a standard convention is used in locating the zero mileage position for a route (i.e., on the western-most terminus for east-west routes and on the southern-most terminus for north-south routes) (*23*). The Michigan control section/milepoint method described above is a form of route-milepoint system.

Utah decided to standardize on a reference system tied to posted route numbers and milepoints. Maps showing milepoints for each route were prepared and distributed to users (Fig. 4) (*7*).

A second location reference method uses a link and node notation. Each intersection, change in highway direction or other critical location along a highway is identified as a node and is assigned a unique node number. Each node is connected to at least one other node by a section of road called a link. Each link represents a unique highway segment that can be identified by the numbers of the nodes at each end of the particular link. Links may be subdivided, if necessary, into numbered segments. Locations within the segments may be specified by distances from nodes or from the beginning of segments. Although the link-node method enjoys an advantage in that it lends itself more readily to the automatic plotting of data by location, only a few states, Maine and New York among them, have chosen to organize their data files using that methodology. Most governmental agencies that administer integrated data systems use route-milepoint methodology or some variation thereof because of the advantage that this type of system enjoys relative to conversion of field location to reference location.

The Washington State Department of Transportation (WSDOT) uses a control-section/milepost system (CSMP) to code the location of traffic accidents and for other purposes. Systems used for other files are compatible. WSDOT had considered revising its location reference system, replacing CSMP with a state-route/milepost system that eliminated the need for equations, as part of the development of its Transportation Information and Planning Support System, but this alternative has not been adopted because of resistance based on application needs from the various using organizations. In lieu of external conversion software, some states enter a factor in each data record that, when applied to the location field in the record, will convert it to a location notation in a second reference system.

For its Base Record Inventory, the Iowa Department of Transportation uses a route/milepoint location reference method to record data. For accident data on its Accident Location and Analysis System (ALAS), Iowa uses a "node" ref-

Route Reference 89	Location Sanpete County Line North to Utah County Line						
County	Number	Dist.&Maint.Sta.No	F.A.System&No.	Functional Class	Route Length	Lanes	Revised
Sanpete	039	3 333/334	FAP-22/FAP-40	Prin. Arterial/Minor Arterial	415.84	2	Nov. 1978

Photo Log Index Reel 5 of 5 M.P. 204.99 to 199.79 Reel 4 of 5 M.P. 219.99 to 205.01

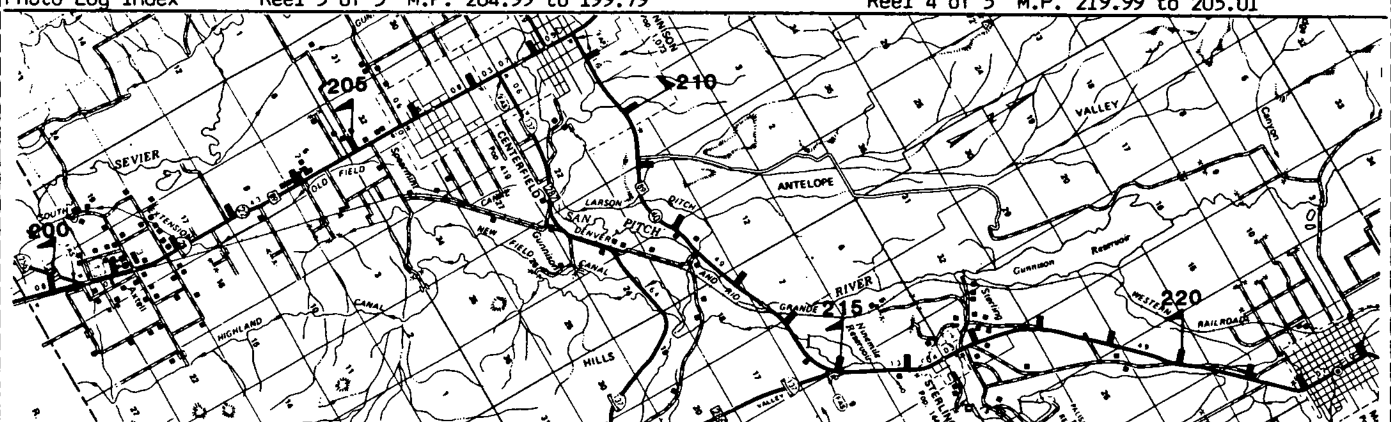

Photo Log Index Reel 1 of 5 M.P. 199.79 to 214.99 Reel 2 of 5 M.P. 215.00 to 229.99

Reference Point	Struct. No.	Reference Point Location	Reference Point	Struct. No.	Reference Point Location
199.79		Sevier-Sanpete County Line	206.27		City Road Crossing Center Street
200.58		Jct. SR-256 Left to Redmond	206.53		City Road Crossing 200 North
		Maint. changes to #328	206.80		City Road Crossing 400 North
201.34		Local Road Crossing	207.50		Centerfield North Limits and
201.86		Local Road Crossing			Gunnison South Limits
202.34		Road Left	207.13		City Street Left
202.60		Road Right	207.32		Jct. SR-137 Right - 6th South Street
203.36		Road Right			Left
204.09		Road Right	207.68	OD-688	Sanpitch River Bridge
204.46		Road Right	207.93		City Street Right 300 South
204.73		Road Left	208.03		Center Street Crossing
205.24		Road Crossing	208.13		City Street Crossing 100 North
205.61		Centerfield South Limits	208.24		City Street Crossing 200 North
205.75		City Road Crossing 400 South	208.57		Jct. SR-28 (Funct. changes to Minor
206.01		City Road Crossing 200 South			Arterial) (FAP Changes to FAP-40)

FIGURE 4 Sample reference sheet (Utah) (*7*).

erence method. Software has been developed to convert node locations to route/milepoint locations so that accident data may be used in conjunction with highway inventory and traffic data from the Base Record Inventory file (*18*). The "node" system used for ALAS is a coordinate system based on the land survey grid which permits location to the nearest sixteenth of a mile with an 8-digit node number.

It is now common practice to make use of computer software designed to facilitate conversion from one location system to another. Because of computer memory and storage capabilities that allow access to data dictionaries, a state is able to, for example, equate a particular link in a link-node location configuration to a route number and milepoint in another location system using a look-up procedure employing the route and milepoint equated to each node location.

Other Links

In addition to highway location references, a number of other methods are used to link data files so that data from two or more files can be combined or correlated. Among the most common are the bridge numbers and railway-highway crossing numbers that have been assigned in conjunction with inventories required by Congress in the 1970s. These are included among Point Location Systems in the Michigan listing above. When bridge and railway-highway crossing numbers are recorded by location in highway inventory files, these unique numbers can be used as links to additional data in bridge inventory and railway-highway crossing inventory files.

In Washington, bridge and rail-highway crossing numbers are to be included in the Transportation Information Planning Support System (TRIPS) data base to provide links from TRIPS to bridge and rail-highway crossing inventory files maintained by other organizations. Similarly, the Iowa Department of Transportation has interfaced its structure file and rail-highway crossing file with its accident data file for all structures or crossings on federal-aid highway systems. The Railroad Division of the Iowa DOT has extended this linkage to include rail-highway crossings that are not on federal-aid highway systems (*18*).

As location-specific data, not only for highways but for specific geographic areas, become more prolific, it should be expected that systems to link data and geographic locations together will also become more plentiful and sophisticated. An example of such a system is the Topologically Integrated Geographic Encoding and Referencing (TIGER) System, an automated geographic system being developed by the Geography Division of the Bureau of the Census. The system will support numerous Census operations beginning with the 1990 Decennial Census. It will use the latest concepts in computer science, together with powerful new computer hardware, to produce an integrated geographic data base for the entire United States.

The key to such a system is an accurate, consistent map base being developed by the U.S. Geological Survey (USGS). USGS is capturing, in computer-readable form, the water and transportation features of the nation, such as rivers, roads, railroads and major power lines and pipelines from its 1:100,000-scale maps. USGS is assigning feature classification codes to the water, railroad, power line, and pipeline data and providing Census with computerized tape files of the results. Census is adding feature classification codes (e.g., freeway, city street, footpath) to the road data.

The following represent a few of the benefits that the Census Bureau hopes to obtain from the TIGER System:

- Ease of data collection operations by creating maps defining streets that census enumerators must walk.
- Ease of census processes for tabulation and manipulation of data so that quality of collected data and resulting products can be at its maximum.
- Improved future sample selection processes.
- Provision of a means to geocode all of the nation's business establishments for improved economic census.

Although TIGER is being developed to meet these Census needs, it has major potential benefits for state transportation agencies, such as:

- providing a digitized base map for states that have not yet begun to automate their state and county maps;
- providing a common denominator between highway location referencing systems and geographically referenced social, economic, and environmental data sets;
- providing a link between statewide and multi-state network analyses (illustrated by the Oak Ridge models) and urban network analyses (such as the Urban Transportation Planning Package);
- providing a common denominator for highway location referencing systems across state lines.

TIGER could become a mechanism for integrating multi-state and nationwide transportation data, and for correlating transportation activity with the economic and social forces that generate the needs to transportation facilities and services.

Development of geographic systems such as these will provide valuable input to the process of integrating highway data. Linking of such sophisticated geographic data to available data related to highway inventory and performance will greatly assist any agency in making maximum use of available technology.

State Experiences

In Colorado, many offices had created data files that met their own needs. These files varied in format, structure, and computer media. Colorado decided on a two-stage solution: (a) to create a data file with frequently needed data and an ability to link additional files and (b) development of additional links. The first stage resulted in the Colorado roadway information system, which has a unique number for each record. Each record can be tied to a specific road segment. One example of the benefits of the system is the annual HPMS report. The availability of links to accounting, accident, and project files allows development of this report without spending many hours reentering data; costs were reduced by 75 percent and confidence level of the data was significantly increased.

In Kentucky, several independent data files were maintained by different sections to meet their own needs. Most used similar reference methods (milepoints) but the references were selected to facilitate data input for the particular file. To create a unified data base, it is necessary to link all files. This can be done through conversion of each file to a common reference system of milepoints, although it is not an easy task to accomplish. Kentucky started this for reporting a merged HPMS and mileage facility reporting system file to FHWA. Further links with other files (traffic, accidents, pavement serviceability index, structure, and capital expenditures) are being or have been developed. Some of the program functions will maintain a subsidiary file for an interim period that will be linked each year with the unified file to avoid data inconsistency and duplication of effort.

Illinois is in the process of developing a comprehensive computerized safety record-keeping system (CCSRS) that will link all traffic record files from several state departments together. The accident and roadway files, which used independent mileage location methods (marked route number and milepoint), had previously been linked through the development of a computerized interface table. The interface development process required some field verification and addition of some descriptors to the roadway file. This interface was not perfect and other location methods were being used by other offices; therefore, a committee was formed to recommend a single reference method for the entire department. The committee recommended a link-node system with an interface to the marked route/milepoint system. A prototype has been developed, tested, and approved.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

In the planning, construction, maintenance, and operation of highways, agencies responsible for highway system management collect, store, and use a wide variety of technical data, often from several sources within the agency. These data are substantially more useful and valuable where data-collection activities have been coordinated and data files have been linked to form integrated highway information systems. As discussed in Chapter 3, coordination reduces duplication of effort and the need to base decisions on inadequate information. But creation of computerized data files is not enough. Hardware and software must be provided to make the data readily accessible to potential users. Where accessibility is a problem, data are routinely unused or underused, markedly reducing the return from a major investment.

Because people represent the largest problem in the implementation of an integrated highway information system, sensitivity to the personality and organizational characteristics of the agency involved must be an inherent part of any steps taken in making such a system a reality. Any recommendations for step-by-step production of such a system should therefore be considered as only general guidelines that must be molded around the characteristics of the particular organization.

Integration of data files can take place on many levels, from the decision of managers of each of two separate data files to use the same location reference system to a high-level management decision to include all state highway data files in an integrated highway information system. The latter commitment can sometimes result in an agency-wide, in-depth study to ascertain that all data integration needs are met. At any level, development of a workable integrated data system involves all or many of the following steps.

1. **Organize.** It is extremely difficult to develop a successful integrated highway information system without strong management support. This support is needed to ensure that equipment, staff, and supplies will be available when they are needed and to resolve problems that arise when compromises must be made among those concerned with the operation or use of the system.

An appointed coordinator or coordinating committee can serve a number of functions. It reassures potential users that the system is not being developed for the convenience of computer specialists and provides a channel for transmission of information about user needs and system limitations. It may also establish procedures for communication between users and system developers during system design and implementation. Such communication greatly increases the likelihood that problems will be identified and resolved at an early stage. The coordinator or coordinating committee should be in close contact with all potential users of the data as well as with the staff responsible for system design.

Support by key management for any proposed effort is imperative. In many organizations, officials, particularly those with computer and data backgrounds, can immediately see the benefits of an integrated system, and they will immediately go to work to ensure its implementation. Managers in other organizations must be thoroughly convinced of benefits before they will support the effort. In these cases, involved personnel have found it helpful to develop a pilot system, using only a fraction of the data and effort envisioned for the whole project, but involving data elements from several stand-alone data bases. The advantages of integration from this small system have convinced managers to proceed with the whole perceived system or, at worst, to expand the pilot test project to encompass a wider range of data.

2. **Define system objectives.** A clear definition of the objectives of the integrated data system is useful in keeping development on track. As needs change, it may be desirable to change objectives, but all of those who work on the development should understand where they are headed. Potential users also need to know what they can expect as the system grows. Objectives should include a general description of the types of output to be produced and should indicate the level of skill needed to use the system.

3. **Determine data needs.** Perhaps the most difficult step in developing any data system that serves a variety of users is determining data needs. Many users are not sure what their future data needs will be and must limit their choices because of the high cost of data collection and processing. Once data items are in a system it is often very difficult to remove them, even if they are seldom used. All potential users of a system should have the opportunity to express their needs at an early stage in system development, before decisions are made that might inadvertently prevent the inclusion of relevant data in the needed form. Where two or more users have similar but not identical needs, it is not always possible to satisfy all users.

4. **Formulate data specifications.** Based on user descriptions of their needs, detailed specifications and definitions for all data to be incorporated must be written for the guidance of data collectors and processors. Users should have the opportunity to review these to ensure that they cover what the users intended. The data specifications should include an existing location reference method (or establishment of a new method) as the primary link among data files. Because of unpredictable changes in programs or for other reasons, it is impossible to define all data that will eventually be included in the system. The system

design should recognize this and be adaptable to future incremental expansion.

5. **Design computer system.** Hardware and software must next be selected that will meet the objectives stated above. Note that rapid changes in computer technology may be expected during the period the system is in use and that system design should not preclude adoption of major improvements in hardware or software when they occur. In general, it is better to take an incremental approach to system design than an all-or-nothing approach. To make it less difficult for managers to justify their support of the system, each increment of the system should be demonstrably cost-effective. If possible, the system, at a minimum, should produce benefits that are readily understood by people who have no experience with computer systems. Available hardware and general-purpose software should be reviewed and used where effective and cost-efficient for the integrated system. In any event, the chosen software must allow use by those who are not experts in the field of computers.

6. **Develop standard reports and custom software.** Many systems produce routine reports for distribution to the public, for use by management, or for other users. This output may be either in printed form or accessible from menu-driven programs at computer terminals. For many users, these routine reports may be the only output that they recognize as coming from the system, even though they may frequently use the results of other analyses of system data. Because these users will judge the system by the routine output, the software should be carefully designed, both from an aesthetic and cost standpoint, to meet their needs.

7. **Test the system.** The system should be tested in an incremental manner, as it is developed. Where it replaces an existing system, the new system should be operated in parallel with the old one while "bugs" are worked out. The amount of testing should be consistent with the severity of problems that might be caused by malfunctions or incorrect output. The testing should be designed to uncover inconsistencies among data sets and should include tests of how easy it is for users to obtain information from the system.

8. **Begin operation.** Operation of an integrated highway information system, like system design and testing, normally begins incrementally. As noted above, increments that replace existing programs should be tested by operation in parallel with the old system until they are working reliably. When users will need computer hardware to get output from the system, training should be available for those who need it. Users should also be told where help is available, if they should have questions about the content of data files or about system operation. For the benefit of system managers, channels should be established for users to report problems with the system or the data.

9. **Evaluate the system.** All increments of a system should be evaluated periodically to ascertain that they are meeting user needs in the most cost-effective manner. Among other things, it should be determined whether changes in user needs indicate that an increment should be modified or abandoned.

Implementation of the above steps should produce a well-designed, workable integrated highway information system. However, as pointed out in the preceding chapters of this report, the most sophisticated and elaborate information system will become worthless if the people responsible for its contents and operation are not fully committed to its successful implementation and proper operation.

Only through wholehearted cooperation by the many organizational units usually involved can highway agencies take maximum advantage of the rapidly expanding state of the art in hardware technology and in data management to provide the highway data products so essential in preserving and overseeing a vital and essential resource—our nation's highways.

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National Research Council
2101 Constitution Avenue, N.W.
Washington, D.C. 20418

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RESEARCH SUPERVISOR
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BOISE ID 83707